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Effects of Anthropogenic Disturbance on the Diversity of Foliicolous Lichens in Tropical Rainforests of East Africa: Godere (Ethiopia), Budongo (Uganda) and Kakamega (Kenya)

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EFFECTS OF ANTHROPOGENIC DISTURBANCE ON THE DIVERSITY OF FOLIICOLOUS LICHENS IN TROPICAL RAINFORESTS OF EAST AFRICA: GODERE (ETHIOPIA), BUDONGO (UGANDA) AND KAKAMEGA (KENYA)

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In Memory of

my late mother Bekelech Cheru

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ABSTRACT

Foliicolous lichens are one of the most abundant epiphytes in tropical rainforests and one of the few groups of organisms that characterize these forests. Tropical rainforests are increasingly affected by anthropogenic disturbance resulting in forest destruction and degradation. However, not much is known on the effects of anthropogenic disturbance on the diversity of foliicolous lichens. Understanding such effects is crucial for the development of appropriate measures for the conservation of such organisms.

In this study, foliicolous lichens diversity was investigated in three tropical rainforests in East Africa. Godere Forest in Southwest Ethiopia is a transitional rainforest with a mixture of Afromontane and Guineo-Congolian species. The forest is secondary and has been affected by shifting cultivation, semi-forest coffee management and commercial coffee plantation. Budongo Forest in West Uganda is a Guineo-Congolian rainforest consisting of primary and secondary forests. Kakamega Forest in western Kenya is a transitional rainforest with a mixture of Guineo-Congolian and Afromontane species. The forest is a mosaic of near-primary forest, secondary forests of different seral stages, grasslands, plantations, and natural glades.

Leaves carrying foliicolous lichens were collected from the forest understorey in the shady understorey and light gap microsite regimes. Morphological and anatomical characters were used for the identification of foliicolous lichens. Different indices were used for the computation of α- and β-diversity. The biogeographical distribution patterns of the foliicolous lichens of the study area and the possible use of foliicolous lichens as indicator of forest disturbance were analysed.

A total of 70 species of foliicolous lichens and lichenicolous fungi belonging to 27 genera and 15 families were recorded from Godere Forest. From Budongo Forest 125 species of foliicolous lichens & lichenicolous lichens belonging to 32 genera and 16 families were recorded. From Kakamega Forest 137 species belonging to 41 genera and 17 families were recorded. In addition, 7 foliicolous lichens new to science have been recorded in this study. The most species-rich families in both forests were Pilocarpaceae, Porinaceae, Gomphillaceae, and Strigulaceae.

In Godere higher foliicolous lichen diversity was recorded in Dushi than in Bishan Waka forest site. In Budongo high foliicolous lichen diversity was recorded in the young secondary and the primary swamp forests. In Kakamega Forest high foliicolous lichen diversity was recorded in the sites of Yala, Buyangu, Isiukhu, and Kisere. Low diversity was recorded in Malava, Kaimosi and Camp site. Among the 3 forests investigated, α-diversity was significantly higher in Kakamega and Budongo than in Godere forest. β-diversity was high in Kakamega and Budongo and low in Godere. Several studies have shown higher foliicolous lichen diversity in undisturbed primary forests than in disturbed secondary forests. Our study showed high foliicolous lichen diversity in both primary forest and secondary forests with little disturbance. Therefore, for the maintenance of high foliicolous lichen diversity in tropical Africa both primary and old growth forests should be conserved.

This study has shown that foliicolous lichens are good indicators of forest disturbance. The composition of foliicolous differed from primary to secondary and disturbed forests. In addition, some foliicolous lichens were found to be restricted to a particular forest type. The distribution of forest sites along PCA ordination axis has been found to depend on the level of disturbance. Based on the distribution of species and forest sites on the PCA ordination biplot, indicator species for three forest types with different disturbance regimes were selected. *Porina sphaerocephala, P. conica, P. radiate* and *Mazosia rotula* were found to have high fidelity to undisturbed or slightly disturbed closed forets. *Coenogonium geralense, C. siquirrense, C. pocsii* and *Byssoloma leucoblepharum* were identified as indicators of closed forest with moderate disturbance. *Asterothyrium rotuliforme, Psorotheciopsis gyalideoides, P. varieseptata, Calenia aspidota* and *Gyalectidium imperfectum* were found to be indicators of disturbed semi-open forests.

Biogeographic affinity of the foliicolous lichens of the study area shows that 57% of the species have pantropical distribution, 18.6% of the species are restricted to the African paleotropics, 17% of the species are distributed both in the African paleotropics and the Neotropics, and 7.2% of the species are distributed both in the African and Eastern paleotropics. In addition 13 species which have not been recorded from Africa have for the first time been recorded in this study.

Chapter 1. GENERAL INTRODUCTION

1.1 Tropical Rainforests

1.1.1 Extents and uses

Tropical rainforests are Earth's most complex ecosystem in terms of both structure and species diversity. They are composed of evergreen broadleaved trees which flourish in the high temperature and humidity of the low altitudes between 10^0 north and 10^0 south of the equator (Park 1992). Although tropical rainforests cover only 6% of Earth's land surface, they harbour roughly half of all the world's plant and animal species (National Research Council 1992).

Tropical rainforests are found in Central and South America, Southeast Asia and Central and Western Africa. The tropical rainforests of Latin America harbours 56 percent of the world total, Southeast Asia harbours 25 percent and Central and West Africa harbour 18 percent (Park 1992, Whitmore 1998).

According to the review made by Richards (1996), the large mass of rainforest in Africa is found in the Congo basin from where it continues westwards into Gabon and Cameroon. From there a narrow belt follows the coast of the Gulf of Guinea through Nigeria to Ghana and beyond, finally ending in Guinea at about 10^0N. This western extension of the rainforest is interrupted from western Nigeria to a little west of the Volta River in Ghana by Dahomey Gap, where savannas reach the sea and divide the forest into an eastern and a western block. South of the Democratic Republic of Congo, the African rainforest extends into Angola to about 9^0S. In East Africa the area of continuous forest reaches its eastern limit at Bwamba in western Uganda. East of the Western Rift Valley, forest similar to tropical rainforest is absent except for outliers of various sizes, e.g. Budongo Forest and fragments near Lake Victoria in Uganda, a relic near Kakamega in western Kenya and some small areas in northwestern Tanzania.

The tropical rainforests of Africa are the most species-riche ecosystem in the region housing more than half of Africa's biota (Sayer *et al*. 1992). They are estimated to contain over 8000 plant species, some 80 % of which are endemic (White, 1983). The total forest cover in Africa is estimated at 635,412,000 ha, accounting for 21 % of the land area and 16 % of global forest cover (FAO, 2006).

Tropical forests provide environmental, economical and aesthetic services and values. They provide row materials for plant improvement programs and modern pharmaceutical industries. They regulate local and global climate and play important role in watershed management, soil erosion control and the carbon dioxide budget of global atmosphere. Millions of people living in or around tropical forests depend on the forests for many forest products and environmental services. Tropical forests are the main source of energy in the form of fuelwood; they provide timber and non-timber forest products; they are sources of food, particularly in times of drought and famine; and they are sources of traditional medicines.

1.1.2 Deforestation and fragmentation in tropical forests

Human activity has had devastating impacts on tropical forests. Human impact could be in the form of conversion of natural forest into other land uses (deforestation), fragmentation into smaller patches with deforested areas in between, and various degrees of disturbance, such as silvicultural activities.

Deforestation is the permanent loss of forest to other land uses such as agriculture, grazing, new settlements, and infrastructure. Deforestation in the tropics is widely recognized as one of the main environmental problems facing the world today. Tropical forests are being destroyed and fragmented at an ever-increasing rate with series environmental and biological consequences including loss of biodiversity (Whitmore & Sayer 1994, Turner 1996) and climate change at local, regional and global levels (Myers 1988). The Food and Agriculture Organization of the United Nations (FAO 2006) estimated that in the 1990s tropical countries have lost 111,350 km^2 of forests annually and 114,270 km^2 of tropical forests were lost between 2000 and 2005.

The forests of Africa have long been affected by humans. Outside the Congo core the African rainforests have been extensively destroyed (Whitmore 1998). The estimate for the annual rates of deforestation in Africa is 43,750 km^2 for the period 1990-2000 and 40,400 km^2 for 2000-2005 (FAO 2006). In East Africa the forest resources are steadily disappearing and those that are left are being degraded. Between 1990 and 2000 the forest covers of Ethiopia, Uganda and Kenya were respectively reduced from 49,960 km^2 to 45,930 km^2, from 51,030 km^2 to 41,900 km^2 and from 180,270 km^2 to 170,960 km^2 (FAO 2001). Most of the remaining forests in these countries today exist as disturbed and secondary forests of different seral stages.

One major consequence of deforestation is the fragmentation of habitats in natural forests. Habitat fragmentation is the subdivision of continuous habitat blocks into clusters of small remnant patches isolated by matrix of other land use types (Andrén 1994, Fahrig 2003). Fragmentation could occur by natural disturbance (e.g. fire, windthrow) or due to anthropogenic disturbance which include clearing of forest for agriculture, road and dam construction and logging (Attiwill 1994, Wade *et al.* 2006).

Habitat fragmentation causes changes in the physical environment and biogeographic entities (Saunders *et al.* 1990). Loss and fragmentation of natural habitat are considered major threats to global biodiversity (Lovett & Wasser 1993, Laurance & Bierregaard 1997). The effect is more severe in tropical forests where diversity is high and forests are being removed and fragmented at an increasing rate (Pineda & Halffter 2004).

General Introduction

Forest fragmentation has impact on biodiversity (Turner 1996), increasing isolation of habitats, endangering species of plants, mammals and birds (Skole & Tucker 1993, Scariot 1999, Laurance *et al.* 2000) and on a variety of population and community dynamic processes (Saunders *et al*. 1991, Valladares *et al.* 2006). However, the effects of habitat fragmentation on species diversity vary among different habitats and taxa. These effects could be both positive and negative (Fahrig 2003). Positive effects include the creation of edge habitat increasing the abundances of edge or gap species (Yahner 1988, Malcom 1994) and negative impacts include increasing the local rate of extinction by reducing population sizes (Leach & Givnish 1996), creating forest edges and altering microclimate at forest edges (Matlack 1993), changing forest dynamics (Wade *et al*. 2006), and increasing predation at forest edges (Chalfoun *et al*. 2002). These impacts may be due to one or a combination of four separate effects: forest fragmentation *per se*, the loss of habitat during fragmentation, habitat degradation following the isolation of fragments, and the effect of isolation *per se* (Harrison & Bruna 1999). Some ecologists (Fahrig 1997, Caley *et al*. 2001, Fahrig 2003) advocate the separation of habitat loss and habitat fragmentation *per se* and claim that species loss and decline in species abundance following fragmentation is associated with habitat loss than with fragmentation *per se* (Caley *et al*. 2001).

Although there are various studies on the impact of habitat fragmentation on bryophytes (Zartman 2003), lichens (Esseen & Renhorn 1998), palms (Fleury 2006), beetles (Davies & Margules 1998), butterflies (Daily & Ehrlich 1995), corals (Caley et al. 2001), amphibians (Pineda 2003), birds (Hagen *et al*. 1996, Carlson 2001, Githiru & Lens 2007, Giraudo *et al*. 2008) and mammals (Laurance 1994, Malcolm 1997), the long-term effect of habitat fragmentation on species diversity is far from being known.

The major causes of forest destruction and degradation in the tropical Africa are conversion to subsistence and commercial agricultural land use, fuelwood collection, human settlement, commercial logging, and overgrazing by domestic animals. These causes are driven and aggravated by poverty and population growth. Most of the people in tropical Africa live in rural area and the rate of population growth in these areas is high (e.g. > 2.5% in East Africa, Masci 2006). The increasing population growth demands additional land for agriculture which in most cases can only be met by forest conversion. Migration and settlement of landless people from densely populated and draught affected parts to areas covered by forest in search of agricultural land and to engage in charcoal production and pit sawing to sell for the rapidly growing urban centers has also accelerated the rate of deforestation. Development policies outside the forestry sector have contributed for the destruction of forests in many African countries. The conversion of natural forests into commercial plantations such as coffee and tea plantations in Ethiopia (Yeshitela 2001), sugarcane plantation in Uganda and sugarcane and tea plantations in Kenya are some of the examples.

1.2 Foliicolous lichens

Santesson (1952) defined foliicolous lichens as those growing on living leaves of vascular plants. Ecologically, foliicolous lichens could be grouped into three groups. Typical foliicolous lichens grow and reproduce entirely on leaves. Facultative foliicolous lichens grow on barks, petioles and twigs but exceptionally grow on leaves. Ubiquitous species equally grow and reproduce on living leaves and twigs. In addition, foliicolous lichens have been observed growing on artificial substrates such as plastics materials (Sipman 1994, Lücking 1998c, Sanders 2002, Sanders & Lücking 2002, Sanders 2005).

Foliicolous lichens are found in tropical forests of central and south America, Africa and Southeast Asia. They are one of the most abundant epiphytes in tropical rainforests (Richards 1996, Lücking 2001, Anthony *et al.* 2002) and one of the few groups of organisms that characterize these forests (Lücking 2001). Outside the tropical areas, foliicolous lichens are found in subtropical areas (Vĕzda 1983, Sérusiaux 1993, 1996, Puntillo & Ottonello 1997, Puntillo *et al*. 2000, Thor *et al*. 2000, Llop & Gómez-Bolea 2006) and temperate rainforests (Malcolm & Galloway 1997, Lücking *et al*. 2003), but then occurrence is very limited and restricted to very humid areas.

After the monographic work of Santesson (1952) on obligately foliicolous lichens, there has been a considerable study on the taxonomy, distribution and even phylogeny of foliicolous lichens and several publications, including revisions and monographs, have been produced. Several new taxa have been described and the taxonomy of already described taxa has been amended. Compared to corticolous microlichens of tropical forests, the taxonomy, diversity and distribution of foliicolous lichens is well understood.

The checklist of foliicolous lichens and lichenicolous lichens (Lücking *et al*. 2000a) listed 716 species and 72 genera of foliicolous lichens. Since then many foliicolous lichens have been described, among others, by Ferraro *et al*. (2001), Lücking & Kalb (2001), Lücking & Lumbsch (2001), Lücking & Santesson (2001), Lücking *et al*. (2001), Sérusiaux & Lücking (2001), Herrera-Campos & Lücking (2002, 2003), Lücking & Kalb (2002), Lücking & Santesson (2002), Ferraro & Lücking (2003), Lücking *et al*. (2003), Sérusiaux & Lücking (2003), Herrera-Campos *et al*. (2004a), Vezda (2004), Lücking *et al*. (2006), Lücking (2006), Rivas-Plata *et al*. (2006), Lücking *et al*. (2007), Papong *et al*. (2007), Sérusiaux (2007), Sérusiaux & Lücking (2007) and Lücking (2008)

Foliicolous lichens exhibit structural diversity of growth form, thallus, ascomata and conidiomata. All foliicolous lichens are crustose except members of the genera *Coccocarpia, Leptogium, Parmeliella* and *Psoroma* which assume foliose/squamulose growth habit. Growth could be supracuticular (most follicolous lichens) or subcuticular (e.g. *Strigula antillarum*, *S. nemathora*, *S. smaragdula*), epiphyllous (most foliicolous lichens) or hypophyllous (*Coenogonium hypophyllous, Strigula janeirensis, Bacidina hypophylla*).

Thallus could be smooth (e.g. *Coengonium pocsii, Porina rubentior*) or verrucose (e.g. *Mazosia melanopthalma, Porina mazosioides, Sporopodium leprieurii*) or farinose-granulose (*Bacidina* sp.), corticate (e.g. species of *Asterothyrium*, and *Psorotheciopsis* and *Calenia bullatinoides*) or ecorticate (most follicolous lichens); with hairs (e.g. species of *Aderkomyces, Tricharia,* and *Rubrotricha*) or with out hairs (most foliicolous lichens); dispersed (e.g. species of *Loflammia*, and *Tapellaria major*) or continuous (e.g. *Strigula macrocarpa*).

Mycobiont could be ascomycetes (most foliicolous lichens), or basidiomycetes (*Dictyonema* sp.). Phycobiont could be *Trentepohlia* sp. (e.g. *Coenogonium* sp.), *Phycopeltis* (e.g. *Porina epiphylla*), *Cephaleuros* (e.g. species of *Strigula*) or *Trebouxia* sp. (e.g. *Sporopodium leprieurii*).

Ascomata could be apothecia (e.g. species of *Fellhanera*, *Chroodiscus*), or perithecia (e.g. species of *Porina* and *Strigula*). Ascomata could occur singly (most foliicolous lichens) or within stromata (e.g. *Flavobathelim epiphyllum*). Conidiomata could be pycnidia (e.g. *Coenogonium subluteum, Fellhanera africana, Caprettia setifera*), campylidia (e.g. *Musaespora kalbii,* species of *Sporopodium, Calopadia, Tapllaria*, and *Badimia*) or hyphophores (species of Gomphillaceae).

Vegetative propagation could be with isidia (e.g. *Chroodiscus mirificus, Coccocarpia domingensis, Phylloblastia borhidii, Porina distans, Bacidina scutellifera, Coenogonium isidiiferum*), or soredia (e.g. *Fellhanera ivoriensis, Bapalmuia napoensis*).

The diversity and distribution of foliicolous lichens is influenced by geographical distribution and environmental factors. Generally foliicolous lichens diversity is high in tropical regions, usually close to the equator (Herrera-Campos *et al*. 2004b) and species richness decreases with increasing latitudes. Altitudinal zonation of vegetation, degree of seasonality and microclimatic condition of light intensity are the most important factors (Lücking 1992b, Lücking 1995, Lücking 1997d). Species richness is highest at low altitude forests and decreases at high altitude forests (Herrera-Campos *et al*. 2004b). Diversity decreases with increasing seasonality where synchronized leaf shading becomes a hindrance for foliicolous lichens establishment, growth and reproduction (Lücking 1997d). Therefore, diversity is high in the wet, humid or moist forests in which a dry season is absent or is slight and decreases as the length of dry season increases. Within a tropical rainforest, diversity is high in the shady understorey and decreases in the light gap and the upper canopy. Not only is there a change in diversity along microclimatic gradient, but also differences in species composition. In tropical rain forest, for example, species of the family Arthoniaceae, Porinaceae and supra-cuticular Strigulaceae dominate in the shady understorey, in the light gap species of Gomphillaceae, sub-cuticular Strigulaceae and campylidia bearing members of the Pilocarpaceae dominate and members of the Asterothyriaceae and Gomphillaceae dominate in the canopy (Cáceres *et al*. 2000, Lücking 2001).

In tropical rainforests, foliicolous lichens exhibit broad phorophyte ranges and low specificity (Aptroot 1997, Lücking 1998b). They exhibit phorophyte preference only in species poor sites of subtropical forests (Conran 1997). The principal features of the phorophytes that govern species richness of foliicolous lichens are leaf surface structure, leaf longevity and presence or absence of hairs (Lücking 1998e). Species richness is high on phorophytes having long-lived leaves with grooved or ornamented fine surface and high surface continuity. Hairs or glands on the upper leaf surface influence the growth of foliicolous lichens by influencing air and water currents on leaf surface (Lücking 1998e), thus rendering the successful establishment of diaspores more difficult.

Lichens are poikilohydric organisms lacking mechanisms for regulating uptake and loss of water. They take water and nutrients across the surface of their body. As a result, their growth and distribution are influenced by microenvironmental features of light intensity, humidity and temperature (Connelissen & Ter Steege 1989, Renhorn *et al.* 1997). Therefore, activities and events that result changes in microhabitat could affect their diversity. Conversion of tropical rainforest into agricultural land (Pócs 1996) and forest fragmentation (Brown & Jarman 1994) are the biggest threat to lichens and other epiphyllous flora. Foliicolous lichens are more vulnerable than corticolus ones as the later could survive in small niches after destruction of the forest (Pócs 1996). Shade loving lichens with higher air moisture requirements are affected by canopy openings and the formation of edges during forest degradation.

As compared to tropical America and South East Asia, the foliicolous lichen flora of tropical Africa is insufficiently known. Among the East African countries Tanzania and Kenya are comparatively better known for their foliicolous lichens with 144 species in Tanzania (Feuerer 2007) and 97 species including 5 lichenicolous fungi in Kenya (Lücking & Kalb 2002). Feuerer (2007) listed only 29 foliicolous lichen species for Uganda while no foliicolous lichen species is included among the 279 lichen species list of Ethiopia. Therefore, much task is ahead before the foliicolous lichens of tropical Africa are adequately known. However, the ongoing high rate of deforestation is frustrating that many lichens may disappear before we discover and name them. It is therefore high time that the foliicolous lichen diversity of primary as well as anthropogenic forests is documented and utilized for the development of a sustainable forest management program.

1.3 Objectives

With the current state of increasing dependence of people on forest resources, degradation and conversion of forests in tropical Africa is not going to stop soon. It is thus necessary to design mechanisms by which biodiversity can be conserved and the conservation value of forests already degraded improved under conditions of high human pressure. However, our knowledge on the biodiversity of tropical forests is fragmentary and many groups of organisms, including cryptogams, are unknown or inadequately known. It is therefore necessary to study diversity in primary forests as well as the impact of human exploitation on biodiversity.

1. The phanerogamic flora of Godere, Budongo and Kakamega forests are comparatively well known. However, there is no information on the cryptogamic flora the area. Therefore, the first objective of the present study is to describe the foliicolous lichen flora of these forests.

2. Anthropogenic disturbances affect the biodiversity of an area and the response of organisms to such disturbances is variable. Therefore, in this study
    - the effects of forest disturbance on the diversity of foliicolous lichens is evaluated
    - the change in the diversity of foliicolous lichens along forest disturbance gradient is analyzed
3. For a sustainable forest management, emphasis should be given to the conservation of forest biodiversity. For this to happen, the current status of biodiversity should be known and assessed. In this regard, the importance of foliicolous lichens as bioindicators of particular forest types and disturbance levels is evaluated.
4. Foliicolous lichens have different geographic distribution patterns. In this regard, the lichenogeographical distribution of the foliicolous lichens of the study area is evaluated.

This study is part of the multidisciplinary research project ‘BIOTA East Africa: Conservation and sustainable use of East African rainforest ecosystems’ financed by the German Ministry for Research and Education.

Chapter 2. GENERAL METHODOLOGY

2.1 Foliicolous lichens sampling

Sampling for foliicolous lichens was performed following the sampling methods outlined by Lücking & Lücking (1996). Transects were laid in a homogenous stand of forest and phorophytes reaching a height of up to 3 m were considered for sampling both in the shady understorey and in the light gap microsites of the understorey vegetation. From each phorophyte individuals, a single branch with comparatively much foliicolous lichen was selected as a sample and the leaves that carried foliicolous lichens were collected. From *Dracaena fragrans,* the shoot was considered as a sample and up to 10 leaves were collected. Leaves were also collected from a recently fallen canopy trees. On average 633 leaves were collected from Godere Forest, 2040 leaves from Budongo Forest and 3040 leaves from Kakamega Forest.

Identification of specimen of foliicolous lichens was based on examination of morphological and anatomical features. Morphological characters of thallus, ascomata and conidiomata were examined under stereomicroscope. Hand cut sections and squash preparations were made for studies of the anatomy of thalli and reproductive structures, including perithecia, apothecia, campylidia, pycnidia, and hyphophores and examined under Olympus light microscope. Luglo's solution was used for the color reactions of ascus walls. Photographs were taken under the light microscope. Voucher specimens of all collections are deposited in the herbarium of the department of Biology of the University of Koblenz-Landau (KOBL) in Germany.

2.2 Foliicolous lichen identification

For a general identification of foliicolous lichen genera, Santesson (1952), Lücking (1992a) and the internet key developed by Lücking (2000a) were utilized. In addition, the following literatures were consulted for generic identification. For genera in the Arthoniaceae Lücking (1995a) and Ferraro & Lücking (1997), for Asterothyriaceae Lücking (1999b) and Henssen & Lücking (2002), for Coccocarpiaceae Swinscow & Krog (1988), for Gomphillaceae Lücking *et al*. (2005), for lichenicolous fungi Matzer (1996), for Pilocarpaceae Vĕzda (1986), for Porinaceae Hafellner & Kalb (1995), for Rocellaceae Grübe (1998) and Sparrius (2004), and for Thelotremataceae Frisch (2006).

For species and infra-specific taxa identification, the following sources of information were used. For *Aderkomyces* Vĕzda (1975a) and Lücking *et al.* (2005); for *Arthonia* Santesson (1952), Lücking (1992a), Lücking (1995a), and Ferraro & Lücking (1997); for *Aspidothelium* Sérusiaux & Lücking (2001); for *Asterothyrium* Santesson (1952), Vĕzda (1979), Lücking (1999b), Henssen & Lücking (2002), and Lücking & Kalb, K. (2002); for *Aulaxina* Vĕzda (1979), Lücking (1997a), and Lücking *et al.* (2005); for *Bacidia* Ekman (1996); for *Bacidina* Vĕzda (1980), Vĕzda (1990a), and Farkas & Vĕzda (1993); for

Badimia Vězda (1980); for *Bapalmuia* Santesson & Lücking (1999), and Kalb *et al.* (2000); for *Brasilicia* Vězda (1974) and Santesson & Lücking (1999); for *Byssolecania* Santesson (1952) and Lücking & Kalb (2000); for *Byssoloma* Santesson 1952, Vezda (1975b), Vězda (1987), Kalb & Vězda (1990), and Lücking (1997c); for *Calenia* Vězda (1979), Lücking (1997a), Lücking *et al.* (2001b), and Lücking *et al.* (2005); for *Calopadia* Santesson (1952), Vězda (1986), Lücking (1997c), and Lücking (1999c); for *Caprettia* Vězda (1975), Malcolm & Vězda (1995b), Sérusiaux & Lücking (2003), and Vězda (2004); for *Chroodiscus* Lücking (1999b), Santesson & Lücking (1999), and Lücking & Grube (2002); for *Coccocarpia* Santesson (1952), Arvidsson (1991) and Lücking *et al.* (2007); for *Coenogonium* Vězda & Farkas (1988), Vězda (1990b), Malcolm & Vězda (1995b), Lücking (1999a), Lücking & Kalb (2000), and Rivas-Plata *et al.* (2006); for *Echinoplaca* Vězda (1979), Lücking (1997a), Lücking *et al.* (2005); for *Enterographa* Herrera-Campos & Lücking (2002), Lücking & Matzer (1996), Sparrius (2004), and Ertz *et al.* (2005); for *Eremothecella* Sérusiaux (1992), and Lücking (1995a); for *Eugeniella* Sérusiaux & Lücking (unpublished); for *Fellhanera* Vězda (1974), Vězda (1975), Vězda (1980), Vězda (1986), Sérusiaux (1996), Lücking (1997b), Lücking & Santesson (2001), and Lücking *et al.* (2001a); for *Gyalectidium* Vězda (1979), Sérusiaux & De Sloover (1986), Lücking (1997a), Ferraro *et al.* (2001), and Lücking *et al.* (2005); for *Gyalidea* Vězda (1966), Vězda (1973), Vězda (1979), Vězda & Poelt (1991), and Henssen & Lücking (2002); for *Gyalideopsis* Lücking & Sérusiaux (1998), and Lücking *et al.* (2006); for *Lasioloma* Vězda (1986), and Lücking & Sérusiaux (2001); for *Loflammia* Santesson (1952), Vězda (1986), and Lücking (1999c); for *Lyromma* Lücking (1992), and Lücking & Kalb (2000); for *Mazosia* Vězda (1973), Farkas (1987), and Kalb & Vězda (1988a); for *Musaespora* Lücking & Sérusiaux (1997); for *Phylloblastia* Vězda (1982), Farkas & Vězda (1993), and Lücking (2008); for *Porina* Santesson (1952), Vězda (1975a), Farkas (1987), Lücking (1991), Vězda (1994), Hafellner & Kalb (1995), Lücking (1996), Lücking & Vězda (1998), Lücking *et al.* (1998), and Lücking (2004); for *Psorotheciopsis* Santesson (1952), Vězda (1973), Vězda (1974), and Henssen & Lücking (2002); for *Sporopodium* Santesson (1952), Vězda (1986), Elix *et al.* (1995), Lücking (1999c), and Lücking & Kalb (2002); for *Strigula* Santesson (1952), Farkas (1987), Lücking (1991), and Lücking (1992a); for *Tapellaria* Santesson (1952), Sérusiaux (1984), and Vězda (1986); for *Tricharia* Vězda (1979), Lücking (1997a), Lücking *et al.* (2005), and Kalb & Vězda (1988b); and for *Trichothelium* Lücking (1991), Malcolm & Vězda (1995a), Lücking (1998a) and Vězda (1994).

Nomenclature follows Lücking *et al.* (2000) for species described until 2000 and for species described after 2000 the most recent literature for the taxon are followed. For species in the genus *Coenogonium* nomenclature follows Rivas-Plata *et al.* (2006).

2.3 Data Analysis

2.3.1 Floristic composition and species frequency

The foliicolous lichen species compositions of Godere, Budongo and Kakamega forests as well as their respective forest types are described. Frequency which is the number of samples in which a species occurs is computed for each forest as a whole and the various forest types separately. The following frequency classes were used to designate the frequency status of a species:

≤10% occurrence = Rare
11-20% occurrence =Occasional
21-30% occurrence =Less frequent
31-40% occurrence =Frequent
41-50% occurrence = Very frequent
>50% occurrence = Dominant

2.3.2 Alpha-diversity

Alpha-diversity is the diversity within a particular sample or community. It is also called the within-habitat diversity. Direct species count to give species richness is the simplest measure of diversity. Many diversity indices, however, take into account two aspects of species diversity: species richness and species evenness (equitability). Species richness describes how large the number of species in a community is, while species evenness describes the relative abundance with which each species is represented in an area. There are various measures of species richness, evenness and diversity to compare communities.

2.3.2.1 Sample based rarefaction and species accumulation curves

Comparison of community samples based on different sample sizes is problematic in the determination of species richness as the number of species observed is dependent on the sample size (Peet 1974, Magurran 1988). To overcome this problem, all samples from different communities should be standardized to a common sample size of the same number of individuals (Krebs 1994). A rarefaction method (Sanders 1968) provides a procedure to scale down all collections to the same sample size number for comparison when the samples are taxonomically similar and the sampling methods the same. A species accumulation curve is the graph of the cumulative number of observed species as a function of some measure of sampling effort (Colwell & Coddington 1994). Sample based accumulation curves result when sampling is based on some sampling units (e.g. quadrats) and the total number of species is accumulated as a result of successively sampling additional sampling units (Gotelli & Colwell 2001). Rarefaction and species accumulation curves are closely related (Magurran 2004). Rarefaction estimates the number of species expected to be seen in a smaller sample. The species accumulation curves are used to estimate the total number of species.

In this study sample based rarefaction curves (Gotelli & Colwell 2001) are computed in order to compare the species richness of different forest types in Godere, Budongo and Kakamega forests. Species accumulation curves were computed for the various forest types to estimate the number of species, to examine the degree of foliicolous lichen collection, and to evaluate the effectiveness of the species richness estimators.

2.3.2.2 Species richness estimation

The observed number of species in a given habitat is usually less than the number of actually occurring species. There are different estimation methods that allow estimation of the expected number of species from sample data (Colwell & Coddington 1994, Magurran 2004). In this study non-parametric species estimators which are appropriate for incidence-based (presence/absence) data were followed. The estimators are Chao 2, First Order Jackknife (Jack 1), Second Order Jackknife (Jack 2), Bootstrap, and Incidence Based Coverage Estimator (ICE), and Michaelis-Menten Means (MMMeans). These non-parametric estimators estimate species that are absent in the sample data, but likely to exist in a larger homogenous sample, from the proportional abundances of species within the total sample (Soberón & Llorente 1993, Chao *et al*. 2005)

EstimateS version 8 (Colwell 2006) which is a public domain software was used to compute the expected species accumulation curves and estimates of the expected species richness. The sample order was randomized 100 times to compute the mean estimator and expected species richness for each sample accumulation level.

The equations EstimateS uses in estimating species richness are as follows (Colwell 2006).

1. The Chao 2 incidence-based estimator is based on the number of uniques (species found in only one sample), and the number of duplicates (species found in exactly two samples). The classic formula is

$$S_{Chao2} = S_{obs} + \frac{Q_1^{\;2}}{2Q_2},$$

and the bias-corrected formula is

$$S_{Chao2} = S_{obs} + \left(\frac{m-1}{m}\right)\left(\frac{Q_1(Q_1-1)}{2(Q_2+1)}\right)$$

where S_{chao2} = the expected species number based on Caho 2 estimator

S_{obs} = the number of species observed

Q_1 = the number of uniques

Q_2 = the number of duplicates

m = total number of species

2. The first order Jackknife estimator is based on the number of species occurring in only one sample.

$$S_{jack1} = S_{obs} + Q_1\left(\frac{m-1}{m}\right)$$

where S_{jack1} = the expected species number based on Jack 1 estimator
S_{obs} = the number of species observed
Q_1 = the number of uniques
m = total number of species

3. The second order Jackknife estimator is based on the number of species occurring in only 1 sample and the number of species occurring in exactly 2 samples.

$$S_{jack2} = S_{obs} + \left[\frac{Q_1(2m-3)^2}{m} - \frac{Q_2(m-2)^2}{m(m-1)}\right]$$

where S_{jack2} = the expected species number based on Jack 2 estimator
S_{obs} = the number of species observed
Q_1 = the number of uniques
Q_2 = the number of duplicates
m = total number of species

4. The Bootstrap estimator is based on the proportion of samples containing each species.

$$S_{boot} = S_{obs} + \sum_{k=1}^{S_{obs}} (1 - p_k)^m$$

where S_{boot} = the expected species number based on Bootstrap estimator
S_{obs} = the number of species observed
p_k = proportion of samples that contain species k
m = total number of species

5. Incidence-based Coverage Estimator is based on species found in 10 or fewer samples.

$$S_{ice} = S_{freq} + \frac{S_{\inf r}}{C_{ice}} + \frac{Q_1}{C_{ice}} \gamma^2{}_{ice}$$

$$C_{ice} = 1 - \frac{Q_1}{N_{\inf r}} \qquad , \qquad N_{\inf r} = \sum_{j=1}^{10} jQ_j \ ,$$

$$\gamma^2{}_{ice} = \max\left[\frac{S_{\inf r}}{C_{ice}} \frac{m_{\inf r}}{(m_{\inf r} - 1)} \frac{\sum_{j=1}^{10} j(j-1)Q_j}{(N_{\inf r})^2} - 1, 0\right]$$

where S_{ice} = expected species number based on incidence-based coverage estimator

S_{freq} = number of frequent species (each found in more than 10 samples)
S_{infr} = number of infrequent species (each found in 10 or fewer samples)
C_{ice} = sample incidence coverage estimator
N_{infr} = total number of incidences (occurrences) of infrequent species
m_{infr} = number of samples that have at least one infrequent species
γ^2_{ice} = estimated coefficient of variation of the Q_1 for infrequent species

6. Michaelis-Menten Mean richness estimator (MMMean) is an asymptotic extrapolation of the species accumulation curve. It computes the estimates once for each sample pooling level based on the species accumulation curve as computed by MaoTau in EstimateS.

2.3.2.3 Shannon-Wiener measure of diversity

The Shannon-Wiener index (Shannon & Weaver 1949) of diversity is the most commonly used to characterize diversity in a community. The index is based on the rationale that the diversity or information in a natural system can be measured in a similar way to the information contained in a code or a message (Magurran 2004). It assumes that individuals are randomly sampled from an infinitely large community, and that all species are represented in the sample (which is always difficult to attain in plant communities). The index has the following formula:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

$$p_i = \frac{n_i}{N}$$

where H'= Shannon-Wiener index of species diversity (calculated with base e logs)
pi = proportion of total sample belonging to ith species
N = total number of species
ni = individual number of species i

The Shannon Diversity Index typically falls between 1.5 and 4.0, with lower values indicating lower diversity, and higher values indicating higher diversity. The Shannon index tends to be weighted slightly towards rare species.

2.3.2.4 Shannon's Index of evenness

The evenness component of diversity expresses how individuals are distributed among the species. A community with all individuals equally distributed among the species is more diverse than a community with high dominance of one or few species. Among the various indicies of evenness, the Shannon's evenness was computed as the ratio of observed diversity to maximum diversity (Magurran 1988).

$$J' = \frac{H'}{H'_{\max}} = \frac{\sum_{i=1}^{s} p_i \ln p_i}{\ln s}$$

where J' = Equitability (evenness)
s = the number of species
p_i = the proportion of individuals of the ith species
ln = log base_e

2.3.3 Beta-diversity

Beta diversity or between-habitat diversity is the measure of the change in species diversity between habitats or communities. It is usually expressed in terms of a similarity index between communities or as a species turnover rate. In this study the former is computed with Sørensen index of similarity for qualitative data (Sørensen 1948) and the latter with Whittaker's index for β-diversity (Whittaker 1960).

$$\beta_w = \frac{S}{\alpha}$$

where β_w = Whittaker's index of diversity
S = the total number of species in a forest type
α = the mean sample species number

$$S_s = \frac{2c}{a+b}$$

where S_s= Sørensen similarity index,
a = the number of species in one forest type
b= the number of species in the other forest types
c= the number of species common to both forest types

2.3.4 Statistical analysis

Statistical analysis were performed to determine whether the data are normally distributed, to check the equality of variances of means and for the comparison of the mean species number of samples. Levene Equal-Variance test was performed to test the equality of variances.

Shapiro-Wilk test (Shapiro & Wilk 1965) was run in order to test for normal distribution of the species distribution of samples. When distributions were found to be non normal, the Kruskal-Wallis Analysis of Variance test (Kruskal & Wallis 1952) was employed for the comparison of samples. This test is a non-parametric method for testing equality of population medians among groups. It is most commonly used when the measurement variable does not meet the normality assumption of an analysis of variance (ANOVA). The basic assumptions of the Kruskal-Wallis test are independent samples, continuous variables, a measurement scale of at least ordinal scale and the distributions for the groups are identical (Hintze 2007). When Kruskal–Wallis test provided significant difference, it was followed by comparisons of mean ranks using Kruskal-Wallis multiple comparison procedures.

The values of Shannon diversity indices of the various study sites in Godere, Budongo and Kakamega forests were compared for significant differences using t-test and ANOVA. Magurran (2004) pointed out that estimate of diversity produced by the Shannon index is approximately normally distributed making comparisons with parametric tests feasible. When ANOVA resulted in significant difference, it was followed by Fischer’s least significant post hoc treatment to see which study sites are significantly different.

For calculating the variance of the Shannon index of diversity, the following formula given by Magurran (1988) was used.

$$VarH' = \frac{\sum p_i (\ln pi)^2 - \sum (pi \ln pi)^2}{N} - \frac{S-1}{2N^2}$$

The t statistic for the t test associated with the Shannon index is

$$t = \frac{H'_1 - H'_2}{\sqrt{VarH_1' + VarH'_2}}$$

where VarH’ = variance of the Shannon index

N= sample size

S= No. of species

A significance probability less than $p < 0.05$ was considered as significant differences between means and medians. All statistical analyses were performed with the software NCSS (Hintze 2007) and Statigraphics version 5 software (Statistical Graphics Corporation).

2.3.5 Multivariate analysis

Data from community ecology usually consist of the abundance or importance of taxa (usually species) indexed by sampling units (Palmer 1993). Such data are multidimensional and multivariate analysis is required for easy summarization of the data. In this study an indirect gradient analysis (indirect ordination) is followed to summarize the floristic data of the study sites. Indirect ordination is based on analysis of floristic data with the assumption that examination of variability in floristics reflects variation in environment (Kent & Coker 1992).

Detrended Correspondence Analysis (DCA; Hill and Gauch 1980) is an indirect gradient analysis for ordination of samples and species. DCA is a method based on the assumption of unimodal response of species abundance to environmental gradient and uses weighted averaging for calculation of ordination scores. The axes of DCA are scaled in units of the average standard deviation of species turnover and describe gradients. The eigenvalue associated with each axis can be thought of as the proportion of variation in sample or species dispersion explained by that axis (Gauch 1982). DCA arranges samples according to their species similarity along axes in a multi-dimensional space with the eigenvalue of the first axis greater than that of the second and so on.

Principal Component Analysis (PCA) is a method that reduces data dimensionality by performing a covariance analysis between factors. It involves a mathematical procedure that transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called principal components. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. PCA is a method based on the assumption of linear response of species abundance to environmental gradient and uses eigenvalues to determine axis values.

The species by sample data matrices of Godere and Budongo forests were subject to ordination analysis by DCA as a means of summarizing the information in the data matrices. Before subjecting the data matrices to DCA analysis, samples with 3 and less species were removed to reduce noise resulting from rare species. Presence/absence data were converted to quantitative value ranging between 0 and 1 expressing the probability of a species occurrence in a sample in relation to the other species in the sample. The resulting data matrix contained 75 species and 60 samples for Godere, 129 species and 164 samples for Budongo, and 146 species and 304 samples for Kakamega. However, the variation explained by the first three axes of DCA ordination of the data matrix of Kakamega was very small (14.3% of the total variation). Therefore, for the ordination of Kakamega's data Principal Component Analysis was performed on the species by forest site data matrix. PCA is preferred to DCA because the gradient length was short (less than 3) in the initial correspondence analysis and ter Braak & Šimilauer (2002) recommended PCA for short gradient lengths. In the DCA ordination detrending by segment (26 segments), downweighting of rare species and log transformation of species data were selected. In the PCA ordination centering by species was selected. Both DCA and PCA ordinations were run using the software CANOCO 4.5 (ter Braak & Šimilauer 2002).

Chapter 3 DIVERSITY OF FOLIICOLOUS LICHENS IN GODERE FOREST, ETHIOPIA

3.1 Study area

3.1.1 Location and physiography

Godere Forest is situated in Godere District of the Gambella People's National Regional State (GPNRS) in southwestern Ethiopia between $07^0$08.395'- $7^0$23.437'N Latitude and 34°52.793'-35°25.445'E Longitude (Fig. 3.1). The forest covers an area of 120,000 ha (Bureau of Agriculture, GPNRS, unpublished document) and altitude in the forest varies from 500 m a.s.l. to 2400 m a.s.l. At altitudes between 500 and 1500 m the natural forests belong to the transitional rainforest type of Friis (1992) and the afromontane rainforest type is found at altitudes above 1500 m. About 52 % of the forest is found at elevations between 500 and 1000 m and 38 % of the forest between 1000 and 1500 m altitude (Ersado 2003).

At altitudes above 1250 m, the topography is characterized by undulating and dissected terrain. At altitudes below 1250 m and the terrain becomes rather flat and about 83 % of the forest develops on this flat terrain. Godere, Achani and Gilo are the major rivers in the forest and belong to the Baro-Akobo drainage system which is the tributary of the Nile River.

3.1.2. Geology and Soil

In Ethiopia, the basement complex upon which all the younger formations were deposited contains the intensively folded and faulted Precambrian rocks (Mohr 1962, Kazmin 1972, Westphal 1975). These rocks are overlain by Mesozoic rocks, mainly sandstone and limestone, and by Tertiary volcanic rocks, mainly basalts, rhyolites, trachytes, tuffs, ignimbrites, agglomerates (Friis 1992). The Southwest Ethiopia Volcanites, which include the Omo Basalts (Oligocene to Miocene) and the Jimma Volcanites (Oligocene to Miocene), are found in southwestern Ethiopia (Asres 1996).

There is no published information on the soils of the study area. From the general account of the soils of southwestern Ethiopia by Asres (1996), it can be deduced that the soils of the study area are Nitosols having a depth of more than 1.5 m. An analysis of soil samples take from Godere Forest undertaken by the National Soil Laboratory of the Ethiopian Institute of Agricultural Research on behalf of the Institute of Biodiversity Conservation shows that the soil is slightly acidic (pH 6.5), and is rich in exchangeable bases (Sodium 0.72 meq/100 g, Potassium 2.4 meq/100 gm, Calcium 22.4 meq/100 g, Magnesium 7.7 meq/100 g) and cation exchange capacity (38.6 meq/100 g). The soils were reddish brown, well drained and clay in texture.

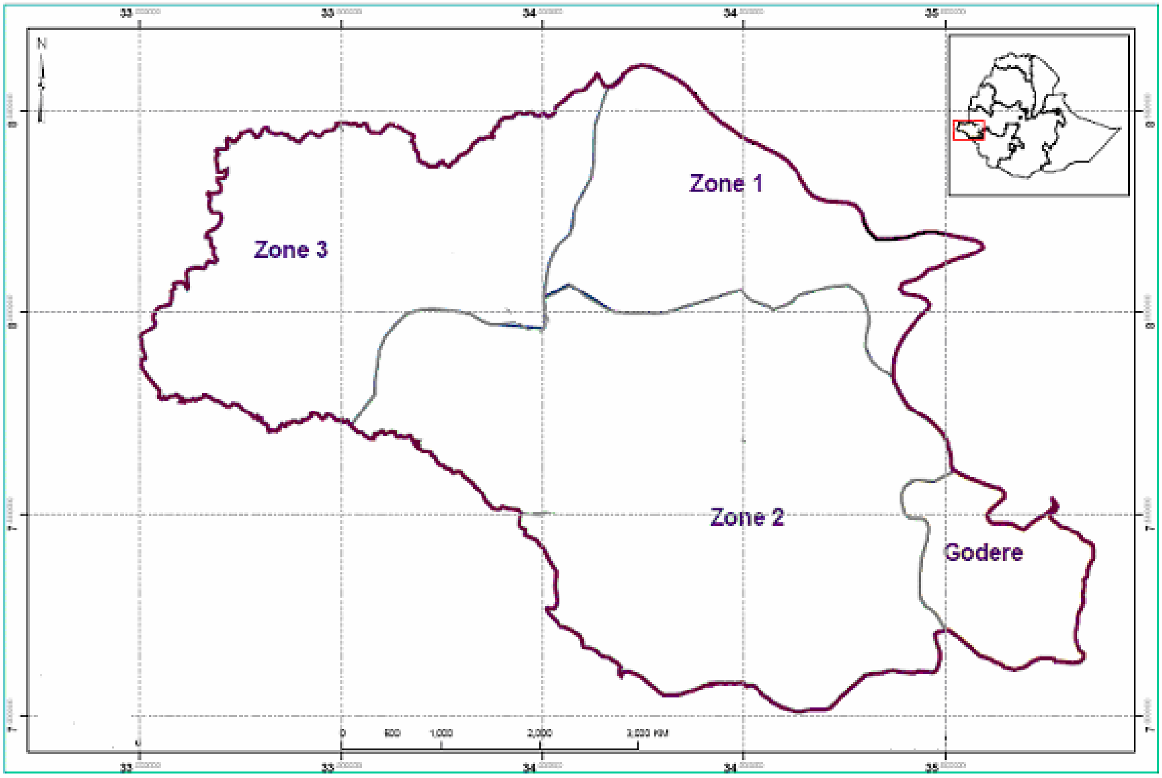

Fig. 3.1 Map of Gambella Regional State in southwestern Ethiopia and the location of Godere District

3.1.3. Climate

The climate in Ethiopia depends on the prevailing winds of the humid Southwest Monsoon and the dry Northeast Trade Winds, which are governed by the movement of the Inter-Tropical Convergence Zone (ITCZ), (Liljequist 1986). In the summer (May to October), the ITCZ is north of the Equator; the prevailing wind over most of Ethiopia is southwesterly. These moisture-laden wind-systems produce rain over large areas of the escarpments and plateaux, the highest rainfall being in the southwestern parts of the country (Friis 1992). In the winter (December to February), the ITCZ is south of the equator, the Northeast Trade Winds influence the climate of southwestern Ethiopia resulting in a dry season.

All the highlands in southwest which are above 1000 m altitude receive an annual rainfall of between 1400 and 2200 mm (Ayele & Al Shadily 2000). At Tepi (7^{0}05’ N, 35^{0}15’ E, 1250 m altitude), a town about 40 km from Godere Forest, the mean annual rainfall is 1562 mm with most of the rain occurring from May to September (Asres 1996). Average annual temperature in the forest ranges between 15-25 ^{0}C.

3.1.4 Vegetation and flora

The forest vegetation of Ethiopia has been classified by various authors (Logan 1946, Chaffey 1979, Friis 1986, Friis 1992). Friis (1992) classified the forests of Ethiopia in to seven types: lowland dry peripheral semi-deciduous Guineo-Congolian forest, transitional rainforest, Afromontane rainforest, undifferentiated Afromontane forest, dry single dominant Afromontane forest of the Ethiopian Highlands, dry single-dominant Afromontane forest of the escarpments, and riverine forest.

According to the classification of Friis (1992), a lowland dry peripheral semi-deciduous Guineo-Congolian forest, transitional rainforests, and Afromontane rainforests are found in southwestern Ethiopia. The following description of these forest types is based on Friis (1992).

The dry peripheral semi-deciduous Guineo-Congolian forests are restricted to the Baro lowlands of Gambella in southwestern Ethiopia. The forests occur on well drained sandy soils on flat area at altitudes ranging from 450-600 m a.s.l. The mean annual maximum temperature is 35-38°C and the corresponding minimum temperature is 18-20°C and the mean annual rainfall ranges from 1300 to 1800 mm, the rainy season being from May to September. The forest is semi-deciduous, with a 15-20 m tall, more or less continuous canopy of *Baphia abyssinica* (endemic to the lowlands of southwestern Ethiopia and adjacent parts of Sudan on the Boma Plateau and Mt. Tomadur) mixed with less common species such as *Celtis toka, Diospyros abyssinica, Lecaniodiscus fraxinifolius, Malacantha alnifolia, Trichilia prieureana, Zanha golungensis,* and *Zanthoxylum leprieurii.* The species that emerge high above the main canopy are *Alstonia boonei, Antiaris toxicaria, Melicia excelsa,* and *Celtis gomphophylla.* Small trees such as *Acalypha neputnica, Erythroxylum fischri, Tapura fischeri, Ziziphus pubescens,* and *Xylopia parviflora* form a continuous stratum below the canopy. The shrub layer is sometimes dense and includes *Alchornea laxiflora, Argomuellera marcophylla, Mimulopsis solmsii, Oncoba spinosa, Oxyanthus speciosus, Rinorea ilicifolia* and *Whitfieldia elongata. Hippocratea parvifolia, H. goetzei, Combretum paniculatum,* and *Ampelocissus abyssinica* are the dominating woody climbers.

The transitional rainforests occur on the escarpments of southwestern highlands in Bench-Maji Zone, Illubabor Zone and Godere District. The forest occurs at altitudes between 500 and 1500 m a.s.l., partly in river valleys, partly in areas presumed to have a high water table. The mean annual rainfall is about 2000 mm with rain falling most of the year, the maximum being between May and September. The mean annual temperatures range from 20 to 25°C. The transitional rainforest is similar in physiognomy and composition to the Afromontane rainforest of southwestern Ethiopia, with additional species from the lowland dry peripheral semi-deciduous Guineo-Congolian forest and with few species restricted to the transitional rainforest. The species in the latter forest type include *Pouteria (Aningeria) altissima, Anthocleista schweinfurthii, Campylospermum bukobense, Celtis philippensis, C. zenkeri, Croton sylvaticus, Dracaena fragrans, Elaeodendron buchananii, Eugenia bukobensis, Ficus exasperata, Garcinia huillensis, Manilkara butugi, Morus mesozygia, Strychnos mitis, Trichilia dregeana,* and *Trilepisium madascariense*.

An inventory of Godere Forest made by the Institute of Biodiversity Conservation in 2001 has recorded 97 woody species. Awas *et al*. (2001) recognized *Manilkara butugi-Cordia africana* community type in Godere Forest. The community type is characterized by *Manilikara butugi* and *Cordia africana*. Other trees include *Mimusops kummel, Pouteria (Aningeria) altissima, Alchornea laxiflora,* and *Celtis zenkeri.* The shrubs include *Justicia schimperiana, Dracaena fragrans, Whitfieldia elongate, Argomuellera macrophylla* and *Acalypha acrogyna*. Lianas include *Hippocratea africana* and *H. pallens*.

The afromontane rainforests are found distributed in Illubabor, Sheka, Kefa, Bench-Maji, and Jimma Zones in southwestern Ethiopia. The forest is found at altitudes between 1500 and 2500 m with mean annual temperatures ranging from 18-20^{0}C and annual rainfall between 1500 and more than 2000 mm with rain most of the year, but a maximum between April and October. *Pouteria* (*Aningeria*) *adlofi-frederici* is an emergent tree in the 20-30 m high canopy. The canopy trees include *Olea capensis, Ilex mitis, Schefflera abyssinica, Ekebergia capensis, Macaranga capensis, Euphorbia ampliphylla, Euphorbia ampliphylla, Schefflera abyssinica, Ficus thonningii, Ocotea kenyensis, Croton macrostachyus, Albizia schimperiana, A. gummifera, A. grandibracteata, Ficus sur. F. ovata, F. thonningii, Prunus africana, Sapium ellipticum, Syzygium guineense,* and *Polyscias fulva*. A discontinuous lower canopy of smaller trees includes *Allophylus abyssinicus, Apodytes dimidiata, Bersama abyssinica, Brucea antidysenterica, Calpurnia aurea, Canthium oligocarpum, Chionanthus mildbraedii, Clausena anisata, Coffea arabica, Cyathea manniana, Deinbollia kilimandscharica, Dracaena afromontana, D. fragrans, D. steudneri, Ehretia abyssinica, Erythrina brucei, Galiniera saxifraga, Lepidotrichilia volkensii*, *Milletia ferruginea* (endemic to Ethiopia), *Nuxia congesta, Oncoba routledgei, Oxyanthus speciosus, Phoenix reclinata, Pittosporum viridiflorum, Psychotria orophila, Ritchiea albersii, Rothmannia urcelliformis, Teclia nobilis, Trema orientalis, Turraea holstii,* and *Vepris dainellii.* Ground herbs include *Aframomum corrorima, Desmodium repandum* and many grass species. Lianas include *Hippocratea goetzei, H. africana, Landolphia buchananii*, *Jasminium abyssinicum*, *Urera hypselodendron,* and *Tiliacora troupinii*.

3.1.5 Fauna

The fauna of the forests of southwestern Ethiopia have not been adequately studied. Brown & Urban (1971) studied the mammals and birds of southwestern Ethiopia including the forest in Godere and came up with a list of 48 mammals species. Godere Forest falls under Metu-Gore-Tepi forest Important Bird Areas (EWNHS 1996) and the area supports Afrotropical highlands biome species and small populations of *Rougetius rougetii* (Rouget's Rail) and *Macronyx flavicoliis* (Abyssinian Longclaw), which are classified as Globally threatend. *Poicephalus flavifrons* (Yellow Fronted Parrot) and *Dendropicos abyssinicus* (Abyssinian Woodpecker) are two endemic birds of Ethiopia found in the area. Species otherwise rarely recorded in Ethiopia include *Podica senegalensis*, *Cossypha niveicapilla*, *Nectarinia chloropygia* and *Euplectes gierowii*.

3.1.6 Management status

Natural forests in Ethiopia are administered by the regional governments. The Yeki Forest in Yeki District and Godere Forest in Godere District were designated as Yeki-Godere state forest in 1988. Following the separation of the regional administration of Yeki and Godere districts, Godere Forest became a state forest and its management and administration rested on the Gambella Peoples' National Regional Government.

Godere Forest is one of the 58 National Forest Priority Areas of Ethiopia established in 1989 for conservation and production purpose. However, nothing has been done to fulfill the articulated purposes as there were no legislations issued to enforce management. Godere Forest lacks proper demarcation and a forest management plan has never been prepared. The Institute of Biodiversity Conservation with financial support from the German Technical Cooperation undertook an inventory of woody plant diversity and socio-economic survey in Godere and other forests in southwestern Ethiopia in order to identify priority woody species for *in situ* and *ex situ* conservation (see Dessie 2003 & Ersado 2003). *Baphia abyssinica, Malacantha alnifolia, Morus mesozygia* and *Celtis zenkeri* were the priority species selected from Godere Forest (Bekele *et al.* 2002).

3.1.7 Human Impact

Human impact in Godere Forest is seen in the form of fallow farming, commercial logging, resettlement and coffee plantation. The lowland part of Godere Forest is predominantly inhabited by the Mejenger ethnic group who are dependent on the forest for their survival. The people speak Mejenger which belongs to the Nilotic language family. Population density in Godere District is 22.7 people per square kilo meter (CSA 2007). Traditionally, the Mejenger people were hunter gatherer and shifting cultivator for long until they lost their forest land for the establishment of state coffee plantation and expansion of agriculture by settlers and changed their life style to fallow and sedentary farming and bee keeping (Tadesse 2007).

In shifting cultivation, the farmers set fire in the forest to remove trees, shrubs and lianas and they cultivate the land for food crops for three to five years. When they assume that the fertility of the land is declined, they abandon the land and shift to another forest area in their surrounding to do the same. The farmers dig hole with traditional wooden stick and plant maize, sorghum, pumpkin and beans together. In addition, root crops like Yam (*Dioscorea cayenensis*), Cassava (*Manihot esculenta*), and Taro (*Colocasia esculenta*) are planted by the Mejenger.

The natural forests of southwestern Ethiopia are the source of logs for most of the forest industries in Ethiopia (Abebe 2003). Godere Forest is the supplier of logs for Bebeka sawmill in Meti, a town 10 km far from Godere Forest, and other three sawmills in the southwestern Ethiopia (Abebe & Holm 2003). Timber extraction from Godere Forest started in 1986 (Abebe 2003). The sawmills use selective logging and the main tree species logged were *Cordia africana* and *Pouteria adolfi-friederici*.

Coffee production has contributed for the decline in the natural vegetation cover of Godere Forest. Two types of coffee production system are practiced in Godere forest area. In the semi-forest coffee production system, all small trees, shrubs and climbers are removed while big trees are maintained to provide shade to the coffee plant. This system is practiced by individual farmers. In the state and private large-scale coffee plantation system, the natural forest is removed for coffee plantation leaving only few shade trees.

For more than two decades, Godere Forest has been affected by commercial coffee plantation by the state-owned Tepi Coffee Plantation Enterprise (TCPE) which was established in 1988 and maintains 7082 ha of coffee plantation in the area (Tadesse 2007). In the last decade, private investors were granted forestland for the same purpose. As the forest is converted for coffee plantation, all shrubs, lianas and most of the trees are removed, leaving only those trees which provide shade for the coffee. *Albizia gummifera, Millettia ferruginea* and *Cordia africana* are the most preferred indigenous shade trees while *Gravillea robusta* is an exotic tree planted as shade tree. In addition, the construction of access roads inside the forest, construction of residences for the staff and families of TCPE, establishment of offices and coffee processing facilities, have resulted in the clearing of the natural forest cover.

The employment opportunity provided by TCPE for the collection of coffee beans has attracted many people from different parts of Ethiopia. Some of these people do not go back home after they finish their contract with the enterprise. They rather try to acquire forestland illegally and start cultivation. Once settled, these people go back to their former home area to bring family members and provoke relatives and friends to come to the forest area of Godere for settlement. As a result of such illegal settlement, most areas of Godere Forest has been converted for settlement, coffee plantation and food crop production.

In the mid of 1980s, the Ethiopian government carried out a large scale resettlement program in parts of southwestern Ethiopia for people from draught affected parts of Ethiopia. In addition to arable lands, natural forests were selected for the resettlement program. Godere Forest was one of the forests selected for the program. Most of these settlers came from parts of the country which practice sedentary agriculture and where no natural forests exist. As a result vast area of the forest had been converted to agricultural land, coffee plantation and villages.

Tadesse (2007) investigated the forest cover change in parts of southwestern Ethiopia including Godere using satellite image analysis. The result showed that the high forest cover of the area decreased from 71 % to 48 % between 1973 and 2005. Commercial coffee plantation accounted for 30 % of the loss and 70 % of the loss was due to the local community farming practice.

3.2 Study sites

Two sites were selected in Godere Forest for the present study: a forest around Bishan Waka Lake in Gubeti Peasant Association and a forest in Dushi Peasant Association.

Bishan Waka is a small lake surrounded by a forest. *Manilkara butugei* forms the 20-25 m upper canopy of the forest. The species in the 15-20 m tree layer are *Mimusops kummel, Cordia africana, Celtis africana, Diospyros abyssinica, Morus mesozygia, Croton macrostachyus, Polyscia fulva, Cassipourea malosana, Phoenix reclinata,* and *Olea capensis* ssp. *welwitschii.* Small trees and shrubs include *Chionanthes mildbraedii, Lepidotrichilia volkensii, Rothmannia urcelliformis, Oxyanthus speciosum, Argomuellera macrophylla, Rinorea friisii,* and *Dracaena fragrans.* Altitude in the forest varies from 1430 to 1560 m. The canopy is open and enough light reaches the ground. Human pressure on this forest in the form of logging and conversion to other land use types is relatively minimal.

The forest in Dushi area is a very disturbed secondary forest severely affected by slash-and-burn agriculture and both semi-forest coffee and commercial coffee management. The sampling site for the present study is in the semi-forest coffee managed area at altitude between 1230 and 1270 m. The forest has three layers, two tree layers and a shrub layer. Trees and shrubs in this area include *Antiaris toxicaria, Millettia ferruginea, Baphia abyssinica, Polyscias fulva, Mimusops kummel, Strychnos mitis, Diospyros abyssinica, Trichilia dregeana, Croton macrostachyus, Celtis africana, C. philippensis, Cordia africana, Pouteria (=Aningeria) altissima, Albizia grandibracteata, Ficus sur, F. mucuso, F. lutea, Morus mesozygia, Trichilia dregeana, , Trilepisium madagascariense, Malacantha alnifolia,* and *Vepris dainellii*, The shrubs layer is dominated by *Coffea arabica*. Other less abundant shrubs include *Argomuellera macrophylla*, *Maytenus gracilipes, Alchornea laxiflora,* and *Dracaena fragrans.*

3.3 Results

3.3.1 Floristic composition

Altogether 75 taxa of foliicolous lichens and lichenicolous fungi growing on foliicolous lichens belonging to 27 genera and 15 families were recorded from Godere Forest (Fig. 3.2). Out of these, 70 were identified to a species level, 4 were identified to a genus level and one species was identified to a variety level. Three species were found to be new to science. The full species list is presented in Appendix 1.

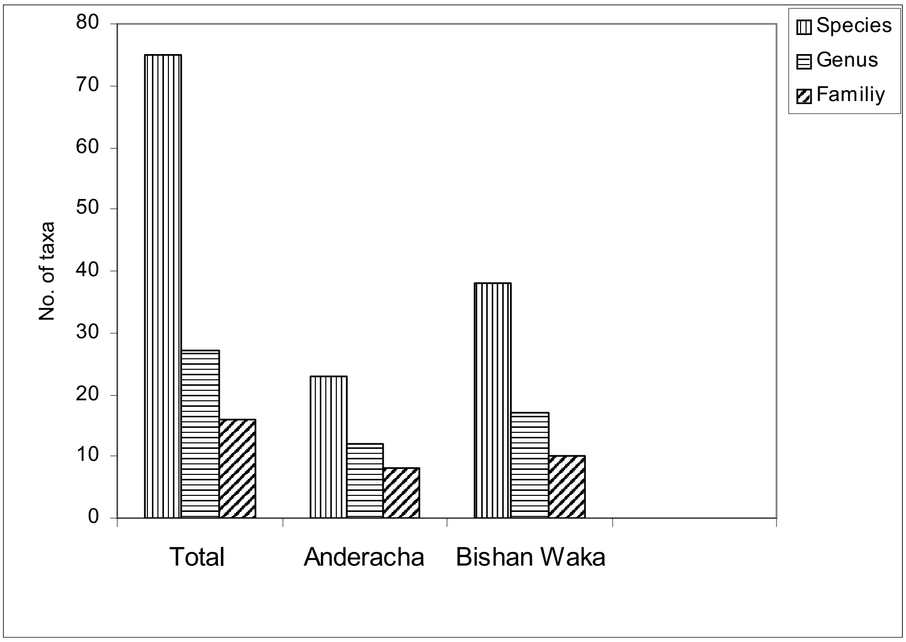

Fig. 3.2 Distribution of foliicolous lichen taxa in Godere Forest and the study sites of Bisha Waka and Dushi

About 93 % of the species in Godere Forest were typically foliicolous, 1.3 % facultatively foliicolous, 1.3 % ubiquitous and 4 % were lichenicolous fungi growing on foliicolous lichens (Fig. 3.3). *Arthonia atropunctata, Opegrapha velata* and an unidentified species of *Opegrapha* are the lichenicolous fungi recorded from the forest. *Coccocarpia stellata* is the facultative foliicolous lichen species and *Fellhanera bouteillei* is the ubiquitous lichen.

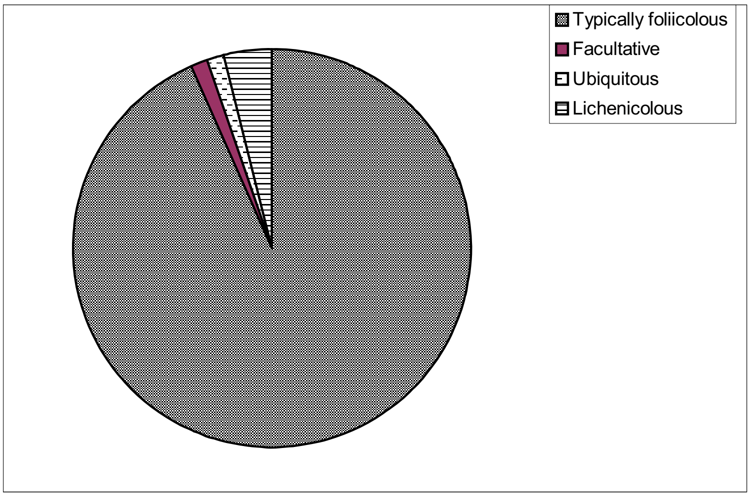

Fig. 3.3 Proportion of typical, facultative, and ubiquitous foliicolous lichens and lichenicolous lichens in Godere Forest

The most dominant lichen family in Godere Forest was Pilocarpaceae with 6 genera and 20 sub generic taxa (Fig. 3.4). Porinaceae was the second largest family with 2 genera, 13 species and 1 subspecies. The family Strigulaceae was represented by one genus, 7 species and 2 subspecies. The families Asterothyriaceae and Gomphillaceae were each represented by 3 genera and 7 species. The families Coenogoniaceae and Ramalinaceae were each represented by one genus and three species. The families Arthoniaceae, Roccellaceae, Aspidotheliaceae, and Thelotremataceae were each represented by one genus and two species. The two taxa of Roccellaceae belonging to the genus *Opegrapha* grew para-symbiotically on foliicolous lichens. The families with one genus and one species were Coccocarpiaceae, Lyromataceae, Monoblastiaceae and Verrucariaceae.

Among the two sampling sites, higher number of families, genera and species were recorded from Dushi with 14 families, 24 genera and 68 species. From Bishan Waka 10 families, 17 genera and 38 species were recorded (Fig. 3.2).

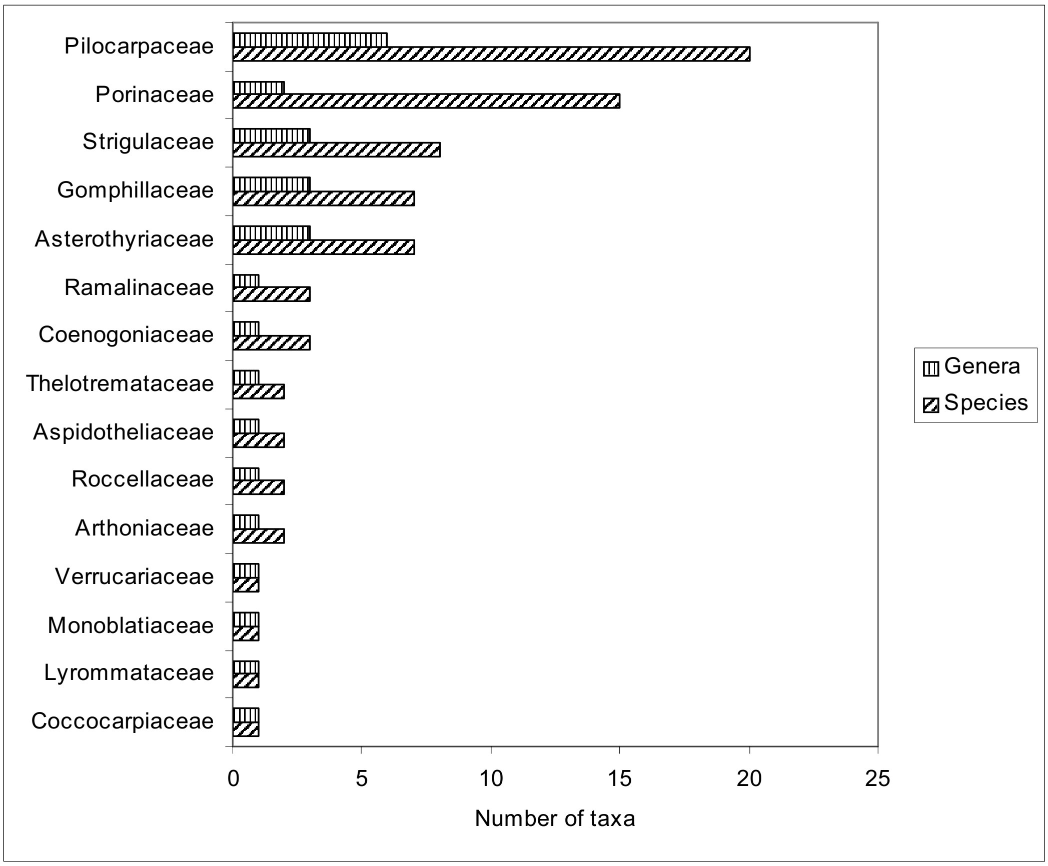

Fig. 3.4 Number of species and genera of foliicolous lichens per family in Godere

The following species were recorded from both Dushi and Bishan Waka study sites: *Aspidothelium fugiens*, *Asterothyrium rotuliforme, Bacidina apiahica, B. pallidocarnea, Calenia monospora, Calopadia fusca, C. puiggarii, Chroodiscus verrucosus, Coccocarpia* *stellata, Fellhanera bouteillei, F. paradoxa, F. sublecanorina, Gyalectidium filicinum, Gyalidea epiphylla, Porina cupreola var. cupreola, P. epiphylla, P. leptosperma, P. nitidula, P. rubescens, P. subpallescens, P.* cf. *triseptata, Sporopodium phyllocharis, Strigula nemathora* var. *hypothelia, S. nitidula, S. phyllogena, S. smaragdula, Trichothelium africanum,T. pauciseptatum,* and *T. epiphyllum.*

The species recorded from Dushi but absent in Bishan Waka were *Arthonia atropunctata, A. lividula, Aspidothelium hirsutum* sp. nov.*, Asterothyrium microsporum, A. octomerum, Bacidina mirabilis, Brasilicia foliicola, Byssolecania hymenocarpa, B. chlorinum, B. leucoblepharum, B. subpolychromum, Calenia triseptata, Calopadia phyllogena, Caprettia goderei* sp. nov.*, Chroodiscus kakamegensis* sp. nov.*, Coenogonium dilucidum, C. subluteum, C. usambarense, Fellhanera* cf. *aurantiaca, F. subfuscatula, F. submicrommata, Lyromma nectandrae, Opegrapha velata, Porina rubescens, P. rufula, P. tetramera, P. trichothelioides, Psorotheciopsis varieseptata, Sporopodium antonianum, S. leprieurii, Strigula schizospora,* and *Tapellaria bilimbioides*

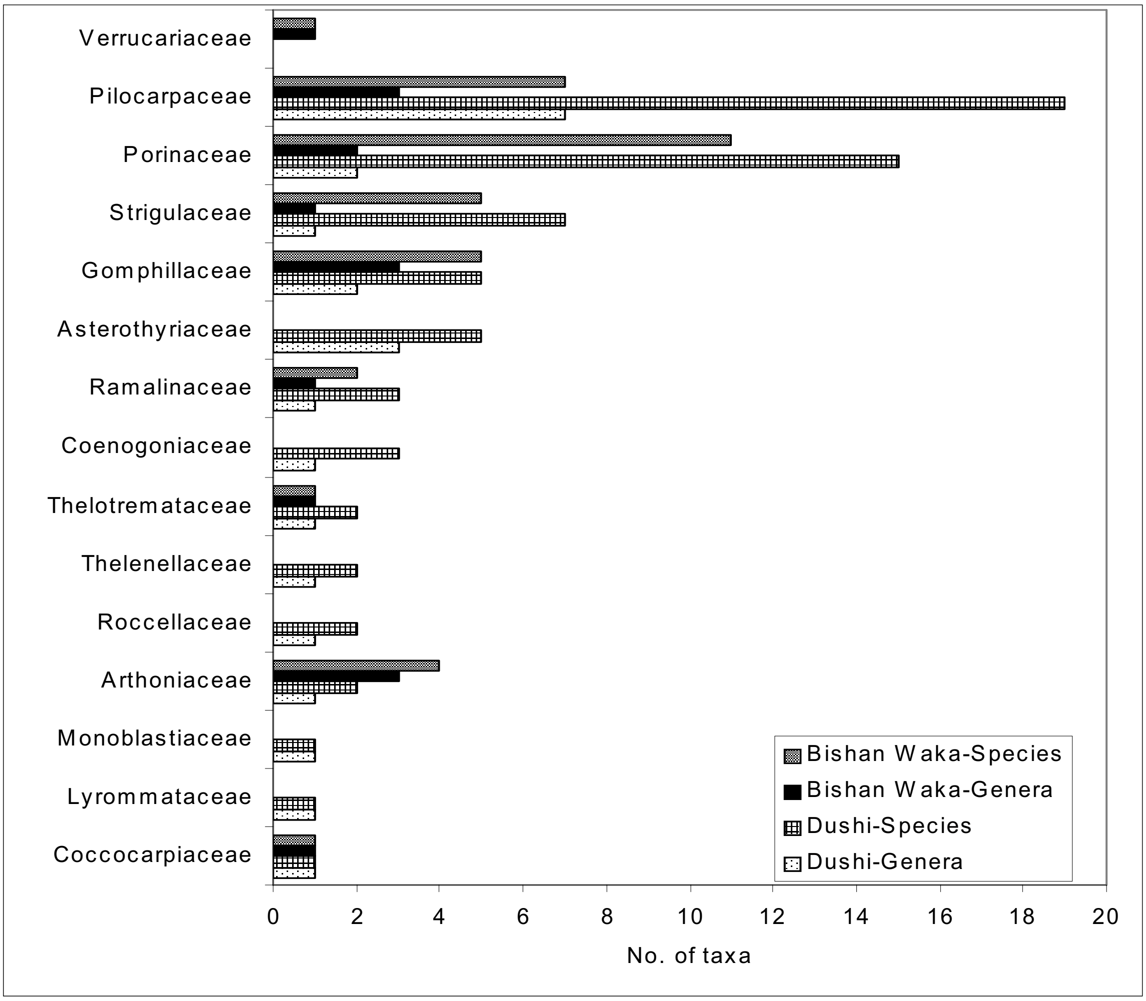

Fig. 3.5 Foliicolous lichen genera and species per family in Dushi & Bishan Waka

The species rich family in Dushi is Pilocarpaceae with 19 species, followed by Porinaceae with 15 species and Strigulaceae with 7 species (Fig. 3.5). In Bishan Waka the family Porinaceae was the richest with 11 species, followed by Pilocarpaceae with 7 species and Gomphillaceae and Strigulaceae had 5 species each.

3.3.2 Species frequency

The frequency of occurrences of species in the sample plots of the study sites of Godere Forest are presented in Fig 3.6. In Dushi most of the species (59%) were rare. Occasional and very frequent species made 18% and 8% of the whole species respectively. The frequent species made 7% and the less frequent species made 6% of the whole species. Only 3% of the species were dominant.

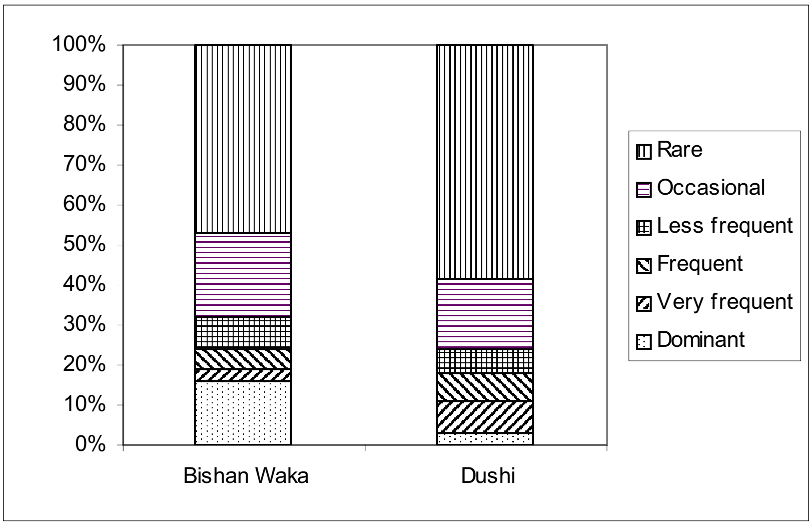

Fig. 3.6 Frequency distribution of species in Dushi and Bishan Waka

The dominant species in Dushi were *Porina nitidula, P. rubentior, P. epiphylla, P. cupreola* var. *cupreola and P. subpallescens. Bacidina apiahica* and *Porina leptosperma* were the very frequent species. The frequent species were *Strigula phyllogena, Strigula smaragdula, Gyalidea epiphylla, Calopadia fusca,* and *Lyromma nectandrae. Calopadia puiggarii, Aspidothelium fugiens, Fellhanera paradoxa, Trichothelium africanum* were the less frequent species. The occasional species were *Brasilicia foliicola, Byssolecania hymenocarpa, Calenia monospora, Gyalectidium filicinum, Strigula nemathora* var. *hypothelia, Trichothelium pauciseptatum. Fellhanera bouteillei, Gyalectidium imperfectum, Strigula nitidula, Fellhanera subfuscatula,* and *F. submicrommata*. The rare species were *Arthonia atropunctata, A. lividula, Aspidothelium hirsutum sp. nov., Asterothyrium microsporum, A. octomerum, Asterothyrium rotuliforme, Bacidina mirabilis, Bacidina pallidocarnea, Byssoloma chlorinum, B. leucoblepharum, B. subpolychromum, Calenia triseptata, Calopadia phyllogena, Caprettia goderei* sp. nov., *Chroodiscus kakamegensis* sp. nov., *C. verrucosus, Coccocarpia stellata, Coenogonium* *dilucidum, C. subluteum, C. usambarense, Fellhanera* cf. *aurantiaca, F. sublecanorina, Opegrapha velata, Porina* cf. *triseptata, P. rubescens, P. rufula, P. tetramera, P. trichothelioides, Psorotheciopsis varieseptata, Sporopodium antonianum, S. leprieurii, S. phyllocharis, Strigula macrocarpa, S. microspora, S. schizospora, Tapellaria bilimbioides* and *Trichothelium epiphyllum.*

In Bishan Waka 47% of the species were rare and 21% occasional. Unlike Dushi, the dominant species in Bishan Waka constituted higher proportion (16%). The less frequent, frequent, and very frequent species constituted 8%, 5% and 3% of the total species respectively

The dominant species in Bishan Waka were *Porina nitidula, P. epiphylla, P. subpallescens, Calopadia puiggarii, Strigula phyllogena* and *Gyalectidium filicinum. Fellhanera paradoxa* was the only species designated as very frequent and *Calopadia fusca* and *Bacidina apiahica* constituted the frequent category. The less frequent species constituted *Fellhanera bouteillei, Calenia monospora* and *Strigula smaragdula. Asterothyrium leucophthalmum, A. rotuliforme, Coccocarpia stellata, Gyalectidium fuscum, Gyalidea epiphylla, Porina leptosperma, P. rubentior* and *Trichothelium africanum* constituted the occasional species. The rare species were *Aspidothelium fugiens, Bacidina pallidocarnea, Chroodiscus verrucosus, Echinoplaca pellicula, Fellhanera sublecanorina, Gyalectidium imperfectum, Phylloblastia pocsii, Porina* cf. *triseptata, P. cupreola* var. *cupreola, Psorotheciopsis patellarioides, Sporopodium phyllocharis, Strigula nemathora* var. *hypothelia, S. nemathora* var. *nemathora, S. nitidula, Trichothelium pauciseptatum,* and *T. epiphyllum*

The frequency occurrences of species in the samples of Godere Forest and in the study sites of Bishan Waka and Dushi are presented in Appendicies 3, 4 and 5 respectively.

3.3.3 New records and new species of foliicolous lichens

The foliicolous lichens and lichenicolous fungi recorded in this study are all new records for Ethiopia. Three species of foliicolous lichens new to science were recorded from Godere Forest. Furthermore, two more records are expected to be new to science; however the specimens were not adequate for description. Some interesting records of foliicolous lichens and lichenicolous fungi are also recorded.

3.3.3.1 *Species new to science*

1. *Caprettia goderei* sp. nov. (Monoblastiaceae) (Fig 3.7 A & B)

A single collection from Godere Forest producing pale brownish to black, wart shaped perithecia and tubular pycnidia looking like those of *Caprettia nyssaegenoides* was found to be new to science. It has been described and sent for publication.

Specimen examined: Godere: Dushi Peasant Association 07^{0}16’13 N and 035^{0}12’17 E, 1230 m, epiphyllous on *Strychnos mitis*, 2005, Kumelachew 301(KOBL)

2. *Chroodiscus kakamegensis* sp. nov. (Thelotremataceae) (Fig. 3.7 C & D)

A single collection from Godere Forest belonging to the genus *Chroodiscus* which was lichenicolous on *Porina epiphylla* and having smooth thallus and 1-3 septate ascospores was found to be new to science. The smooth thallus points to *Chroodiscus africana* described from Ivory Coast (Santesson & Lücking 1999) but this species had consistently 1-septate ascospores. It was described and sent for publication.

Specimen examined: Godere: Godere Forest, Dushi Peasant Association, 1230 m, 07^{0}16’13 N and 035^{0}12’17 E, epiphyllous on *Diospyros abyssinica*, Kumelachew 297(KOBL).

3. *Aspidothelium hirsutum* sp. nov. (Aspidotheliaceae) (Fig. 3.7 E & F)

A single collection having small thallus with hairs produced by the fungus and on which the photobiont growing up from the thallus was collected from Godere Forest. No member of the genus produced hairs on the thallus and therefore this collection represents a species new to science. It has been described and sent for publication.

Specimen examined: Godere Forest, Dushi Peasant Association, 1262 m, 07^{0}16’56 N and 035^{0}12’14 E, epiphyllous on *Strychnos mitis*, 1262 m Kumelachew 277 (KOBL).

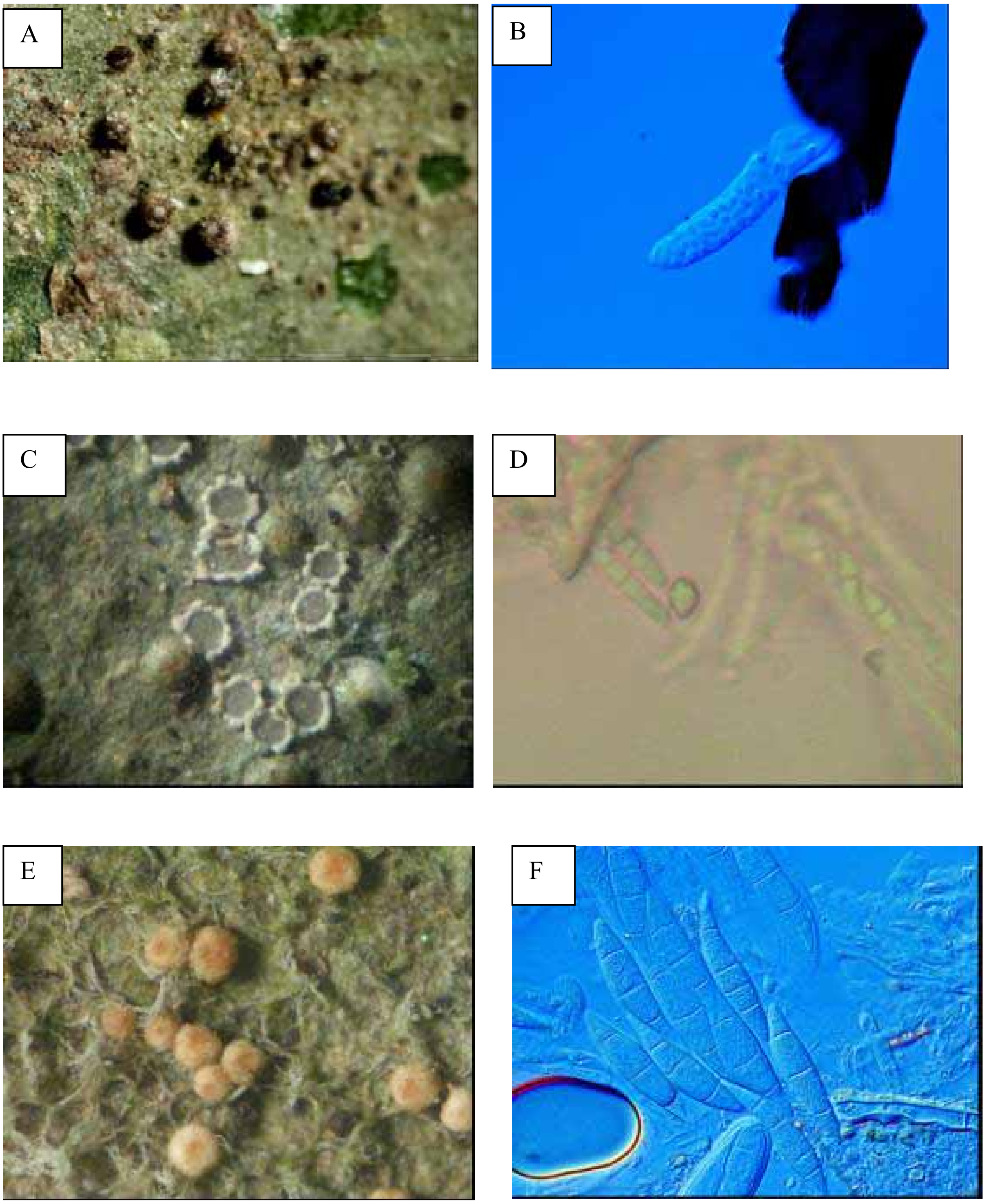

Fig. 3.7 Pictures of new species. (A) *Caprettia goderei* sp. nov., habit, (B) *Caprettia goderei* sp. nov. , conidia in saccus being expelled from pycnidium, (C) *Chroodiscus kakamegensis* sp. nov., habit, (D) *Chroodiscus kakamegensis* sp. Nov., ascospores (note the different septation), (E) *Aspidothelium hirsutum* sp. nov., habit, (F) *Aspidothelium hirsutum* sp. nov., ascospores in ascus

3.3.3.2 *Interesting records of foliicolous lichens*

1. *Fellhanera* cf. *aurantiaca* (Pilocarpaceae) (Fig. 3.8A & B)

Two collections listed below had green thallus; a typical paraplectenchymatous excipulum with large cells (upto 8-10 µm) under the hypothecium; hypothecium K+ red-brown; ascospores 3-septate, 12-18 x 3-4.5 µm. Our specimens match the description of *Fellhanera aurantiaca* from Guinea (Vĕzda 1974) and also known from the DR Congo except that the excipullar cells under the hypothecium are not said to be large. From the photos of Lücking & Colin (2004), our specimen looked like *F. rubida* (only known from South America) and said to have very large cells in the excipulum under the hypothecium (Lücking 1997b).

Specimen examined: Godere Forest, Dushi Peasant Association, 1230 m, $07^0$16'53 N, $035^0$12'11 E, on living leaves of *Argomuellera macrophylla*, Kumelachew 3/275 & 1250 m; $07^0$16'16 N, $035^0$12'24 E, on living leaves of *Diospyros abyssinica*, Kumelachew 297 (KOBL)

2. *Fellhanera* aff. *bouteillei* (Pilocarpaceae) (Fig. 3.8C)

The collection cited below had green, rather coherent thallus, apothecia medium sized, pale orange to brownish orange, with a thin but distinct margin, ascospores 1-septate, 22-25 x 4-5 µm. The collection belongs to the *Felhanera subternella* aggregate (Lücking 1997b) and is close to *F. bouteillei,* a species known to exhibit variations in thallus and apothecial morphology. It differs from *Fellhanera bouteillei* in thallus morphology and having longer (22-25 µm) ascospores with the proximal and distant cells being more or less equal in size.

Specimen examined: Godere Forest, Bishan Waka, 1370 m, on living leaves of *Phoenix reclinata,* 2005, Kumelachew 318 (KOBL).

3. *Calenia* sp. (Gomphillaceae) (Fig. 3.8D)

Thallus continuous, smooth, pale green, to 2 mm in diameter; apothecia 0.025-0.05 mm in diameter, slightly pruinose, ascospores muriform, one per ascus, 38-45 x 12-18 µm. This specimen seems to represent a new species, but the material is scanty for proper description.

Specimen examined: Godere Forest, 1230 m, $07^0$16'04 N, $035^0$12'11 E, on living leaves of *Dracaena fragrans*, Kumelachew 308, (KOBL).

4. *Opegrapha* sp. (Rocellaceae) (Fig. 3.8E)

Ascomata lichenicolous on *Strigula phyllogena*, asci 8-spored, ascospores 3-septate, 10-13 x 2.5-3.5 µm. The size and shape of the asci and size of ascospores and septation of this collection are similar with those of *Opegrapha phylloporinae.* However, the host of our collection is *Strigula phyllogena* where as O. *phylloporinae* grows on *Porina conica, P. epiphylla, P. similis, P. virescens* (Matzer 1996).

Specimen examined: Godere Forest, Dushi Peasant Association, 1230 m, $07^0$16'04 N, $035^0$12'11 E, on living leaves of *Argomuellera macropylla,* 2005, Kumelachew 304 (KOBL).

5. ***Porina* cf. *triseptata* (Porinaceae) (Fig. 3.8F)**

Porina triseptata was described by Vězda (1994) as *Trichothelium triseptatum* but it was later transferred to the genus *Porina* by Lücking (1998). The present collections match perfectly with the description of the species except that ascospores are shorter (15-25 µm) and lobules, instead of stiff setae, are present on the perithecia.

Specimen examined: Godere Forest, Dushi Peasant Association, 1232 m, $07^0$16'53 N and $035^0$12'11 E, on leaves of *Argomuellera macrophylla,* Kumelachew 1/275 (KOBL).

6. ***Sporopodium* sp. (Pilocarpaceae) (Fig. 3.8G)**

Two collections had campylidia producing pearl-shaped conidia and thallus is sorediate. Soredia have so far not been observed in the species of *Sporopodium*. Therefore, these collections could represent new taxon of *Sporopodium*, but proper description was not possible as the specimens were with out apothecia.

Specimen examined: Godere Forest, Dushi Peasant Association, 1232 m, $07^0$16'53 N and $035^0$12'11 E, on leaves of *Argomuellera macrophylla,* Kumelachew 3/275; 1250 m, $07^0$16'19 N and $035^0$12'21 E, on living leaves of *Argomuellera macrophylla,* Kumelachew 290 (KOBL).

7. ***Trichothelium pauciseptatum* (Porinaceae) (Fig. 3.8H)**

Trichothelium pauciseptatum was described by Vězda (1994) from a collection of S. Lisowski from the Orientale province (former Haut Zaire) in the DR Congo. The present collection matches well with the description of the species except for the color of the tip of the setae. In the description of *T. pauciseptatum*, setae are black in color. In our collection, the setae are black with pale tip. In addition, the ascospores of Kumelachew 307 were longer (27 x 3 µm), those of Kumelachew 325 were narrower (17.5 x 2.5 µm) and of Kumelachew 293 narrower and shorter (15-17.5 x 2.5 µm) than the holotype (16-20 x 3-3.5 µm).

Specimen examined: Godere Forest, Dushi Peasant Association, 1270 m, $07^0$16'56 N, $035^0$12'14 E, on living leaves of *Argomuellera macropylla,* 2005, Kumelachew 284; 1250 m, $07^0$16'19 N, $035^0$12'21 E, on living leaves of *Tiliachora funifera,* 2005, Kumelachew 293; 1230 m, $07^0$16'04 N, $035^0$12'11 E, Kumelachew 307; (KOBL).

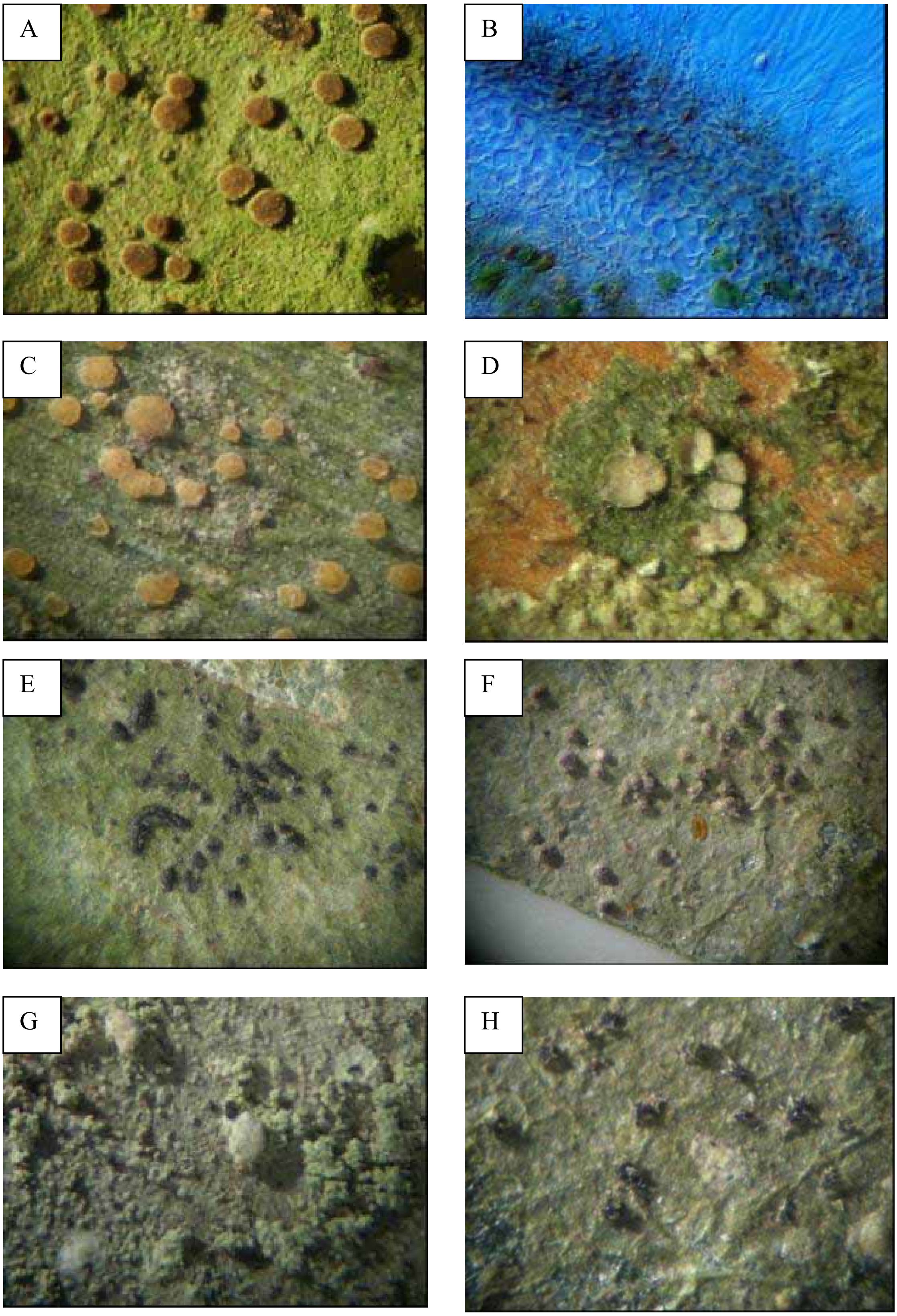

Fig. 3.8 A) *Fellhanera* cf. *aurantiaca*, B) Excipulum of *Fellhanera* cf. *aurantiaca*, C) *Fellhanera* aff. *bouteillei*, D) *Calenia* sp., E) *Opegrapha* sp. growing on *Strigula phyllogena*, F) *Porina* cf. *triseptata*, G) Sorediate specimen of *Sporopodium* sp.
H) *Trichothelium pauciseptatum*

3.3.2 Alpha-diversity

3.3.2.1 Mean species number

There were more species per sample in Dushi than in Bishan waka. In Dushi a mean of 11 species were recorded per sample and in Bishan Waka a mean of 8.04 species were recorded (Fig. 3.9). This difference is statistically significant (t-value 1.98, $p<0.05$).

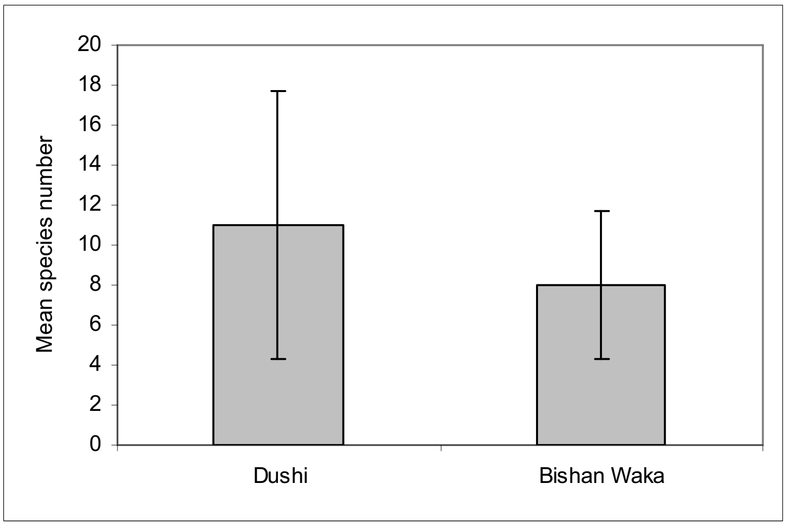

Fig. 3.9 Mean number of species per sample per study site of Godere Forest (values are mean ± SD)

3.3.2.2 Species accumulation curve

Species accumulation (rarefaction) curves were plotted for the foliicolous lichen species recorded from Dushi and Bishan Waka forest parts of Godere (Fig. 3.10). The graphs were plotted for the mean number of species against the number of samples pooled (Fig. 3.10a) and the mean number of species against the number of individuals pooled (Fig. 3.10b). The first graph compares species density and the second graph compares species richness.

Although the rate of species accumulation decreased as increasing number of samples were successively added to the total, neither of the curves reached an asymptote. The number of species for Dushi was higher than for Bishan Waka at all levels of sample accumulation. For 24 samples (sample size of Bishan Waka) pooled, 38 species were observed in Bishan Waka and 59.7 species in Dushi. To see if there is significant difference in species richness, Magurran (2004) recommended to check if the observed richness of the smaller community lies within the 95% confidence limits of the rarefaction curve of the larger community. Accordingly, the observed species accumulation curve of Bishan Waka is out side the 95% confidence intervals of the species accumulation curves of Dushi (Fig. 3.10b) indicating significantly higher species richness in Dushi than in Bishan Waka.

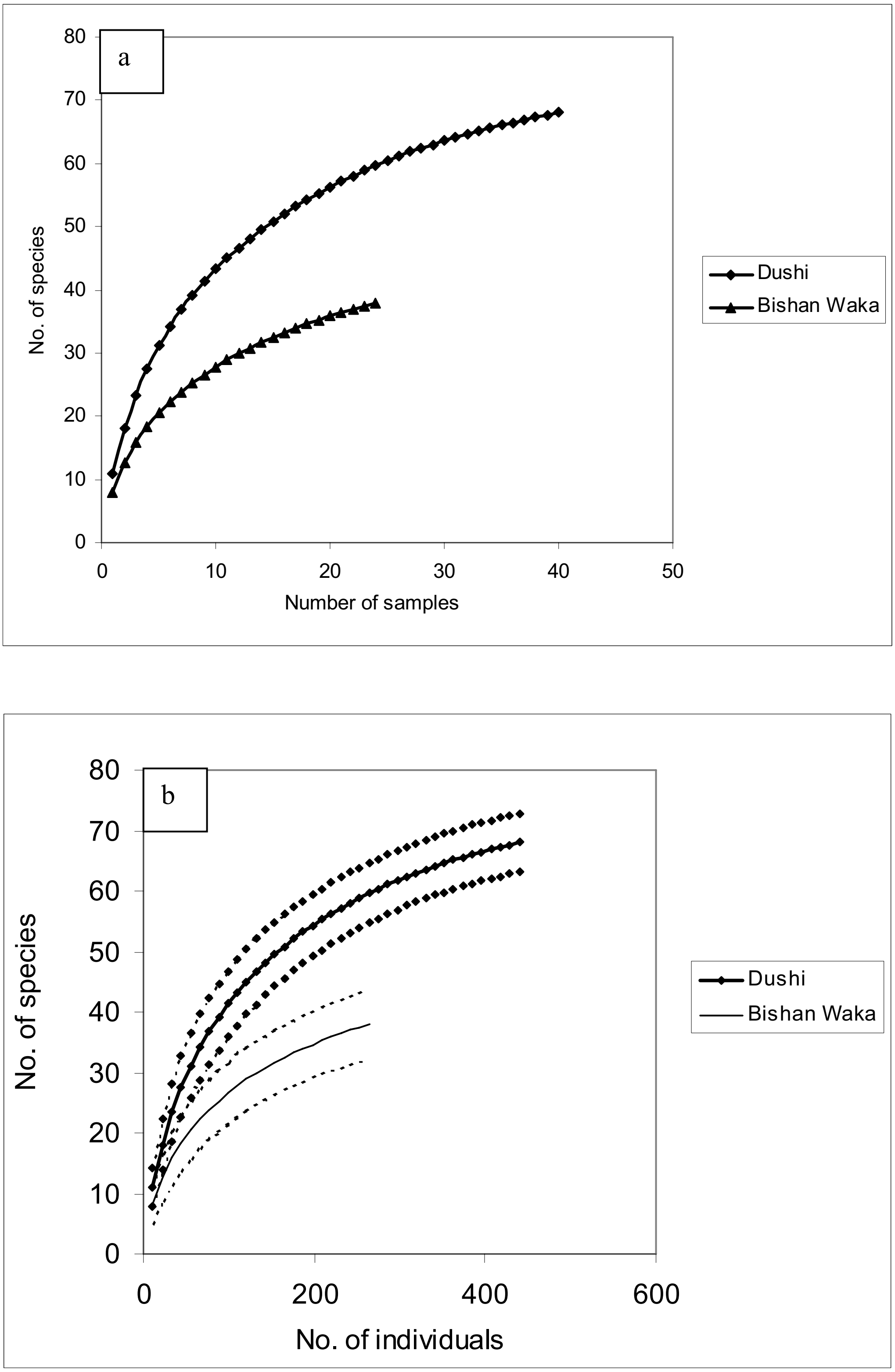

Fig. 3.10 Species accumulation (rarefaction) curves (solid lines) and 95% confidence intervals (dotted lines) for Dushi and Bishan Waka. a) Species density b) Species richness.

3.3.2.3 Estimation of species richness

The Chao 2, first and second order Jackknife, Incidence Based Coverage Estimator, Bootstrap and the Michaelis-Menten Mean species richness estimators estimated more species than the observed species (S_{obs}) for the study sites of Dushi and Bishan Waka. Table 3.1 presents the observed species number, the mean (and standard deviation for some) of estimated species. For the study site of Dushi, S_{obs} was 68 among 40 pooled samples, and for Bishan Waka 38 species were observed among 24 pooled samples.

For the data set of Dushi and Bishan Waka study sites, the second order Jackknife estimated the highest species richness of 82 for Dushi, and 55.2 for Bishan Waka. On the other hand, MMMeans estimated the lowest species number of 38.6 for Bishan Waka. Chao 2 estimated the lowest species number of 73.9 for Dushi. The difference between the highest and the lowest species estimates is 8.1 species for Dushi, and 11.9 species for Bishan Waka. In all cases, Jack 2 estimator gave the highest estimates. In Dushi 83-92% and in Bishan Waka 69-88% of the species richness estimated by the various estimators were collected in this study.

Table 3.1. Number of samples, number of individuals and species richness estimates values for the study sites of Dushi and Bishan Waka

	Dushi	Bishan Waka
No. of samples	40	24
No. of individuals	440	193
S_{obs}	68	38
MMMeans	76.6	38.6
Chao 2	73.9±4.3	50±9.2
Jackknife 1	81.7±4.5	49.5±4.2
Jackknife 2	82	55.2
ICE	78.2±0.01	50.8±0.03
Bootstrap	75.4	43.3
Collection degree	83-92 %	68.8-87.8 %

3.3.2.4 Shannon-Wiener diversity

The result of the α-diversity analysis of foliicolous lichens based on Shannon-Wiener index is presented in Table 3.2. Calculation of t-test showed a very high significant difference (t-value =3.56, $p<0.001$) in the Shannon index of Dushi and Bishan Waka evidencing a higher α-diversity in Dushi than in Bishan Waka.

Table 3.2 Values of Shannon-Wiener and Simpson diversity indices

	Dushi	Bishan Waka
Shannon index (H’)	3.72	3.17
Shannon evenness index (J’)	0.88	0.87

3.3.3 Beta-diversity and similarity in species composition

Total β-diversity, measured as total species number divided by mean number of species in samples, for Dushi and Bishan Waka is presented in Table 3.3. Total β-diversity is higher (6.2) for Dushi than for Bishan Waka (4.7). The similarity in species composition between Dushi and Bishan Waka computed from Sørensen index of similarity is not found to be high (S_s=0.58).

Table 3.3 β-diversity along the study sites of Dushi and Bishan Waka

	Number of species (a)	Mean number of species per sample (b)	β-diversity (a/b)
Dushi	68	11	6.2
Bishan Waka	38	8.04	4.7
Sørensen index of similarity (S_s) between Dushi and Bishan Waka			
Number of shared species	31		
S_s	0.58		

3.3.4 Ordination

The Detrended Correspondence Analysis (DCA) of the presence/absence data of Godere ordered the samples and species along the ordination axes. The first DCA axis with eigenvalue of 0.395 explained 11.9% of the variation and the second axis with eigenvalue of 0.192 explained 5.8% of the variation. Thus most of the variation in site condition and species composition can be explained by the gradient corresponding to the first DCA axis. Eigenvalues of the third and fourth axes are 0.158 and 0.116 respectively.

In the sample ordination plot (Fig. 3.11), samples from less disturbed sites are distributed along the left side of the first DCA axis, and samples from high disturbed sites are distributed along the right side. The variation in the distribution of samples along the first axis of DCA is thus explained by difference in disturbance level. Most of the samples from Bishan Waka are distributed along the gradient where disturbance is higher and the samples from Dushi are distributed along the gradient where disturbance is lower.

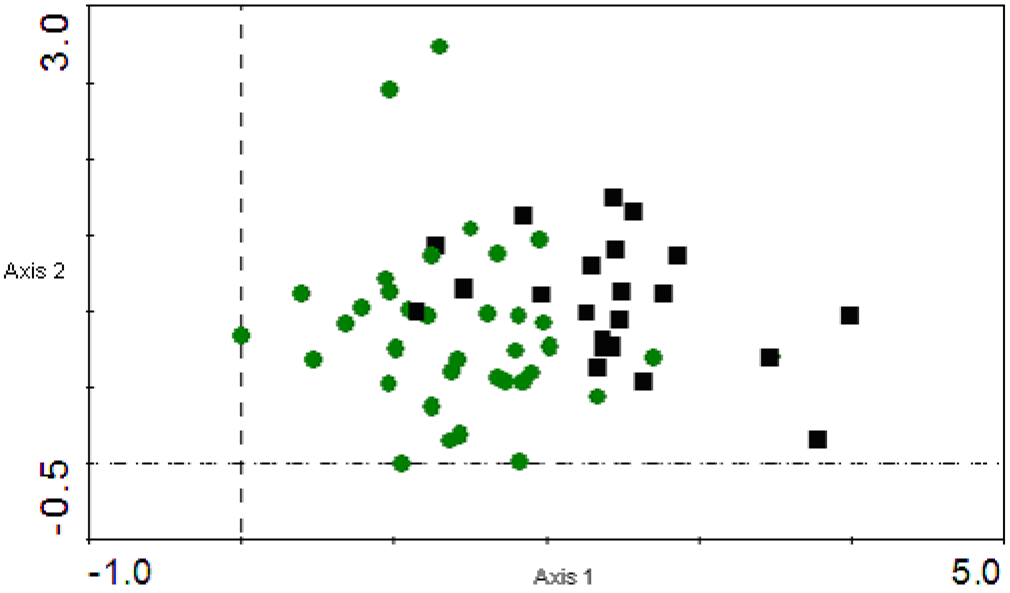

Fig. 3.11 DCA diagram of samples of Godere Forest. Circles = samples from Dushi, squares = samples from Bisahn Waka.

The species ordination diagram (Fig. 3.12) shows that species from highly disturbed samples are distributed on the right side of the first DCA axis and species from less disturbed samples are distributed on the left side of the first axis. The first group of species includes *Asterothyrium rotuliforme, A. octomerum, Gyalectidium filicinum, Calenia monospora, Calopadia puiggarii, Gyalectidium fuscum,* and *Fellhanera bouteillei.* Among the second group of species include *Porina leptosperma, P. rubescens, P. cupreola* var. *cupreola, Byssolecania hymenocarpa, Arthonia lividula,* and *Coenogonium dilucidum.*

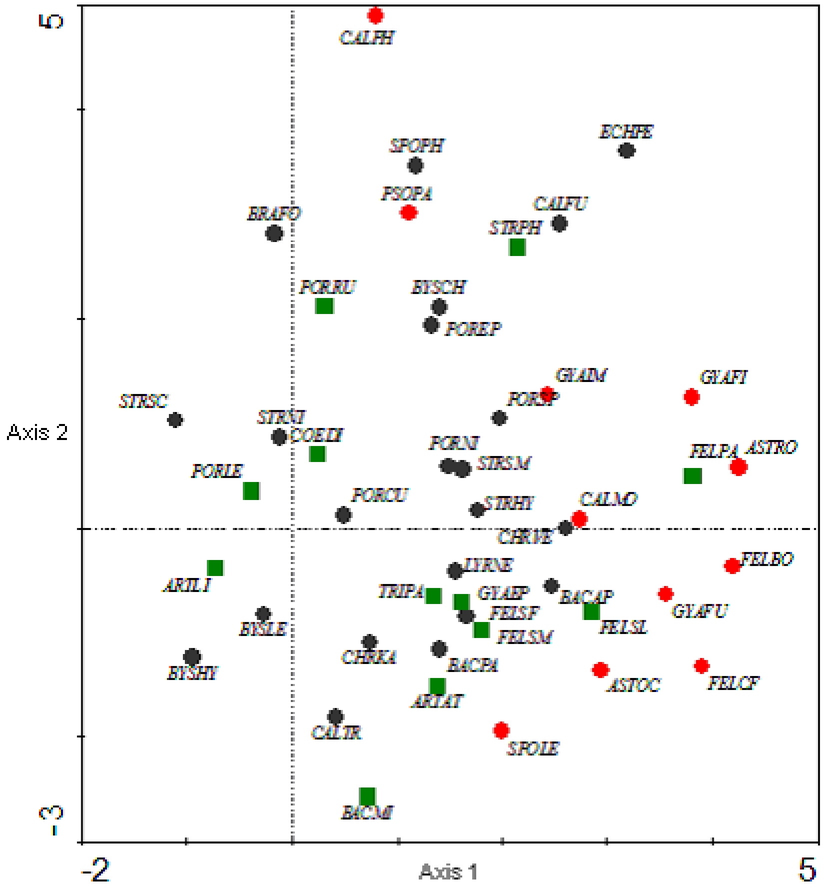

Fig. 3.12 DCA diagram of species of Godere Forest. Green squares = shady understorey species, red circle = light gap and canopy, black circle = species with wide amplitude. For clarity only some of the species are shown. For Acronyms see Appendix 1.

3.3.5 Phorophytes

Various phorophyte species were hosts of foliicolous lichens in Godere Forest including *Argomuellera macrophylla, Baphia abyssinica, Blighia unijugata, Coffea arabica, Dracaena fragrans, Hippocratea africana, Landolphia buchananii, Manilikara butugi, Olea capensis* ssp. *welwitschii* (=*O. welwitschii*), *Phoenix reclinata, Piper guineense, Rinorea friisii, Strychnos mitis, Tiliachoa troupinii,* and *Trilepisium madagascraiense*. Of these, *Argomuellera macrophylla* is the phorophyte that supported the highest species of foliicolous lichens (58 species). *Strychnos mitis supported* 28 species, *Dracaena fragrans* supported 25 species, *Diospyros abyssinica* supported 24 species, and *Trilepisium madagascariense* supported 22 species. *Coffea arabica*, the most abundant shrub in Dushi, supported only 10 species of foliicolous lichens.

3.4 Discussion

3.4.1 Foliicolous lichen flora

All the foliicolous lichens recorded in this study are the first record for Ethiopia. The checklist of lichens and lichenicolous fungi (Feuerer 2007), listed 279 species of lichens from Ethiopia. However, foliicolous lichens were not included in the checklist indicating that no foliicolous lichens were collected until this time. Ethiopia is a tropical country with varied climatic and topographic features resulting in diverse flora and vegetation types which could also support high lichen diversity. However, cryptogams in general and lichens in particular have been overlooked for so long that the lichen flora of the country is almost unknown. The book on macrolichens of East Africa (Swinscow and Krog 1988) incorporates some lichen species collected by Hildur Krog from the southern part of Ethiopia in 1971. This book is the first and the only available source of information for the lichens of Ethiopia.

Tropical rainforests are the suitable habitats for foliicolous lichens (Santesson 1952, Lücking 1995). In Ethiopia most of the natural forests are Afromontane type, distributed at altitudes above 1500 m. Forests of a lowland type are very restricted in parts of southwestern Ethiopia. Floristically, Godere Forest occupies a transitional position between a lowland Guineo-Congolean rainforest and afromontane rainforest of the higher altitude. However considering the topographic position and climatic features of the forest with high temperature and rainfall, it is the most suitable habitat for foliicolous lichens. However, due to shifting cultivation and the semi-forest coffee management system, no trace of undisturbed natural forest can be found in Godere. The foliicolous lichens recorded in this study came from a disturbed secondary forest and it is not known what the foliicolous lichen flora of an undisturbed primary forest would have looked like. A number of species (e.g *Coenogonium geralense, C. pocsii*) which would be expected in a primary or old growth forest were not recorded from the forest.

The tropical forests of Africa are the least explored in terms of their foliicolous lichens. This is reflected by the number of new species or species of interesting characters recorded from Godere. Considering the continuous anthropogenic disturbance affecting the forests, it is highly probable that several species of foliicolous lichens have locally been extinct.

Most of the samples in this study were from the study site of Dushi since it covers the most part of Godere Forest. The forest surrounding Bishan Waka Lake was selected for this study since it was not utilized for coffee development and large-scale logging did not take place. However, the forest is a fragment isolated from the large mass of forest in Godere and forms an island surrounded by human settlement and cultivation. In addition it covers a very small area around the lake and the distance between the forest edge and the interior is very small. Consequently, the available habitat for the growth of foliicolous lichens is considerably lower than in Dushi. Due to its isolation from the large main forest block, there are no enough sources of diaspore for the establishment of foliicolous lichens. These might be the reasons for the low foliicolous lichen diversity compared to the study site of Dushi.

In a natural forest, three major light regimes or microsites (the shady understorey, the natural light gap and the canopy) and two transition types (transition to light gap and transition to outer canopy) are distinguished (Lücking 1997). In Dushi, the shady understorey light regime is reduced due to removal of some canopy trees which the farmers assumed to have impact on the growth and quality of the coffee plant. In addition many possible phorophyte individuals were removed to enhance the growth of coffee beans. Therefore, the available microsite conditions and phorophyte individuals are fewer compared to undisturbed forest. However, the proportion of shady understorey species is higher in Dushi (52.4%) than in Bishan Waka (39.5%) and the proportion of light gap and canopy species are higher in Bishan Waka (50% light gap, 10.5% canopy) than in Dushi (42.6% light gap, 4.9% canopy).

3.4.2 Alpha-diversity

Ecologists often need to know the number of species (species richness) found in a given area or they need to compare the number of species in different areas (Colwell *et al* (2004). Complete enumeration of all species of a given area is often difficult for many groups of organisms including lichens. Various methods are now available for the estimation of species richness from available samples. These methods have mostly been applied for the estimation of the richness of animals (Toti *et al*. 2000, Longino et al. 2002, Schulz and Wagner, Sørenson 2004), plants (Butler & Chazdon 1998, Chazdon *et al.*1998, Chiarucci *et al*. 2003) and lichens (Nöske 2004). Using non-parametric species richness estimators the species richness of foliicolous lichens has been for the first time estimated in this study.

The sample sizes of Dushi and Bishan Waka are very different and comparison of species richness based on different sample size is misleading. Using the species accumulation curve (rarefaction curve), however, species richness can be compared at comparable sample size. The lowest sample size of the areas to be compared is usually selected as a basis for comparison. As it can be seem from the rarefaction curves and their 95% confidence intervals, there are significantly more foliicolous lichen species in Dushi than in Bishan Waka. The high diversity of foliicolous lichens in Dushi as compared to Bishan Waka is due to the availability of different microsite habitats in the former than in the latter.

The degree of foliicolous lichen collection or sample sufficiency can be evaluated based on the degree to which species accumulation curves approach a horizontal asymptote, the rate of accumulation of new species or using the predicted values of the species richness estimators. (Soberón and Llorente 1991, Gotelli and Colwell 2001). If the species accumulation curve reaches a stable asymptote, it is an indication of adequate sampling. As additional samples are pooled and the observed species richness curve stabilizes beyond a particular number of samples, then the observed species richness is considered as adequate estimate of community species richness for that number of samples (Longino *et al.* 2002). Although the species accumulation curves of Dushi and Bishan Waka did not reach an asymptote, the rates of accumulation of new species as more samples were pooled have decreased. From Dushi 83% of the species were collected based on the highest estimator and 92% of the species were collected based on the lowest estimator. From Bishan Waka 69% of the species were collected based on the highest estimator and 88% of the species were collected based on the lowest estimator. Heck *et al*. (1975) reported that collection of 50-75% of the total number of species of a given area might be satisfactory. Accordingly, the sampling efficiency for Dushi and Bishan Waka can be considered satisfactory.

The 95% confidence intervals of the species accumulation curves of Dushi and Bishan Waka (Fig. 3.18) did not overlap indicating the presence of significant difference in species richness. Colwell *et al*. (2004), comparing tropical rain forest sampling in old growth and second growth forests, concluded that when confidence intervals overlap, the differences in species richness is not significant and when confidence intervals do not overlap the differences in species richness is significant.

In Bishan Waka, the species richness estimators predicted that more species are yet to be sampled than from Dushi. This is due to the higher number (31.6 %) of uniques (species restricted to one sample only) in Bishan Waka. In Dushi uniques accounted for 20.6 % of the whole species. Species richness estimators use the frequency of rare species to predict the total sample species richness (Williams *et al*. 2007). The presence of many rare species means higher probability of encountering more new species with increased sampling effort.

Considering the results of the species accumulation curve and Shannon diversity index, it can be concluded that α-diversity is significantly higher in Dushi than in Bishan Waka.

3.4.3 β-diversity

The proportion of shared species of Dushi with the total foliicolous lichen flora of Godere is 91% and that of Bishan Waka 51%. Total β-diversity, calculated by dividing the total species number by a mean number of species in a sample, indicates the degree of turnover (species change). The higher total β-diversity of Dushi is an evidence for a higher species turnover than in Bishan Waka. The similarity in foliicolous lichens composition between Dushi and Bishan Waka, as measured by the Sørenson index, is medium (S_s=0.58) showing a medium species turnover.

3.5 Conclusion

The present study has shown that:

- both alpha and beta diversity are higher in Dushi than in Bishan Waka.
- low diversity in Bishan Waka is because of it is fragmented nature and isolation from the main forest by cultivations and settlement.
- the effect of human disturbance on foliicolous lichens diversity in Dushi is mainly due to the removal of phorpohytes from the shrub stratum.
- the variation in foliicolous lichens diversity between Dushi and Bishan Waka can be explained by the difference in the level of disturbance. This has been shown in the ordination diagram where samples distributed along the low disturbance gradient were from Dushi and samples from the high disturbance gradient were from Bishan Waka.
- the forest canopy is relatively closed in Dushi and thus there are more shady understorey species and low light gap species in Dushi than in Bishan Waka.
- semi-forest coffee management system maintains foliicolous lichen diversity than land uses such as cultivation and clear-cutting that may result in partial or complete removal of forest vegetation.

Chapter 4 DIVERSITY OF FOLIICOLOUS LICHENS IN BUDONGO FOREST, UGANDA

4.1 Study area

4.1.1. Location and physiography

Budongo Forest Reserve lies in western Uganda, in Masindi District, Bujenje, Buliisa and Buruli Counties (Muhereza 2003). It is situated on the top of the escarpment east of Lake Albert on the edge of the western rift valley (Howard *et al.* 1996; Sheil 1999, 2001, Sheil *et al.* 2000) between $1^0$37’ and $2^0$03’ N latitude and $31^0$22 and $31^0$46’E longitude (Sheil 1999, 2000, 2001; Reynolds 2005) (Fig. 4.1). The Budongo Forest Reserve is divided into two parts by the road connecting Masindi and Butiaba which is located on the shore of Lake Albert; the northeastern part is called the Budongo and the other is called the Siba (Sugiyama 1968). The reserve lies approximately 10 km west and north of Masindi and 10 km east of Lake Albert (Howard *et al.* 1996).

The gazetted area of Budongo Forest Reserve includes four forest blocks viz. Siba, Budongo, Kaniyo-Pabidi and Kitigo (Fig. 4.2). The reserve covers an area of almost 793 km^2, of which 428 km^2 is closed forest; the rest is savanna woodland or grassland (Howard *et al.* 1996; Sheil 1997, Sheil *et al.* 2000, Plumptre 2001).

The reserve lies at altitudes between 950 and 1200 m, with mean altitude of 1100 m (Plumptre 2001), on gently undulating terrain with a gentle NNW slope to the edge of the rift escarpment. There are few steep ridges and no deep gullies (Eggeling 1940). Several isolated hills of similar heights rise above the general level of the forest, the most prominent of which are Kasene (1171 m a.s.l.), Kaniyo (1187m a.s.l.), Lukoho (1160 m a.s.l.), Nyabyeya (1247 m a.s.l.), Little Kasenene (1173 m a.s.l.), and Busingiro (1201 m a.s.l.) (Howard 1991). The valley bottoms mostly contained ‘swamp forest’, but the ground there, though soft, is rarely swampy.

Budongo Forest is a catchment area for four small rivers which flow north-west through the forest, over the escarpment and into Lake Albert. (Eggeling 1947; Paterson 1991, Reynolds 2005). These rivers from east to west are the Waisoke, the Sonso, the Kamirambwa and the Siba (Reynolds 2005).

Fig. 4.1 Map of Uganda and the location of Budongo Forest (red square). Source: CIA World Factbook

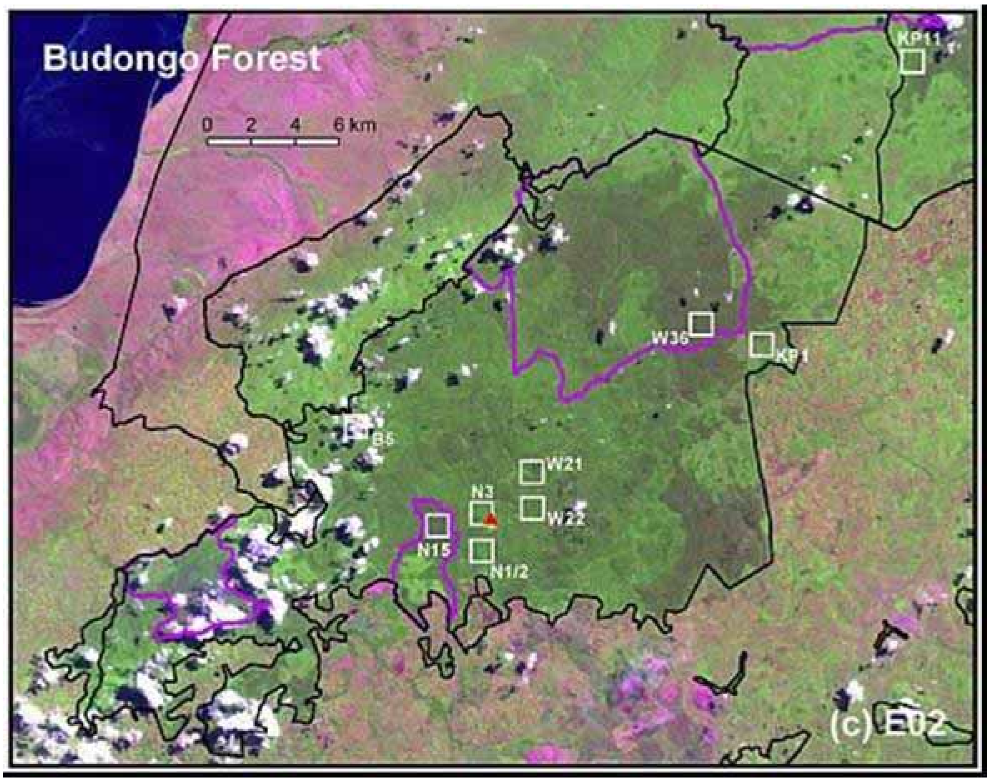

Fig. 4.2 Satellite imagery of Budongo Forest (Source: BIOTA E02).

4.1.2. Geology and Soil

Crystalline rocks of the Ancient Basement Complex of Pre-Camberian origin, intruded by granites, underlie Budongo Forest. The Basement Complex is an assemblage of schistose and gneissose rocks which are metamorphosed sandstones, shales, limestones, and eruptives. (Eggeling 1947). It is from these rocks that the soils are formed.

Advanced laterization in the Budongo area is likely to have coincided with peneplanation and the hills around and in the forest indicate the past level of the lateritic blanket which once covered the whole area. Following the Rift uplift, which resulted into the formation of the Western Rift Valley, it is probable that widespread erosion removed the greater part of the laterite and led to the formation of fresh soils from crystalline rocks, some of which were quickly colonized by forests (Philip 1996, Sheil 1996).

The soils of Budongo are predominantely tropical red earths (Eggeling 1947, Paterson 1991), of a type regarded as almost the final stage in tropical weathering. These soils are red in profile and vary from a heavy loam or sandy clay to a very sandy loam characteristic of the many of the valley bottoms (Eggeling 1947). These soils are termed as ‘ferralitic’ (Sheil 2001). A second much less common soil type called ‘murram’ is localized in the forest on low rounded ridges or gentle slopes and is always underlain by quartzose rocks. (Eggeling 1947). This soil has undergone laterization and varies from a red loam containing small concentrations of ironstone, capable of supporting forest, to tiny ridge-top pavements of solid cellular ironstone (Eggeling 1947).

4.1.3. Climate

Unlike many forest areas in Africa, there is a long-term climatic data for Budongo Forest. In 1937 five meteorological stations were established in Budongo Forest. Of these, four stations were established inside the forest and one outside the forest (Eggeling, 1947). The data are summerized by Eggeling (1947), Paterson (1991) and Sheil (1997).The Budongo Forest Project has been collecting rainfall and temperature data since 1993 (Reynolds 2005).

Rainfall in Budongo is bimodal with two peaks from March to May and from September to November with monthly rainfall more than 150 mm (see Fig.4.3). There is only one dry season from mid December to mid February with monthly rainfall not more than 50 mm. Annual rainfall is between 1200-1800 mm (Sheil 1995, 1997, 1998; Reynolds 2005). The annual minimum mean temperatures in Budongo Forest range from 17 to 20^0C and maximum mean temperatures range from 28 to 29^0C (Howard 1991).

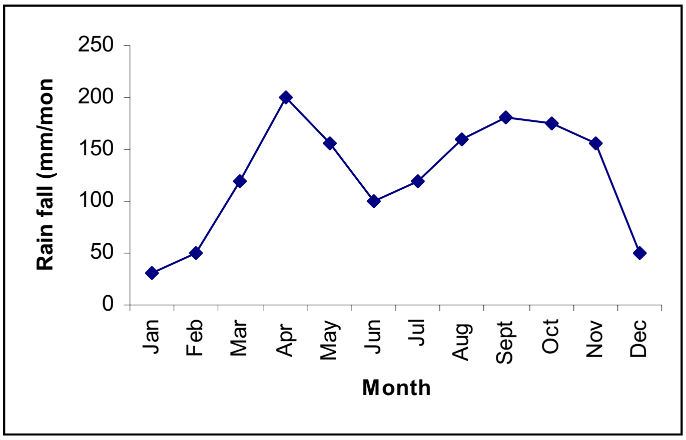

Fig.4.3 Mean monthly rainfall (mm) records from 1944 to 1989 in Nyabyeya meteorological station. Source: Sheil (1997)

4.1.4. Biotic attributes

4.1.4. 1 Vegetation and flora

Budongo Forest is among the easternmost outlier blocks of the Congo basin forest (Paterson 1991). Based on its structure and constituents, Eggeling (1947) described Budongo as lowland rain forest. Langdale-Brown *et al.* (1964) classified Budongo as a medium altitude moist semi-deciduous forest. Hamilton (1974) classified the lowland forests of Uganda into four zones, viz. the *Parinari*, the *Celtis-Chrysophyllum*, the *Cynometra-Celtis*, and the *Piptadeniastrum* zones. The *Celtis-Chrysophyllum* and the *Cynometra-Celtis* zones are represented in Budongo Forest. Philip (1965) and Howard (1991) classified Budongo as moist semi-deciduous tropical forest. According to Paterson (1991), the vegetation of Budongo Reserve consists of a rich mixture of rainforest communities and a broad intermixture or ecotone with the surrounding tree savannas and grasslands.

Eggeling (1947), Synnott (1985), Paterson (1991), and Sheil *et al.* (2000) described the flora of Budongo Forest. Of these, Synnott (1985) provided the full plant species composition including 240 species of trees, 123 species of shrubs, 19 species of scrambling shrubs, 66 species of woody climbers and lianas, 61 species of herbaceous climbers, 246 species of terrestrial herbs, 109 species of vascular epiphytes, 1 parasitic species and 1 saprophytic species. Howard *et al.* (1997) reported 465 species of trees and shrubs for Budongo Forest. Budongo Forest has the largest number of tree species recorded in the Ugandan forest (Howard 1991, Sheil 1996) and it is the richest mahogany forest in Uganda (Lind and Morrison 1974, Howard *et al.* 1997). *Artabotrys lastoursvillensis, Discoglypremna caloneura*, *Iodes africana*, *Mammea africana*, *Microdesmis puberula*, *Ritchiea aprevaliana* and *Telfairia occidentalis* are species limited to Budongo Forest in Uganda (Synnott 1985).

Based on the observations of earlier workers (Haris 1934, Brasnett 1946), Eggeling (1947) described the natural forest types of Budongo Forest and proposed succession from colonizing forest through mixed forest to climax forest. This successional model was later conformed by Sheil (1999) with objective measures of development.

According to Eggeling (1947), the Budongo Forest contains four forest types viz. colonizing forest, mixed forest, *Cynometra* forest, and swamp forest.

1. Colonizing forests are of two types: the *Maesopsis* and woodland forest. The *Maesopsis* colonizing forest is found in slightly better soil than the woodland forest. It is composed of a matrix of colonising species such as *Maesopsis eminii, Cordia millenii* and *Diospyros abyssinica*. *Maesopsis eminii* forms 50-80 percent of the canopy. The woodland forest is found on poorer or shallow soils, and is composed of *Olea welwitschii, Phyllanthus discoideus* and *Sapium ellipticum* in the upper story with a general domination of the understorey by *Calconcoba* and old remnant *Terminaila* derived from the tree savanna (Eggeling 1947; Paterson 1991).

2. Mixed forest is the richest of the forest type in number of tree species, covers much of the forest and contains the valuable mahoganies (Eggeling 1947, Paterson 1991, Plumptre 1994). The most common species are *Celtis mildbraedii, C. zenkeri, Chrysophyllum albidum*, *C. perpulchrum*, *Funtumia elastica* and the mahoganies *Khaya anthotheca*, *Entandrophragma cylindericum*, *E. angolense*, and *E. utile*.

3. *Cynometra* (Ironwood) forest is the climatic climax forest of Budongo (Eggeling 1947). It is characterized by the abundance of *Cynometra alexanderi*, which accounts for up to 35 percent of all trees and as much as 90 percent of all large trees. Other typical tree components include *Strychnos mitis, Celtis wightii*, and *C. mildbradeii*. The understorey is characterized by *Lasiodiscus mildbraedii.*

4. Swamp forest is found in valley bottoms in which the soil is flooded by permanent and seasonal slow running streams. The dominant tree is *Mitragyna stipulosa*. Others include *Pseudspondias microcarpa*, *Parkia filicoidea*, *Erythrina excelsa*, *Bombax bunopozense* subsp. *reflexum*, *Macaranga schweinfurthii* and *Bridelia micrantha*.

According to Eggeling (1947) the first three forest types follow an ecological succession from the colonizing forest to mixed forest and finally to *Cynometra* forest with colonising-mixed and *Cynometra*-mixed transitions. The *Cynometra* forest is an ecological climax and the swamp forest is an edaphic climax.

4.1.4.2 Fauna

Budongo Forest is known for its diversity of fauna with 24 species of small mammals including nine primates, 289 species of butterflies and 130 species of large moths (Howard *et al*. 1997). There are 366 species of birds out of which 197 species are forest dwellers (Friedmann & Williams 1973, Owiunji & Plumptre 1998).

Some of the mammals in the forest are tree hyrax (*Dendrohyrax buck*), red duikers (*Cephalophus rufilatus*), blue duikers (*C. monticoloa*), bush buck (*Tragelaphus scriptus*), bush pig (*Potamochoerus porcus*), porchpines (*Hystrix cristata*) and guines fowls (*Guttera edouardi*). Four species of monkeys live in Budongo Forest (Reynolds 2005) viz. baboon (*Papio anubis*), black and white colobus monkey (*Colobus guereza),* redtail monkey (*Cercopithecus ascanius*), and blue monkey (*C. mitis*). Potto (*Periodicticus potto*) is the commonest species of prosimian in Budongo Forest. Budongo is also home to one of the largest populations of chimpanzees (*Pantroglodytes schweinfurthii*) in Uganda with a population of about 700 (Tweheyo *et al.* 2004).

4.1.5. Management History

The management history of the Budongo Forest Reserve is well documented (Eggeling 1947, Paterson 1991, Plumptre, 1994, 1996; Reynolds 2005). The value of Budongo Forest had been recognized as early as 1905 when a permit was granted to a European firm for the tapping of wild rubber (*Funtumia*) (Eggeling 1946). In 1932 the British colonial administration gazetted the Budongo Forest an Undemarcated Forest reserved to the Crown (Eggeling 1947).

4.1.5.1 Forest administration

Since 1920 Budongo Forest was administered by the Forest Department of the colonial administration. After independence, it was administered by the Forest Department of the central government. Since 1993 forest management in Uganda has been decentralized to district and sub-county councils and Budongo Forest was administered by the Masindy District Council as Central Forest Reserve. Since 1998 the administration of central forest reserves was transferred to the central government and the management of Budongo Forest rested under the Forest Department which was later replaced by a semi-autonomous National Forestry Authority (Muhereza 2003).

4.1.5.2 Management plan

Management plans were prepared for Budongo Forest for the periods 1935-1945, 1945-1955, 1955-1965, and 1997-2007. The plans indicate the principles of management of the forest including ways of demarcation, licensing for timber cutting and silvicultural methods. For the sake of management, Budong forest was divided into 68 compartments in the Siba, Bullaba, Biiso, Nyakafunjo, Waibira, and Kaniyo-Pabidi forest blocks.

The current management plan (Kamugisha and Nsita 1997) which covers the period from July 1997 to June 2007 provides emphasis for biological conservation. The plan separates the forest into zones for conservation, commercial use, community use, recreation and research. The majority of Budongo Forest is earmarked as a production zone for the utilization of timber. The plan establishes 'Conservation Working Circle' which includes Strict Nature Reserve (SNR) and Buffer Zones. The SNR is maintained for biodiversity conservation and water catchment and tree felling is strictly prohibited. New compartments, mostly in the Waibira block, are included in the SNR raising the number of compartments to 17. The buffer zone which includes 14 compartments is established around the nature reserve to separate the SNR from the production zone. The total area allocated for the nature reserve is 11,722 ha and 5,293 ha for the buffer zones.

4.1.6. Human Impact

4.1.6.1 Fire

In the 19th century, anthropogenic fire used to control the spread of Budongo Forest into the surrounding savanna (Paterson 1991). Annually the local people who live around Budongo Forest set fire to clear away dry growth from the previous year and produce fresh grass for their cattle. The fire which started this way also cleared away the savanna and expanded to the edges of the forest. These fires kept the forest blocks of Budongo and Siba from spreading into the surrounding savanna land. This process continued until the arrival of Europeans who controlled fires and managed the forest for timber (Paterson 1991).

4.1.6.2 Logging

Logging in Budongo Forest started in a regular basis in 1917 (Paterson 1991). By then only small amounts of timber were cut on the southern side of the Budongo Forest block using pitsaws (Eggeling, 1947). Timber cutting became mechanized when the first sawmill was established towards the end of 1926 (Eggeling 1946). From this time onwards, there has been considerable exploitation by concession holders operating in two concessions, one in the Siba and another in the Budongo Forest block.

Of the 68 forest compartments, logging took place on the 60 compartments. One compartment in Nyakafunjo block (N15), 4 compartments in the Waibira block (W17, W30, W31, W32), and 3 compartments in the Kaniyo-Pabidi block (K11, K12, K13) were left unlogged. The compartments N15, W17, W30, W31, and W32 are protected as nature reserve (Plumptre 1996, Owiunji & Plumptre 1998).

The main timbers exploited were *Khaya anthotheca*, *Entandrophragma cylindericum, E. angolense*, *E. utile, Cynometra alexanderi, Erythrophleum guineense, Mildbraediodendron* *excelsum.*, *Maesopsis eminii, Alstonia congensis, Ricinodendron africanum*, *Chlorophora excelsa*, and *Morus lactea*. Table 4.1 shows the volume of mahoganies and other timbers extracted from the various forest blocks of Budongo between 1928 and 1992. In the Biiso, Nyakafunjo, Waibira and Kaniyo forest blocks, more than 60 percent of the timbers extracted were mahoganies. In the Siba block 42 percent of the timbers extracted were mahoganies. In general, 872,627 m^3 of timber were extracted in the 60 years period (Plumptre 1996).

Paterson (1991) and Plumptre (1996) summarized the logging activities in Budongo Forest between 1930 and 1970. At the beginning, logging operations was aimed at extracting all the old timber trees above 1.3 m diameter at breast height (DBH) and creating a two-stage uniform crop of trees which would be felled at 40-year intervals (polycyclic felling). In the 1950s research showed that damage to the forest due to the logging operations and the slow growth rates of the trees meant that polycyclic felling would lead to lower yields than felling on longer cycles. Therefore the logging plans were changed to monocyclic felling at 80-year intervals and felling limits of timber trees were reduced to 85 cm DBH. Replanting of mahoganies was carried out in logged areas during the 1940s and early 1950s. However, research showed that natural regeneration was successful and replanting ceased by the mid 1950s.

Table 4.1 Volume of timber extracted in the Budongo Forest blocks between 1928 and 1992. (Source: Plumptre 1996).

Forest block	Area (ha)	Year logged	Volume of timber extracted (m^{3}ha^{-1})	Volume of mahogany extracted (m^{3}ha^{-1})
Biiso	4350	1935-1944, 1981-1992	219.7	152.9
Nyakafunjo	8134	1945-1954, 1956-1962	535.7	371.7
Waibira	21358	1960-1976, 1978-1980	448.9	282.7
Kaniyo	4818	1970-1972, 1977, 1985-1992	103.7	65.6
Siba	5288	1928-1935, 1963-1977, 1979, 1990	118.1	49.8

In addition to mechanized harvesting of timber, harvesting by pitsawing used to take place in some compartments in the 1980s (Plumptre 1996). After realizing that mechanized logging was harmful to natural regeneration, the Uganda Forest Department in the 1990s started providing license to organized pitsawyers to carry out selective extraction of mahoganies and other timber trees (Muhereza 2003). Between 1991 and 1996 the annual off-take of timber by pitsawyers and saw millers averaged 11,522.82 m^3 of round wood (Muhereza 2003). At present mechanized logging is not taking place as all the sawmills are not opereting. However, illegal pitsawing has been taking place in various parts of the forest including the SNR (Muhereza 2003; Reynolds 2005).

4.1.6.3 Silviculture

In the 1950s and 1960s, silvicultural measures were taken in order to promote the growth and regeneration of the most valuable timber species, such as *Khaya* and *Entandrophragna* spp (Plumptre 1996). It was found that opening up the canopy during the logging operation aided the growth of the mahoganies. Consequently, arboricide, made from 1:2 mixture of butyl esters 2,4,5-T and 2,4-D dissolved in diesel oil, was applied to trees that were not marketable, particularly *Cynometra*. A total of 34 blocks were treated with arboricide. In 1970 the treatment ceased when more trees became marketable and it became difficult to import the chemicals.

4.1.6.4 Wild animal control

Budongo Forest used to harbour a good population of elephants, buffalo, wild pigs and leopards. Control shooting and legal and illegal hunting have diminished the population of these animals to an alarming level. Rinderpest epidemic in 1889 in the Bunyoro area eliminated most of the cattle. (Paterson 1991). Epidemic of trypanosomiasis at the beginning of the 20th century initiated the colonial administration killing of most of the large wild mammals including buffaloes, wild pigs, bushbuck and Uganda kob (Harris 1934). The decline of these animals resulted in substantial increase of the elephant population in the areas of Budongo Forest to the extent that they converted most of the woody vegetation to treeless grasslands (Paterson 1991). Elephant control measures started in 1928 (Paterson 1991) under the Uganda Game Department in order to protect the young individuals of valuable timber species.

4.1.6.5 Population pressure

The population of Masindi District is growing at a high rate. It increased from 260,796 in 1991 to 466,204 in 2002 (Muhereza 2003). The populations of Budongo and Bwijanga sub-counties near Budongo Forest increased from 44,054 to 76,929 during the same period (Muhereza 2003). This population increase is leading to encroachment to the forest, increased fuelwood collection and, charcoal production and illegal pitsawing.

4.1.7 Effects of previous management measures

4.1.7.1 Effects on vegetation

The management history of Budongo Forest has resulted changes in the distribution of forest types and structure. Areas of colonizing-mixed forest in the Biiso area developed into mixed forest and areas of mixed forest in compartment N15 developed into

Cynometra-mixed forest. The ironwood forest which covered 32 % of the main Budongo Forest block in 1944 (Eggeling 1947) reduced to 15 to 20 % by 1970 (Paterson 1991). Comparison of the forest type maps of 1951 and 1990 (Plumptre 1996) shows that there was a marked increase in the spread of the mixed forest at the expense of *Cynometra* forest. The mixed forest increased by 41% while the C*ynometra* forest decreased by 24% (Plumptre 2001).

Logging and silvicultural treatment have also resulted change in the structure of the forest. Basal area, bole and crown heights, and crown position decreased in the logged than the unlogged compartments, while lianas were more abundant in the logged than unlogged compartments (Plumptre 1996). Logging and arboricide treatment, however, did not result changes in the tree species composition of the forest. Plumptre (1996) showed that geographical position of the forest compartment with in the forest influenced the forest composition before and after logging and arboricide treatment.

4.1.7.2 Effects on fauna

Plumptre (2001) studied the densities of primates, rodents, birds, and frogs in unlogged and selectively logged compartments in Budongo Forest. The result showed that the densities of blue monkey, redtail monkey and black and white colobus monkey increased in the logged compartments while the densities of olive baboon and chimpanzee showed no difference. The density of rodents was significantly higher in the unlogged than the logged compartment. The result on birds showed that most species did not show significant differences between logged and unlogged forest. Frugivore, bark-gleaning insectivore, nectarivore and omnivore birds constituted higher percentage in the logged than unlogged forest compartments. Leaf-gleaning and Sallying insectivore birds constituted higher percentage in the unlogged than the logged compartments. Diversity of frogs was higher in the logged than the unlogged compartments. Study of canopy ants and beetles in logged and unlogged compartments in Budongo Forest (Wagner 2000, Schultz and Wagner 2002) showed that canopy ant and beetle species are more diverse in the unlogged than logged compartments while abundance of phytophagus beetles is higher in the logged than unlogged compartments.

4.2 Study sites

In Budongo Forest, foliicolous lichen sampling took place in *Cynometra alexanderi* primary forest (hereafter called primary forest), primary swamp forest (hereafter called swamp forest), old secondary forest and young secondary forest (Fig. 4.4).

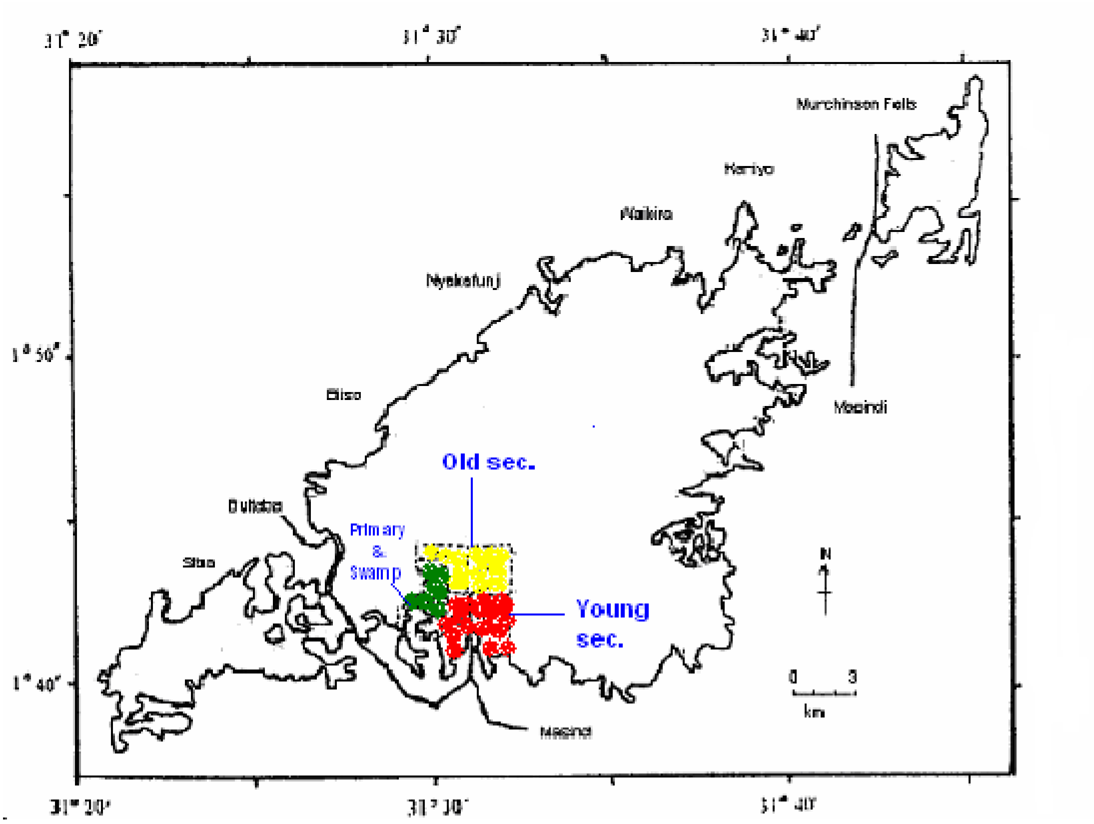

Fig. 4.4 Map of Godere forest and the location of the study sites

In the primary forest, the upper 30-40 m canopy is dominated by *Cynometra alexanderii, Khaya anthotheca* and *Entandrophragma utile*. *C. alexanderi* accounts for 35% of all trees and as much as 90% of all large trees (Paterson 1991). *Lasiodiscus mildbraedii* is a common understorey tree. Due to the closed canopy, no light reaches the forest interior. As a result, the shrub layer and the ground floor are sparse. The primary forest has never been logged and it is protected as nature reserve. From this site, 41 phorophyte individuals were sampled.

The swamp forest is a type of primary forest which is flooded in the wet season and waterlogged during the dry season (Eggeling 1947, Paterson 1991). It is the smallest asscociation in Budongo (Paterson 1991). It is two storied, with irregular canopy. Lianas and straggling figs are abundant. Logging did not take place in this forest type. From this site, 64 phorophyte individuals were sampled.

The old secondary forest has four tree layers, with abundance of large trees 25 to 55 meters high (Paterson 1991). The canopy is formed by evergreen trees and *Cynometra alexanderi* which is leafless for short time. Other common trees are *Chrysophyllum albidum, Khaya anthotheca* and *Trichilia.emetica*. In this site, trees were logged between 1947 and 1952. Twenty-two phorophytes individuals were sampled from this site.

The young secondary forest is two-storied, lacks tall and big trees and lianas are absent (Eggeling 1947). The forest is dominated by an even-aged growth of *Maesopsis eminii* which forms 50-80% of the canopy (Paterson 1991). *Calconcoba schweinfurthii* is the dominant species in the understorey. This site was mechanically logged between 1945 and 1947 and by pitsawing between 1990 and 2000 (Babweteera *et al.* 2000). Sixty-seven phorophyte individuals were sampled from this site.

4.3. Results

4.3.1 Floristic composition

A total of 129 taxa of foliicolous lichens and lichenicolous fungi belonging to 32 genera and 16 families were recorded from Budongo Forest (Fig. 4.5). Of these 125 were identified to the species level, one species was further identified to variety level (*Strigula nemathora* var. *nemathora* & *S. nemathora* var. *hypothelia*). Four were identified to the genus level only (*Calenia* sp., *Coenogonium* sp., *Opegrapha* sp. and *Biatora* sp.). Two species belonging to the genera C*hroodiscus* and *Tricharia* were found to be new to science. For the sake of simplicity, for the analysis of various parameters, all subspecific taxa and taxa identified to a genus level were treated as species. The foliicolous lichen and lichenicolous fungi species recorded from Budongo Forest is presented in Appendix 2.

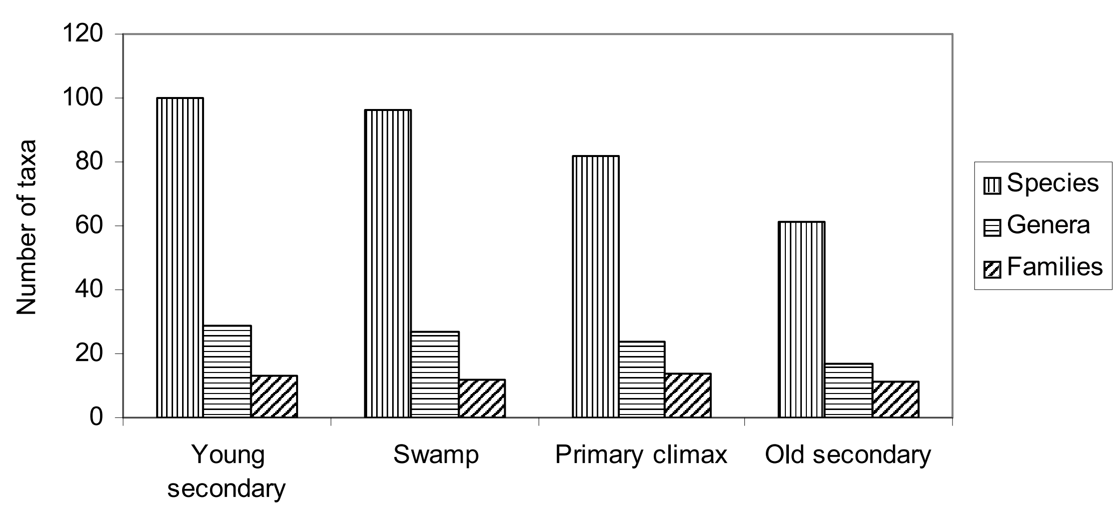

Fig. 4.5 Number of families, genera & species in the four forest types of Budongo

About 95 % of the species in Budongo Forest were typically foliicolous, 3 % were lichenicolous fungi growing on foliicolous lichens and 1.5 % was facultative foliicolous species and 0.8 % was ubiquitous species (Fig. 4.6).

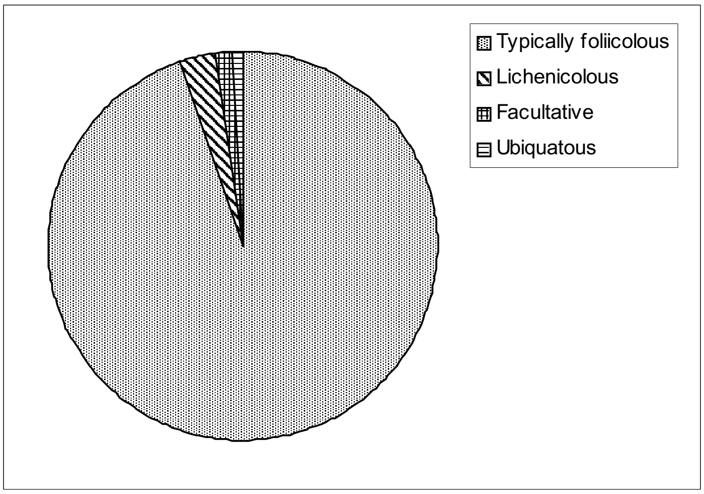

Fig. 4.6 Proportion of typical, facultative, ubiquitous foliicolous lichens and lichenicolous fungi

In the young secondary forest type, 100 species, 29 genera and 14 families were recorded making this forest type the richest in terms of generic and species diversity. With 96 species, 27 genera and 12 families, the swamp forest type is the second diverse. In the primary climax 82 species, 24 genera and 14 families were recorded. The old secondary forest is comparatively the poorest both in the number of families (12), genus (17) and species (61).

The family Pilocarpaceae is the most dominant in the number of genera (10 genera) and species (28 species). In the number of species, the family Porinaceae is the second dominant with 26 species. The family Gomphillaceae possessed 16 species and 5 genera. The families Coenogoniaceae and Strigulaceae both possessed 14 species and 1 genus each. Nine species and 2 genera were recorded in the family Roccellaceae. Seven species and 3 genera were recorded in the family Asterothyriaceae. In the family Thelotremataceae one genus and three species were recorded. The families Arthoniaceae and Aspidotheliaceae each possessed two species and one genus. The families Coccocarpiaceae, Microthyriaceae, Bacidiaceae and Lyrommataceae each possessed one species.

Fig. 4.7 presents the number of genera and species in each family in the four forest types of Budongo. In the primary climax forest type, the family Porinaceae had the highest species numbers (21 species), followed by Pilocarpaceae (17 species), Strigulaceae (10 species), Coenogoniaceae and Gomphillaceae (8 species), Roccellaceae (4 species), Asterothyriaceae, Ramalinaceae, and Thelotremataceae (3 species) and Arthoniaceae, Aspidotheliaceae, Lyrommataceae and Microthyriaceae had 1 species each. Pilocarpaceae is the family with the highest number of genera (8 genera), followed by Gomphillaceae (4 genera), Asterothyriaceae and Porinaceae (2 genera), the rest of the families had one genus each.

In the swamp forest type, Pilocarpaceae had the highest species number (20 species), followed by Porinaceae (19 species), Strigulaceae (14 species), Coenogoniaceae (13 species), Gomphillaceae (10 species) Roccellaceae (7 species); Asterothyriaceae (4 species), Ramalinaceae (3 species), Thelotremataceae (2 species), and Arthoniaceae, Aspidotheliaceae and Lyrommataceae each with one species. In terms of generic diversity, the family Pilocarpaceae had the highest number of genera (8 genera), followed by Gomphillaceae with 4 genera, Asterothyriaceae with 3 genera, Porinaceae and Roccellaceae with 2 genera each, and the families Arthoniaceae, Aspidotheliaceae, Coenogoniaceae, Lyrommataceae, Ramalinaceae, Strigulaceae and Thelotremataceae had one genus each.

In the old secondary forest the family Porinaceae possessed the highest number of species (17 species). The family Strigulaceae is represented by 12 species, Pilocarpaceae, Coenogoniaceae and Roccellaceae by 7 species each, Ramalinaceae by 3 species and Gomphillaceae by 2 species. The families Arthoniaceae, Asterothyriaceae, Lyrommataceae, Bacidiaceae and Microthyriaceae each possessed one species. The family Pilocarpaceae had 4 genera, Porinaceae and Roccellaceae 2 genera each and the families Arthoniaceae, Asterothyriaceae, Bacidiaceae, Coenogoniaceae, Gomphillaceae, Lyrommataceae, Microthyriaceae, Ramalinaceae and Strigulaceae had one genus each. The family Thelotremataceae which was represented in the other three forest types is not represented in the old secondary forest type.

The species rich family in the young secondary forest is Porinaceae (23 species), and it was followed by Pilocarpaceae (18 species). Thirteen species were recorded in the family Gomphillaceae, 12 species in Strigulaceae, 11 species in Coenogoniaceae, 7 species in Roccellaceae, 6 species in Asterothyriaceae, 2 species in Thelotremataceae, and 1 species in Arthoniaceae, Aspidotheliaceae, Bacidiaceae, Coccocarpiaceae, and Lyrommataceae. In the number of genera, the family Porinaceae is the richest with 9 genera and Gomphillaceae is the second with 5 genera. The family Asterothyriaceae is represented by 3 genera, Porinaceae and Roccellaceae by 2 genera each and the remaining families are represented by one genus each.

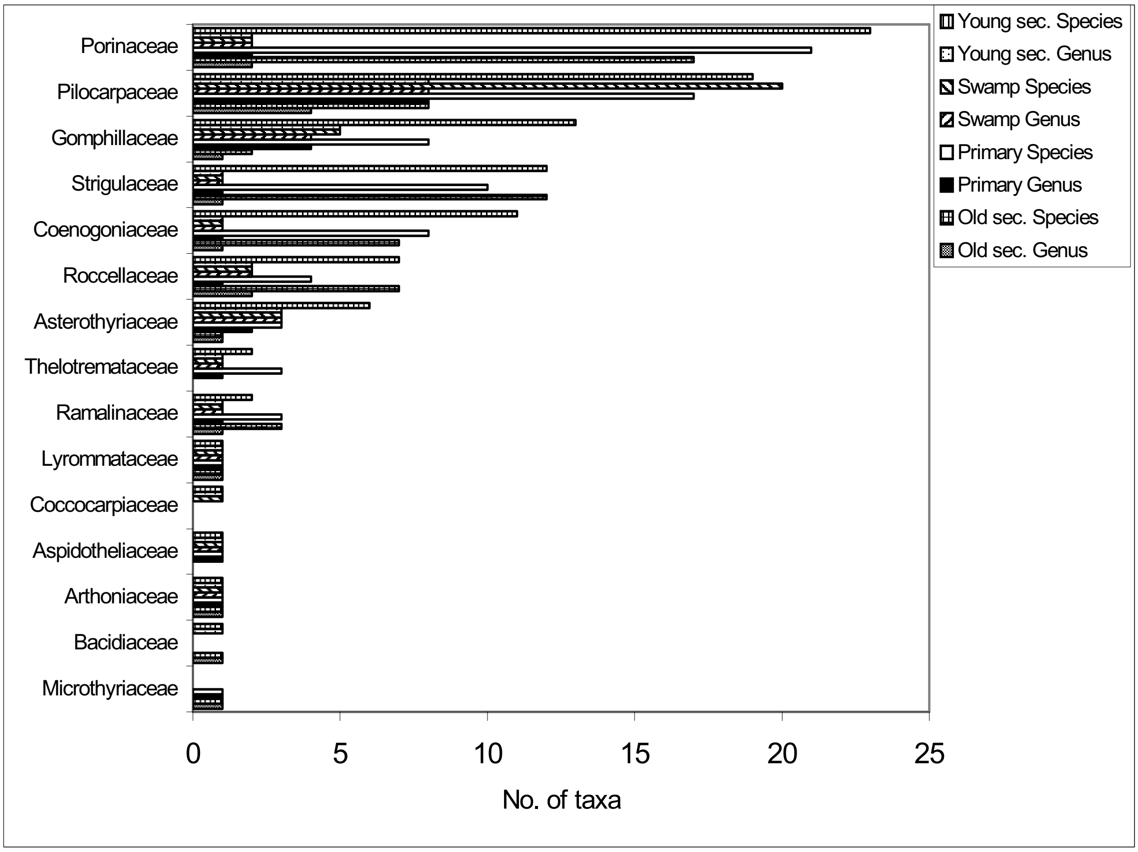

Fig. 4.7 Number of species and genera of foliicolous lichens per family per forest type of Budongo Forest

4.3.2 Species frequency

The frequency occurrences of the foliicolous lichens in the samples of the four forest types of Budongo Forest are presented in Fig. 4.8. In all study sites of Budongo Forest, the rare species constituted more than 57% of the whole species and 11-21% of the species were occasional. These two species groups constituted more than 80% of the species in the primary, swamp and young secondary forest types and about 71% of the species in the old secondary forest type. Comparatively the rare species in the old secondary forest type were fewer (57.4%) than those in the primary (64.2%), swamp (69.8) and young secondary forests (66%). Similarly, there were more dominant species (9.8%) in the old secondary forest type than in the other forest types which have less than 5% dominant species.

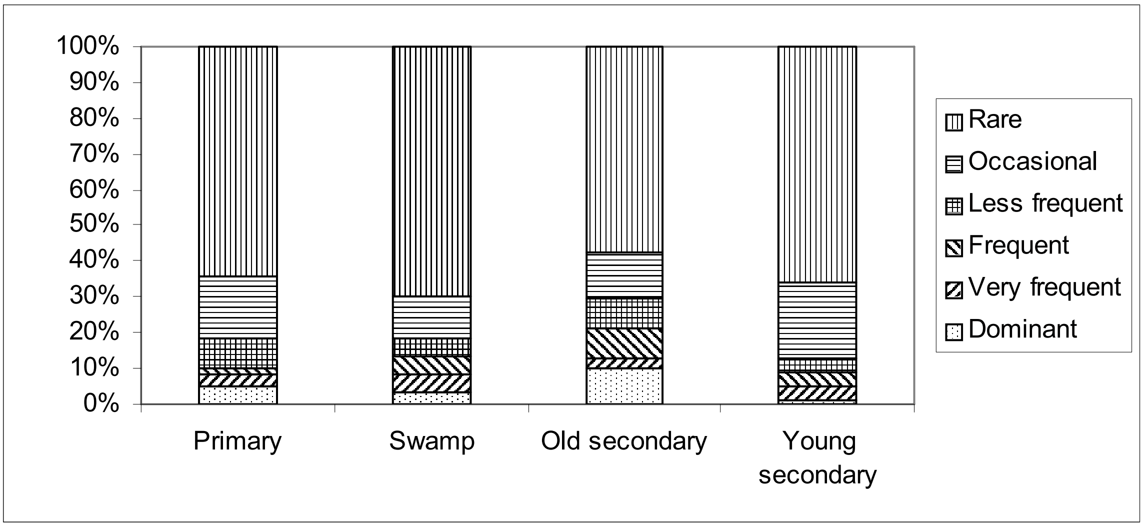

Fig. 4.8 Frequency distribution of species in the four forest types of Budongo Forest

In the primary forest type *Coenogonium dilucidum, Porina radiata, P. epiphylla* and *Mazosia melanopthalma* were the dominant species. *Mazosia rotula, Porina nitidula* and *Strigula phyllogena* were the most frequent species while *Porina semicarpi* was the only frequent species. The less frequent species were *Porina sphaerocephala, P. alba, Brasilicia foliicola, Byssolecania deplanata*, *Strigula microspora, S. nitidula* and *S. smaragdula*. The occasional species were *Byssolecania fumosonigricans, B. hymenocarpa, Bacidina mirabilis, Calopadia fusca, Coenogonium pocsii, C. subluteum, Echinoplaca pellicula, Lyromma nectandrae, Porina cupreola* var. *cupreola, P. epiphylloides, P. kamerunensis, P. rubentior, Sporopodium leprieurii* and *Strigula nemathora* var. *hypothelia.* The rare species were *Coenogonium fallaciosum, Arthonia lividula, Aspidothelium fugiens, Asterothyrium microsporum, A. monosporum, Bapalmuia ivoriensis, B. palmularis, Bacidina apiahica, Bacidina simplex, Byssoloma chlorinum, Byssoloma subpolychromum, Brasilicia dimerelloides, Byssolecania variabilis, Calenia depressa, Calenia graphidea, Calenia bullatinoides, Coenogonium geralense, C. pannosum, C. subdilucidum, C. usambarense, Chroodiscus australiensis, Chroodiscus kakamegensis sp.nov., Chroodiscus verrucosus, Fellhanera bouteillei, F. submicrommata, Gyalectidium filicinum, G. imperfectum, Gyalidea epiphylla, Lichenopeltella epiphylla, Mazosia dispersa, M. phyllosema, Phylloblastia pocsii, Porina* cf. *triseptata, P. conica, P. leptosperma, P. rubescens, P. rufula, P. sphaerocephaloides, P. subpallescens, Strigula janeriensis, S. macrocarpa, S. multipunctata, S. obducta, S. pilocarpoides, S. subtilissima, Sporopodium antonianum, Tapellaria nigrata, Tricharia nigriuncinata* sp. nov.*, T. vainioi, Trichothelium africanum, Trichothelium pauciseptatum, T. alboatrum,* and *T. epiphyllum.*

In the swamp forest *Porina epiphylla, Strigula phyllogena,* and *Coenogonium dilucidum* were the dominant species. *Mazosia rotula, Porina alba, P. radiata, P. rubentior* and *P.*

nitidula were very frequent. The frequent species were *Porina semicarpi, Strigula nitidula, S. smaragdula, Mazosia melanopthalma* and *Porina sphaerocephala.* The less frequent were *Porina conica, Strigula nemathora* var. *hypothelia, S. microspora, S. obducta* and *Sporopodium leprieurii.* Occasionals were *Porina leptosperma, P. epiphylloides, P. rubescens, P. rufula, Brasilicia foliicola, Byssolecania deplanata, Gyalectidium filicinum, Lyromma nectandrae, Strigula nemathora* var. *nemathora, Tricharia vainioi,* and *Trichothelium pauciseptatum.* The rare species were *Arthonia orbygniae, Aspidothelium geminiparum, Asterothyrium microsporum, A. monosporum, Bacidina apiahica, B. mirabilis, B. pallidocarnea, Bapalmuia ivoriensis, Bapalmuia palmularis, Brasilicia dimerelloides, Byssolecania fumosonigricans, Byssolecania hymenocarpa, Byssoloma chlorinum, Byssoloma leucoblepharum, Calenia aspidota, Calenia depressa, Calenia graphidea, Calopadia fusca, Calopadia puiggarii, Chroodiscus australiensis, Chroodiscus verrucosus, Coenogonium barbatum, C. fallaciosum, C. geralense, C. lisowskii, C. pocsii, C. siquirrense, C. subdilucidum, C. subfallaciosum, C. subluteum, C. usambarense, C. zonatum, Echinoplaca pellicula, Fellhanera africana, F. rhaphidophylli, F. subfuscatula, F. submicrommata, Gyalectidium caucasicum, G. eskuchei, G. imperfectum, Gyalidea epiphylla, Lichenopeltella epiphylla, Loflammia epiphylla, Mazosia dispersa, M. paupercula, M. phyllosema, Opegrapha epiporina, O. phylloporinae, Porina mazosoides, P. sphaerocephaloides, P. subpallescens, Psorotheciopsis patellarioides, Sporopodium antonianum, S. phyllocharis, S. pilocarpoides, Strigula antillarum, Strigula janeriensis, Strigula macrocarpa, Strigula maculate, Strigula multipunctata, Strigula schizospora, Strigula subtilissima, Tricharia nigriuncinata* sp. nov., *Trichothelium africanum, Trichothelium alboatrum* and *Trichothelium epiphyllum.*

In the old secondary forest type the dominant species were *Porina epiphylla, P. kamerunensis, P. nitidula, P. rubentior, Mazosia melanopthalma* and *Strigula phyllogena. Porina cupreola* var. *cupreola* and *Strigula nitidula* were very frequent species. The frequent species were *Porina radiata, P. rubescens, P. sphaerocephala, Strigula nemathora* var. *hypothelia* and *Strigula smaragdula. Bacidina apiahica, Byssolecania hymenocarpa, Strigula multipunctata, S. microspora* and *Porina rufula* were the less frequent species. The occasional species were *Brasilicia foliicola, Byssoloma chlorinum, Coenogonium dilucidum, Lyromma nectandrae, Opegrapha epiporina, O. phylloporinae* and *Porina semicarpi.* The rare species were *Arthonia lividula, Asterothyrium microsporum, Bacidina mirabilis, Bacidina simplex, Brasilicia dimerelloides, Byssolecania deplanata, B. fumosonigricans, B. subdiscordans, Coenogonium geralense, C. pocsii, C. siquirrense, C. subluteum, C. usambarense, C. zonatum, Fellhanera submicrommata, Gyalectidium filicinum, G. imperfectum, Lichenopeltella epiphylla, Mazosia phyllosema, M. rotula, Opegrapha mazosiae, Porina alba, P. conica, P. leptosperma, P. subpallescens, Strigula janeriensis, S. macrocarpa, S. nemathora* var. *nemathora, S. obducta, S. schizospora, S. subtilissima, Trichothelium africanum, Trichothelium pauciseptatum* and *T. epiphyllum.*

In the young secondary forest type *Strigula smaragdula* is the only dominant species. *Porina nitidula, P. rubentior, Strigula nemathora* var. *hypothelia* and *S. nitidula* were the very frequent species. The frequent species were *Strigula phyllogena, Coenogonium dilucidum, Mazosia rotula* and *Porina epiphylla.* The less frequent species were *Porina radiata, P. sphaerocephala, Strigula microspora* and *Echinoplaca pellicula*. The occasional species were *Bacidina apiahica, Byssolecania deplanata, B. hymenocarpa, Byssoloma chlorinum, Calenia depressa, C. graphidea, Fellhanera submicrommata, Gyalectidium filicinum, G. imperfectum, G. microcarpum, Lyromma nectandrae, Mazosia melanopthalma, Porina cupreola* var. *cupreola, P. epiphylloides, P. kamerunensis, P. leptosperma P. rubescens, P. sphaerocephaloides, P. subpallescens,* and *Strigula multipunctata.*

The frequency of occurrences of foliicolous lichens in Budongo Forest and the primary, swamp, old secondary and young secondary forest parts are presented in Appendices 8, 9, 10, 11 and 12 respectively.

4.3.3 Foliicolous lichens from canopy trees

In the sampling site of the primary climax forest type, a recently fallen tree of *Celtis durandi* reaching a height of 35 m was encountered. Leaves carrying foliicolous lichens were collected from the branches at a height of 20 to 35 m. Only *Strigula smaragdula* was recorded from the leaves. This species covered upto 80% of the leaf areas. In addition, a recently fallen tree of *Ficus lutea* was encountered in a place called Susungiru, about 8 km from the Budongo Forest project office. The following foliicolous lichens were recorded from the leaves of this canopy tree: *Asterothyrium monosporum, Asterothyrium pittieri, Asterothyrium rotuliforme, Calenia aspidota, Psorotheciopsis patellarioides, Psorotheciopsis varieseptata, Strigula antillarum,* and *Strigula smaragdula*. From this forest site 68 species of foliicolous lichens were recorded from the understorey.

4.3.4 New species and new records of foliicolous lichens

The checklist of lichens and lichenicolous fungi of Uganda (Feuerer 2007) listed 362 species. Out of these 29 species are foliicolous lichens. Sixteen of the species recorded in this study have already been included in the checklist. The remaining 108 species are new records for Uganda.

4.3.4.1 Species new to science

Two species of foliicolous lichens belonging to the family Gomphillaceae and Thelotremataceae were found to be new to science. These are *Tricharia nigriuncinata* sp. nov. and *Chroodiscus kakamegensis* sp. nov.

1. *Tricharia nigriuncinata* sp. nov. (Gomphillaceae). Fig. 4.9A

This new species of *Tricharia* is distinguished from all other species of the genus by the presence of hooks on the sterile setae (see arrow in Fig. 4.9).

Specimen examined: Budongo Forest, 01^{0}43’22.9 N, 031^{0}31’45.3 E, 900 m, epiphyllous on *Argomuellera macrophylla* in the primary forest type, 2005, Kumelachew 16, 65, 66, 71, 75 (KOBL).

2. *Chroodiscus kakamegensis* sp. nov.

Chroodiscus kakamegensis is a facultative lichenicolous lichen growing on *Porina epiphylla*. It has been collected from Godere, Budongo and Kakamega forests. A brief description of the species was provided in section 3.3.3.1

Specimen examined: Budongo Forest, 01^{0}43’22.9 N, 031^{0}31’45.3 E, 1082 m, epiphyllous on *Argomuellera macrophylla*, Kumelachew 96 (KOBL)

4.3.4.2 Interesting records of foliicolous lichens

From the foliicolous lichen collection of Budongo Forest, the following interesting records were obtained.

1. *Brasilicia foliicoloa* (Pilocarpaceae)

The apothecia of the specimens cited below grew marginally hypophyllous which is untypical for *Brasilicia foliicola*.

Specimen examined: Budongo Forest, 01^{0}43’22.9 N, 031^{0}31’45.3 E, 1082 m, epiphyllous on an unidentified species of tree in the primary forest, 2005, Kumelachew 92, 93 (KOBL).

2. *Gyalidea epiphylla* (Asterothyriaceae)

The specimen cited below had smaller ascospores (10 x2.5 µm) than the typical species whose ascospore size is 13-25x3.5-4.5 µm (Vězda 1966).

Specimen examined: Budongo Forest, 01^{0}42’46.6 N, 031^{0}32’.31.7 E, 1038 m, epiphyllous on unidentified species of Sapindaceae in the young secondary forest type, 2005, Kumelachew 115 (KOBL).

3. *Calenia* sp. (Gomphillaceae) Fig. 4.9B

The collection of *Calenia* cited below has got pruinose apothecia, a single muriform, ellipsoid ascospore per ascus and a prosoplectenchymatous excipulum. This collection is assumed to be a new species of *Calenia* but the material is scanty for a proper description.

Specimen examined: Budongo Forest, Royal Mille, 01^{0}42’46.6 N, 031^{0}32’.31.7 E, 1038 m, epiphyllous on unidentified species, 2005, Kumelachew 117 (KOBL).

Difficult specimens

1. unknown taxon of Pilocarpaceae (Fig. 4.9C, D & E)

A single specimen belonging to the family Pilocarpaceae was difficult to identify even to the genus level. It had centrally continuous and marginally dispersed thallus, and black apothecia (Fig. 4.12a), single muriform ascospore per ascus, branched and anastomised pharaphyses, tubular campylidia (Fig. 4.12b) and simple and bacilliform conidia with thickened ends (Fig. 4.12c). Such types of conidia are unknown in the foliicolous members of Pilocarpaceae.

Specimen examined: Budongo Forest, Royal Mille, 01^{0}42’46.6 N, 031^{0}32’31.7, 1038 m, epiphyllous on an unidentified species of Rubiaceae, 2005, Kumelachew 118 (KOBL).

2. *Coenogonium* sp.

Several collections of the genus *Coenogonium* were difficult to identify. The recent worldwide key for *Coenogonium* (Rivas-Plata *et al*. 2006) doesn’t have sufficient information for the identification our collection. It is highly likely that some of these specimens could represent new taxa of *Coenogonium*. This shows that further investigation in the African *Coenogonium* is required.

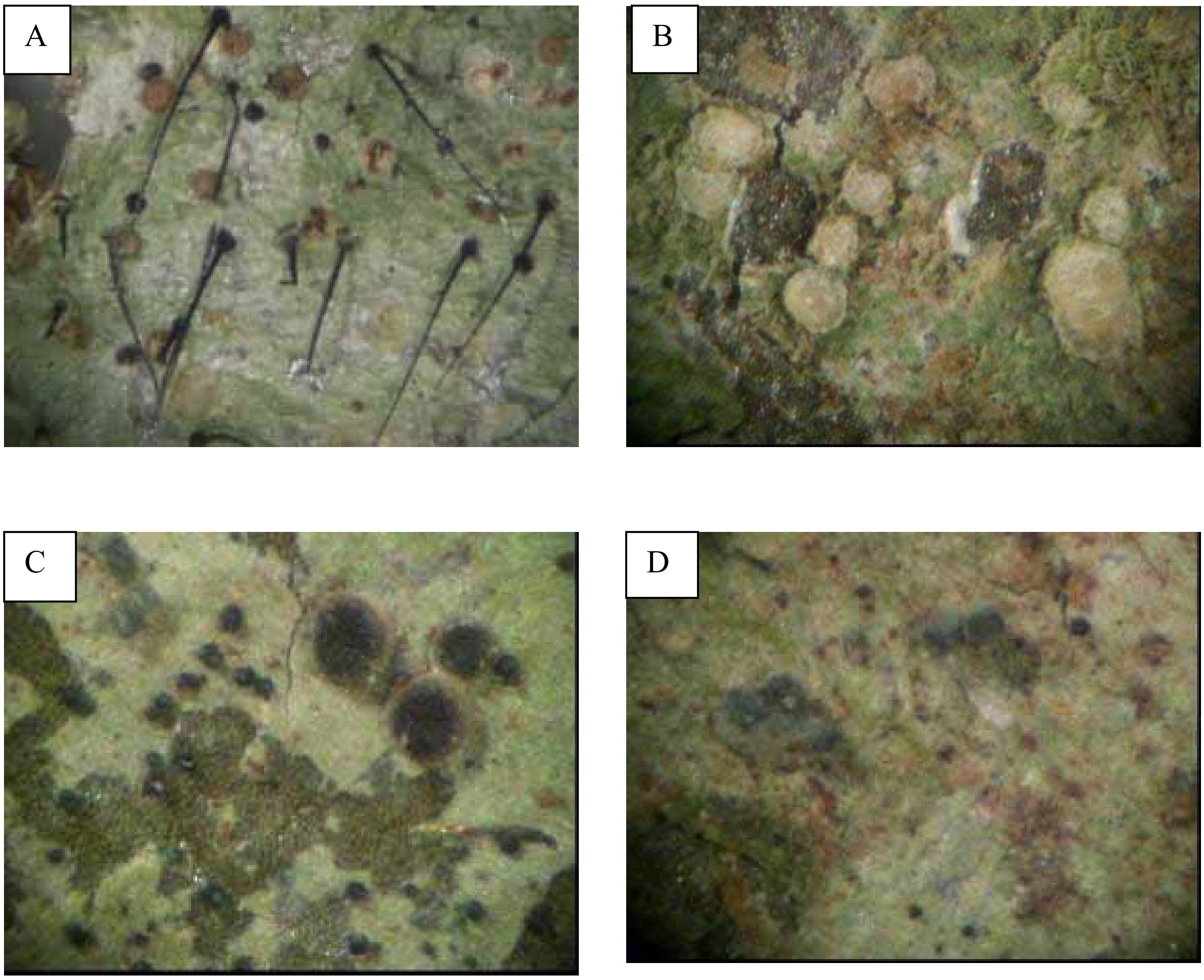

Fig. 4.9 Pictures of new secies and interesting records of foliicolous lichens from Budongo forest. (A) *Tricharia nigriuncinata* sp. nov., (B) *Calenia* sp., (C, D & E) an unknown specimen in Pilocaraceae in (C) thallus with apothecia (arrows), in (D) thallus with campylidia (arrows), in (E) conidia

3. aff. *Biatora sp.*

Three corticolous lichen specimens belonging to the family Bacidiaceae and growing facultatively on margins of living leaves were difficult to identify. They have simple and cylindrical ascospores and are close to the genus *Biatora*.

Specimen examined: Budongo Forest, Royal Mille, 01042’28.7 N, 031032’33.5 E, 1050 m, epiphyllous on *Rawsonia lucida*, 2005, Kumelachew 192, 193, 207(KOBL).

4.3.2 Alpha-diversity

4.3.2.1 Mean species number

The mean number of species recorded per sample was 10.5 for the primary forest type, 11.3 for the swamp forest type, 10.7 for the old secondary forest type and 10.3 for the young secondary forest type (Fig. 4.10). Kruskal-Wallis one-way analysis of variance test showed absence of significant differences (Chi square = 2.26, p > 0.05) among the four forest types in the mean number of species per sample.

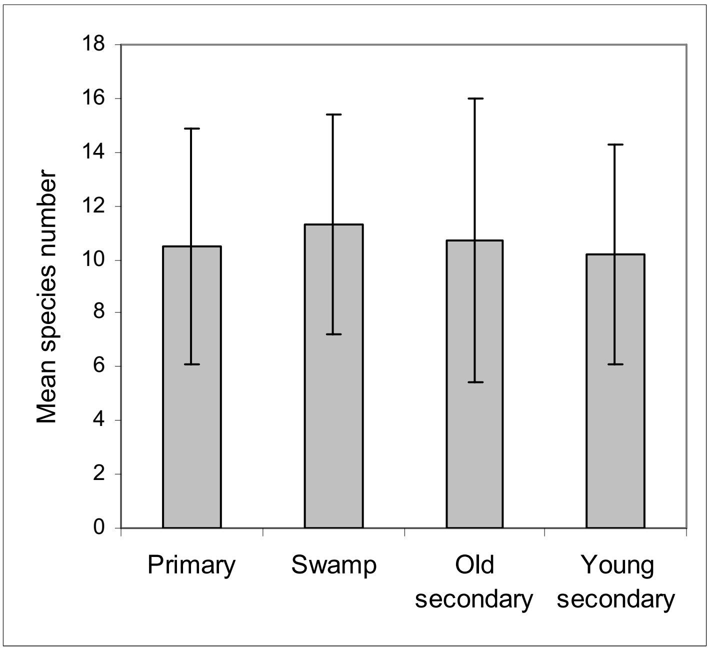

Fig. 4.10 Mean number of species per sample per forest type (values are mean ± SD)

4.3.2.2 Species accumulation curve

The species accumulation curves for the primary, swamp, old secondary and young secondary forests types of Budongo are presented in Fig. 4.11. The x-axis of the first graph is scaled by the number of accumulated samples and it compares species density between

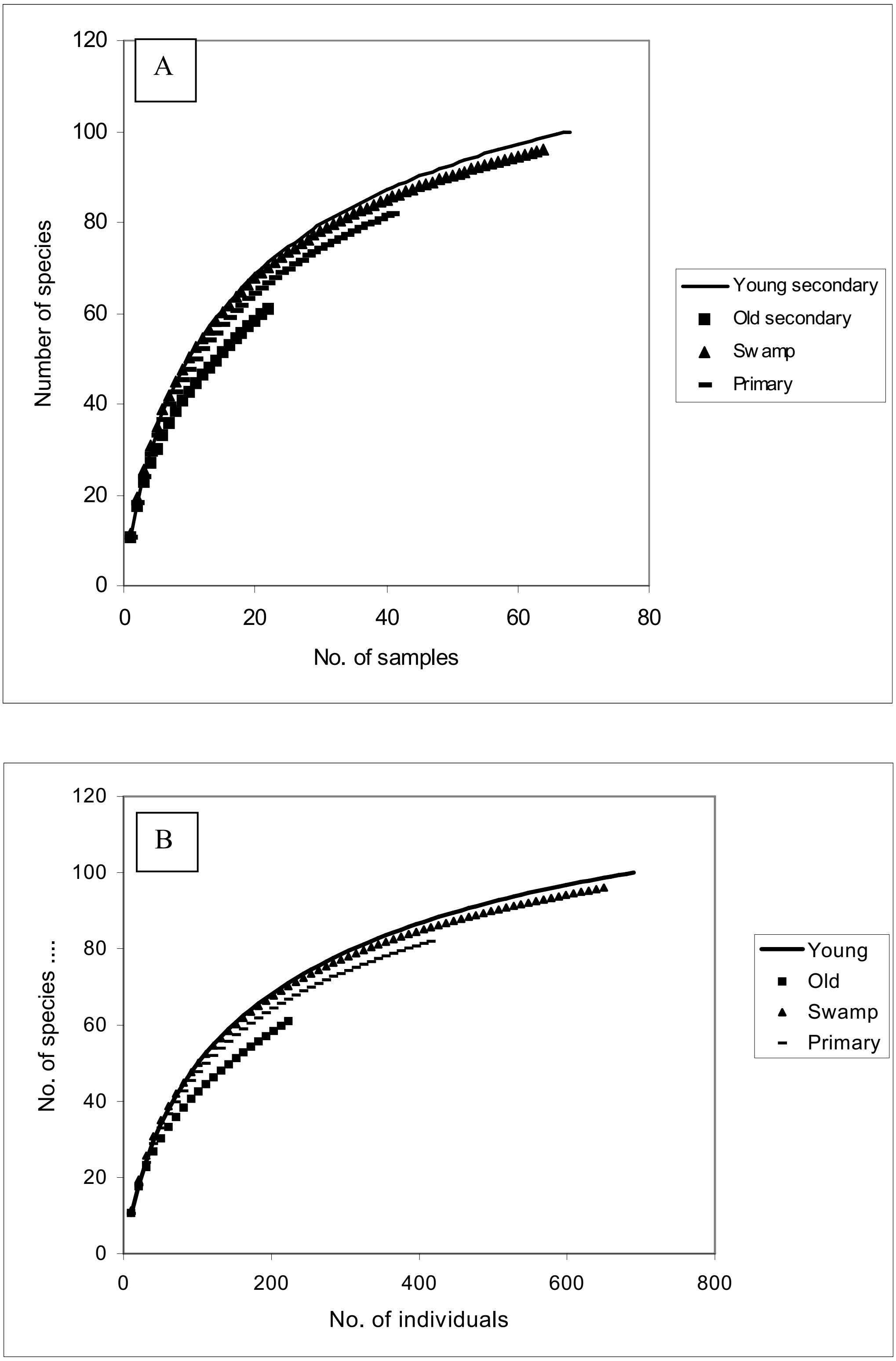

Fig. 4.11 Species accumulation curves for the primary, swamp, old secondary and young secondary forest types. A) Species density, B) Species richness

the forest types. The x-axis of the second graph is scaled by the number of individuals and thus compares species richness. The species accumulation curves for the four forest types did not approach an asymptote, but the rate of accumulation of species as successively more samples are accumulated to the total is decreasing.

As can be seen from the species accumulation curves, more species numbers are expected in the swamp and young secondary forest types than in the primary and old secondary forest types at all levels of sample accumulation (Fig. 4.11a). More species were observed in the swamp forest when lower samples were accumulated. At higher number of sample accumulation, however, more species were observed in the young secondary forest. The old secondary forest has the lowest number of species at all level of sample accumulation. The number of species expected from the species accumulation curves when 22 samples (the sample size of the old secondary forest type) were pooled is 71.1 for the young secondary forest type, 70.2 for the swamp forest type, 66.2 for the primary forest type and 61 species for the old secondary forest type. To see if there is significant difference in species richness, Magurran (2004) recommended to check if the observed diversity of the smaller community lies within the 95% confidence limits of the rarefaction curve of the larger community. Accordingly, the observed species accumulation curve of the primary forest is within the 95% confidence intervals of the corresponding species accumulation curves of the swamp and young secondary forests indicating absence of significant difference. Similarly, the observed species accumulation curve of the swamp forest is within the 95% confidence intervals of the young secondary forests. The observed species accumulation curve of the old secondary forest is within the 95% confidence intervals of the primary forest but outside the 95% confidence intervals of the swamp and the young secondary forests indicating absence of significant difference in species richness between the old secondary and the primary forest types but the swamp and young secondary forests are significantly more species richer than the old secondary forest type (Fig. 4.11b).

4.3.2.3 Estimation of species richness

The non-parametric species richness estimators for incidence data variously estimated the species richness of the four forest types of Budongo Forest (Table 4.3). For the primary and young secondary forest types, the Bootstrap estimator gave the lowest and the second order Jackknife estimator gave the highest estimate of species richness. The second order Jackknife estimator gave the highest species richness estimate for the swamp forest type and the Michalis-Menten Mean estimator gave the lowest estimate. For the old secondary forest type, Chao 2 estimator gave the highest estimate and Bootstrap the lowest estimate of species richness.

Table 4.3. Number of samples, number of individuals and species richness estimate values for the four forest types of Budongo.

	Primary forest	Swamp forest	Old secondary forest	Young secondary forest
No. of samples	41	64	22	67
No. of individuals	431	725	235	689
S_{obs}	81	96	61	100
MMMeans	94.7	105.5	74.4	112.3
Chao 2	103.4±6.8	113.8±9.8	117±30.9	117.8±9.8
Jackknife 1	104.4±6.8	118.6±5.5	87.7±6.9	122.7±5.4
Jackknife 2	117	128.5	107.1	132.6
Bootstrap	91.8	106.6	72.2	111
ICE	104.04±0.03	111.1±0.01	102.3	118.1±0.02
Degree of foliicolous lichen collection	69.2-88.2%	74.7-91%	52.1-84.5	75.4-90.1

Comparison of the number of species observed and the species richness estimated by the various richness estimators showed that 69.2-88.2% of the species have been collected from the primary forest, 74.7-91% of the species from the swamp forest, 52.1-84.5% of the species from the old secondary forest and 75.4-90.1% of the species were collected from the young secondary forests. The differences between the highest and the lowest species estimators were 15.2 species for the primary forest type, 23 species for the swamp forest type, 44.8 species for the old secondary forest type and 21.6 species for the young secondary forest type. The big difference in the old secondary forest type is due to the overestimation of Chao 2 estimator which relies on uniques (species restricted to one sample only) which accounted for 46% of the whole species in this forest type.

4.3.2.4 Shannon-Wiener diversity

The Shannon diversity index and evenness values in each forest type are shown in Table 4.4. Analysis of Variance (ANOVA) of the Shannon diversity values of the four forest sites showed the presence of significant difference (F-ratio = 3.49, $P<0.05$). Fischer's *post hoc* comparison test indicated that the old secondary forest type is significantly different from the other three forest types. There was no significant difference among the Shannon diversity of the primary, the swamp and the young forest types. Accordingly, the primary (H'=3.9), swamp (H'=4.0) and young secondary (H'=4.1) forest types have higher diversity than the old secondary forest type (H'=3.6). The Shannon evenness values are the same (J'=0.88) for the primary, old secondary and young secondary forests and slightly lower in the swamp forest type.

Table 4.4 Shannon-Wiener diversity and evenness index values.

	Primary	Swamp	Old secondary	Young secondary
Shannon index (H')[1]	3.9^a	4.0^a	3.6^b	4.1^a
Shannon evenness index (J')	0.89	0.88	0.89	0.89

[1] Different alphabetical letter designations indicate significant difference ($p<0.05$) among Shannon diversity values of the forest types

4.3.3 Beta-diversity and similarity in species composition

Total β-diversity, measured as total species number divided by mean number of species in samples, along forest types of Budongo Forest is presented in Table 4.5. This index of β-diversity is a measure of the species turnover or the degree of change in species composition. The young secondary forest had the highest β-diversity (9.8) and therefore high species turnover, followed by the swamp forest (8.5) and primary forest (7.8) and the old secondary forest has the lowest β-diversity value (5.7) and therefore low species turnover.

Table 4.5 β-diversity along the forest types of Buyangu

	Number of species (a)	Mean number of species per sample (b)	β-diversity (a/b)
Primary forest	82	10.5	7.8
Swamp forest	96	11.3	8.5
Old secondary forest	61	10.7	5.7
Young secondary forest	100	10.2	9.8

Table 4.6. Sørenson’s index of similarity among the four forest types

	Primary	Swamp	Old secondary
Primary	-		
Swamp	0.77	-	
Old secondary	0.7	0.68	-
Young secondary	0.74	0.75	0.67

The similarity in foliicolous lichen species composition, as measured by Sørenson’s index of similarity, shows generally a high similarity among the four forest types of Budongo with a mean Sørenson’s similarity index of 0.72. The highest species composition similarity among the forest types was observed between the primary and swamp forest types (S_s=0.77) followed respectively by the young and swamp forest types (S_s=0.75), the primary and young secondary forest types (S_s=0.74), the primary and old secondary forest types (S_s=0.7), the old secondary and swamp forest types (S_s=0.68) and the least similarity was observed between the young and old secondary forest types (S_s= 0.67) (Table 4.6).

4.3.4 Ordination

Fig. 4.12 shows a graphic representation of the first two axes of a DCA ordination. The first axis of the ordination had eigenvalue of 0.401 contributing to 7.3% of the total variation. The second axis with eigenvalue of 0.217 contributed to 4% of the variation. The third and fourth axes had eigenvalues of 0.180 and 0.163 respectively, each contributing to less than 4% of the total variation. Therefore, most of the variation in the DCA ordination is explained by the first axis.

Along the first DCA axis, samples with low first axis scores are from the closed forest sites with dominating shady understorey micrositic conditions and they are arranged on the left side of the axis. Samples with high first axis scores are from open forest sites where light gap microsite conditions dominate and are arranged on the right side of the axis. Most of the samples from the swamp, primary forest and old secondary forest sites are located on the left side of the first ordination axis. While few samples of the young secondary forest site are distributed on the left side of the first DCA axis, the majority of the samples being distributed on the right side of this axis. These distribution patterns indicate that vegetation type (degree of anthropogenic disturbance; in the terminology of Lücking 1997b) seems to be the factor for the variation in the distribution of the samples.

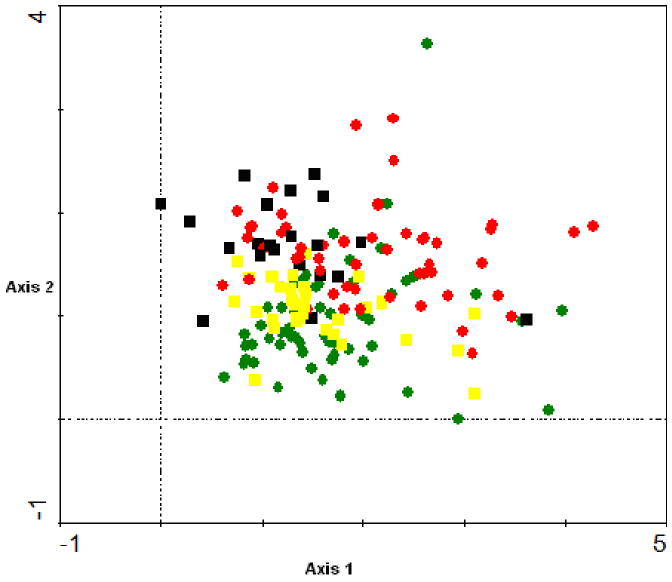

Fig. 4.12 DCA plot of samples of Budongo Forest. Black circles = samples from swamp, white squares = samples from primary, black squares = samples from old secondary, and red circles = samples from young secondary forest types.

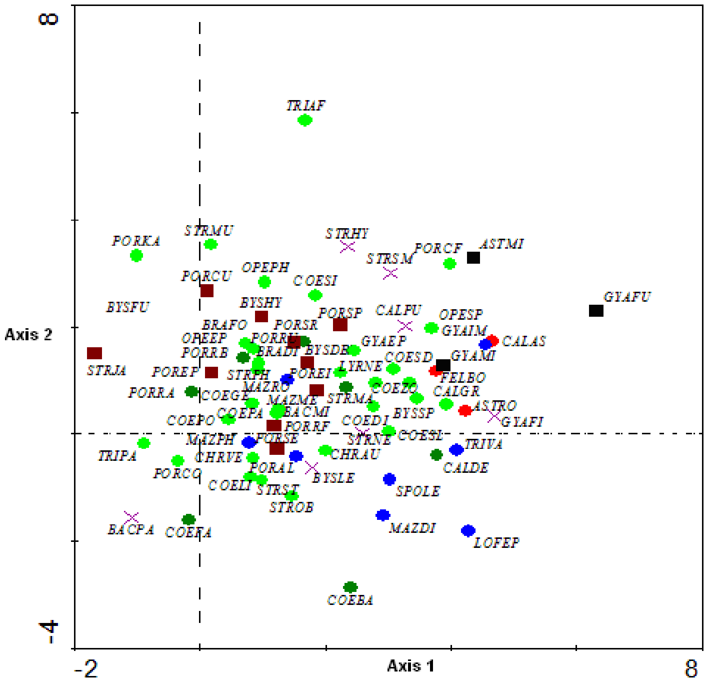

Fig. 4.13 DCA plot of foliicolous lichen species of Budongo Forest. Only species with high occurrences are shown. Green circles = species of undisturbed primary forest, light green circles = species of primary & old growth forest, brown squares = species of semi-open forest, blue circles = species of open forest (forest margin), black squares = species of open to exposed forest, red circles = species of exposed forest, x = species with wide amplitude. For acronyms, refer to Appendix 2.

For the interpretation of the species ordination (Fig. 4.13), the environmental index values of foliicolous lichens (Lücking 2000b, with addition of my personal observation) with respect to vegetation type (degree of anthropogenic disturbance) and light regime (microsite), was first determined. Species with high scores on the first DCA axis are canopy species distributed in the open to exposed forest parts. Species with low scores are from shady understorey and light gap of closed forests and semi-open forest.

4.3.5 Phorophytes

Argomuellera macrophylla, Cynometra alexandri, Trichilia emetica, Maranthacloa sp., Rawsonia lucida, Rinorea ardisiaeflora, Hippocratea sp., *Antiaris toxicaria, Chrysophyllum albidum, Campylospermum* sp., *Memecylon jasminoides, Teclea nobilis, Pterygota mildbraedii, Aframomum* sp., *Oxyanthus lepidus, Tabernaemontana holstii, Trichilia rubescens, Celtis mildbraedii, Chionanthus mildbraedii, Funtumia africana, Blighia unijugata, Coffea canephora, Conarus longistipitatus, Dracaena fragrans, Lasiodiscus mildbraedii, Ouratea densiflora, Schefflera* sp., *Alchornea florubinda, Khaya anthotheca, Macaranga* sp., *Citropsis articulate, Melianthus westii, Turreantus africanus, Agelaea ugandensis, Commelina* sp., *Pollia condensate, Acalypha* sp., *Leptaspis cochleata, Uvariopsis congensis, Lychnodiscus cerospermus, Bequaertiodendron oblanceolatum, Kigelia africana, Strychnos* sp., *Ficus asperifolia, Mitragyna stipulosa* and some unidentified species in the family Euphorbiaceae, Rubiaceae, Sapindaceae, Annonaceae, Sapindaceae and ferns were the phorophytes that supported foliicolous lichens in Budongo Forest. *Argomuellera macrophylla* was the phorophyte that supported the most species (75 species) and the highest record (229 records of foliicolous lichens). *Cynometra alexanderi* supported 5 species and 124 records of foliicolous lichens, *Trichilia emetica* supported 43 species and 43 records of foliicolous lichens, *Maranthacloa* sp. supported 39 species and 9 records of foliicolous lichens, *Rawsonia lucida* supported 34 species and 47 records of foliicolous lichens and *Rinorea ardisiaeflora* supported 33 species and 50 records of foliicolous lichens.

4.4 Discussion

4.4.1 Sample size sufficiency

Sufficiency of sampling can be evaluated using species accumulation curves and by comparing the values of various species richness estimators. Sampling is said to be sufficient when the species accumulation curve reach a horizontal asymptote (Soberón & Llorente 1993). The species accumulation curves for the observed species of the four forest types of Budongo did not reach a horizontal asymptote indicating more species could be recorded with additional sampling effort. Soberón & Llorente (1993) have indicated that in evaluating species accumulation curves, the rate of accumulation of new species should be compared. The rate of accumulation of new species as more samples were pooled has very much reduced for the primary, swamp, and young secondary forest types and less reduced for the old secondary forest type.

According to the estimates of the various species richness estimators, 69-88% of the species from the primary forest part, 75-91% from the swamp forest, 52-85% from the old secondary forest and 75-90% from the young secondary forest were collected in this study. According to the report of Heck *et al*. (1975) which considers collection of 50% to 75% of the total species richness of an area as satisfactory, the numbers of foliicolous lichen species collected from the four study sites are quite satisfactory.

4.4.2 Diversity of foliicolous lichen families and genera in the four forest types

In terms of family diversity the young secondary and the primary forest types are comparatively more diverse than the swamp and the old secondary forest types. The families Aspidotheliaceae, Thelotremataceae and Verrucariaceae were not represented in the old secondary forest type. The families Aspidotheliaceae and Verrucariaceae were not represented in the swamp forest. In terms of generic diversity, the young secondary forest is the most diverse and the old secondary forest is the least diverse. The genera *Aspidothelium, Bapalmuia, Calenia, Calopadia, Chroodiscus, Echinoplaca, Gyalidea, Loflammia, Psorotheciopsis, Phylloblastia, Tapellaria* and *Tricharia* were not represented in the old secondary forest. Most of these genera are represented in the primary, swamp and young secondary forest types.

4.4.3 Species richness in the four forest types of Budongo

At all levels of sample accumulations, the species accumulation curves showed higher estimate of species richness for the young secondary and swamp forests than for the primary and old secondary forest types. When comparing the absolute number of species, the young secondary forest type is the most species rich, followed respectively by the swamp forest, the primary forest and the old secondary forest is the least species rich. Observation of the species accumulation curves and their 95% confidence intervals, however, shows that the young secondary and the swamp forest types are not significantly different in species richness. Considering this statistical significance, the young secondary and the swamp forest are the most species rich forest type; the primary forest is the second species rich and the old secondary forest type is the least species rich forest type.

Alpha diversity, as measured by the species accumulation curves, species richness estimators and Shannon index, and β-diversity of foliicolous lichens were found to be high in the young secondary and swamp forest types. The primary forest assumes an intermediate position and the old secondary forest has the lowest α-diversity and β-diversity of foliicolous lichens. The similarity in foliicolous lichen species composition of the four forest types of Budongo is mainly due to similar microclimatic conditions. Shady understorey and transition to light gap species accounted for 62% of the species in the primary, 60% in the swamp, 58% in the old secondary and 55% of the species in the young secondary forest.

Previous studies on the diversity of foliicolous lichens in the Neotropics (Lücking 1992b, Lücking 1998b) observed high species richness in undisturbed forests and a reduced richness in disturbed and secondary forests. Our study, however, showed that secondary forests could also support similar or even higher foliicolous lichen diversity than undisturbed primary forests. The high diversity in the swamp and young secondary forest is due to occurrence of the whole microsite habitats which are suitable for the growth of foliicolous lichens. In addition to the shady understorey and light gap microsite species, canopy specialists (e.g. *Asterothyrium pittieri, A. rotuliforme, Psorotheciopsis patellaroides, Canlenia aspidota*) are also recorded in the understorey of the young secondary forest type. The most recent selective logging by pitsawing in the period between 1990 and 2000 (Babweteera *et al*. 2000) might have contributed for the appearance of such species in the understorey of this forest type. Lücking (1998d) postulated that diversity of microsites with different microclimate provoked by strong gap dynamics is important for the diversity of foliicolous lichens.

The finding from this study is in line with the Intermediate Disturbance Hypothesis (Connell 1978) which states that species diversity in a landscape is highest in areas with an intermediate level of disturbance. The effect of disturbance on foliicolous lichen diversity is dependent on the frequency and intensity of disturbance. When the intensity of disturbance is high leading to wide canopy openings, the increasing light intensity and the reduced atmospheric moisture affect the shady understorey and the transition to light gap species thereby reducing the diversity of foliicolous lichens. Under moderate level of disturbance, for example small scale logging by pitsawing, partial canopy openings could enhance the establishment of light demanding species without seriously jeopardizing the shade loving species.

4.4.4 β-diversity

Total β-diversity, measured by the total number of species divided by the mean species number per sample, is relatively high in the young secondary forest (β-diversity = 9.8) with a relatively higher species turnover and low in the old secondary forest (β-diversity = 5.7) with a relatively lower species turnover. The high Sørenson indices (0.67-0.77) among the four forest types are evidence for a low species turnover and therefore low β-diversity in Budongo Forest. The low β-diversity in turn is an indication of comparable microenvironmental conditions in the forest types.

4.5 Conclusion

- The foliicolous lichen species richness of Budongo Forest is considerably high.
- Diversity of foliicolous lichens in Budongo Forest is high not only in the primary forest parts, but in the young secondary forests as well.
- High foliicolous lichen diversity in Budongo Forest is due to the availability in close proximity of forest types with different succession stages and disturbance history.
- The high proportion (> 55% of species) of shady understorey and transition to light gap species in the four forest types is due to closed forest canopy which is indicative of minimal forest disturbance.

Chapter 5. DIVERSITY OF FOLIICOLOUS LICHENS IN KAKAMEGA FOREST, KENYA

5.1 Study area

5.1.1 Location and physiography

Kakamega Forest is located in Shinyalu Division of Kakamega District in the Western Province of Kenya. It is situated about 40 km northwest of Lake Victoria between $0^0$10’ and $0^0$21’ N latitudes and $34^0$47’ and $34^0$58’ E longitudes (Fig. 5.1).

The Kakamega District is situated in the Lake Victoria Basin and most of the forest lies on flat to undulating terrain with only few steep hills including Buyangu and Lirhanda (Blackett 1994). The forest has an area of 240 km^2 though only approximately 100 km^2 still consists of indigenous forest (Fashing & Gathua 2004). The remaining portion of the reserve consists of plantations, tea field, and grasslands (Wass 1995). The official forest boundary of Kakamega Forest lies between 1460 and 1765 m a.s.l. (Lung & Schaab 2006). Two major rivers pass through the forest, each with several tributaries, particularly in the eastern blocks of the forest (Kokwaro 1988). In the northern section of the forest is the Isiukhu River, which rises in the North Nandi Forest and the Nandi Escarpment. The southern section of the forest is dissected by the Yala Rivers, together with its many tributaries with sources mainly in the Tinderet Forest and South Nandi Forest.

Kakamega Forest covers 8,500 ha of a main forest block surrounded by five forest fragments of various sizes (130-1,400 ha): Malava and Kisere in the north, and Yala, Ikuywa and Kaimosi in the south (Farwig *et al*. 2006) (Fig. 5.2).

5.1.2 Geology and Soil

Kakamega Forest is located in the Lake Victoria Basin whose underlying bedrock is the Precambrian rock (Lovett & Waser 1993). The Precambrian rock is composed of basalt, phenolites and ancient gneiss which are associated with gold-bearing quartz veins (Blackett 1994). The underlying rock is overlain by soils of low fertility ferralo-chromic/orthic acrisols, which are well-drained, deep, heavily leached, medium to heavy texture clay-loams and clays, usually with pH below 5.5 (Blackett 1994). The soils to the east and north-east of the forest are humic cambisols and acrisols (Blackett 1994, Tattersfield *et al*. 2001, Glenday 2006). To the south-east of the forest, there is an area of more fertile nitosols (Blackett1994). Musila (2007) identified four soil classes in Kakamega Forest: Ferralsols (in Salazar and Kisere), Cambisols (in Isecheno, Kaimosi and Yala), Phaeozems (in Ikuywa), and Lixisols (in camp site).

Fig.5.1 Map of Kenya showing the location of Kakamega Forest (red square). (Source: www.village-sanctuary.com)

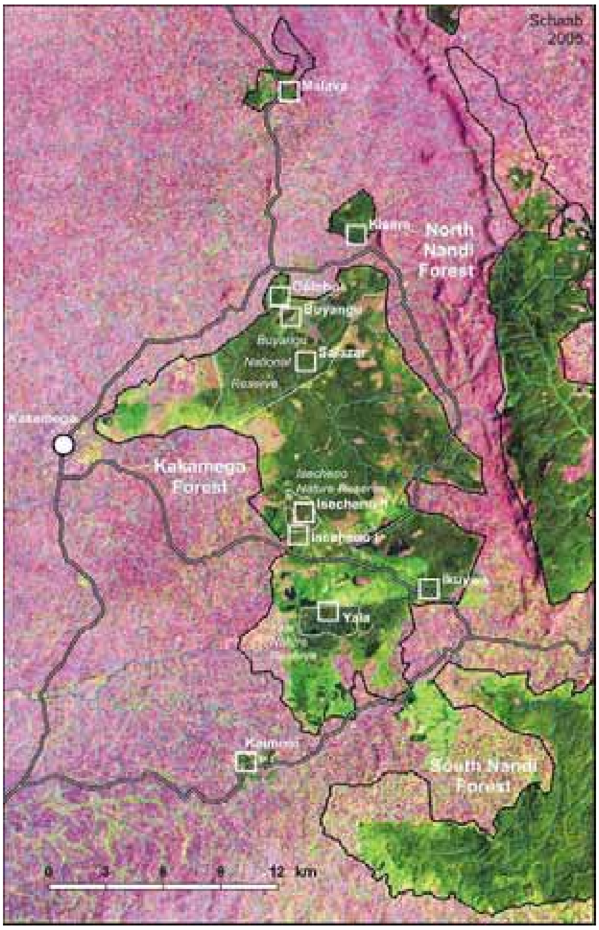

Fig. 5.2. Satellite image (Landsat 7 ETM+, 05 Feb 2001) of Kakamega Forest and its fragments (source: BIOTA-E02, G. Schaab).

5.1.3.Climate

The area around Kakamega Forest has one of the highest levels of annual rainfall in Kenya. Rainfall in Kakamega is bimodal, the long rains falling in April and May and the short rains falling in September and October. The dry season is from the end of December to February. The Forest Department records rainfall at Isecheno forest station and the average annual rainfall between the period 1982 and 2006 was between 1343 and 2638 mm. The average annual temperature of the forest is between 10.6 and 27.7 ^{0}C and the average monthly maximum temperature ranges from 18 to 29^{0}C while the corresponding minimum temperature varies from 4 to 21^{0}C (Muriuki & Tsingalia 1990).

5.1.4. Vegetation, flora and plant communities

The vegetation of Kakamega Forest contains a mosaic of primary rainforest, secondary forests of different seral stages, swamp and riverine forest, selectively logged forest, plantations of indigenous and exotic tree species, natural glades, and clearings made following human disturbances (Mutangah et al. 1994, Tattersfield *et al* 2001).

The forest type of Kakamega has been classified differently by various authors: upland rainforest (Greenway 1973), transitional rainforest (White 1983), tropical rainforest (Beentje 1990), mid-altitudinal tropical rainforest (Bleher *et al*. 2005) and dry peripheral semi-evergreen Guineo-Congolian transitional rainforest (Althof 2005). Kokwaro (1988) described Kakamega Forest as the easternmost relic of the equatorial forests that stretch across the Congo basin and the only tropical rainforest of the Guineo-Congolian type found in Kenya. It occupies a transitional position between the Guineo-Congolian lowland forests and the afromontane forests of the highlands to the west of the Rift Valley (Blackett 1994). Floristically, the forest consists of species from the Guineo-Congolian floral region, from the Afromontane floral region and species which fall neither in the former nor in the latter regions, and are thus transitional.

Several authors documented the flora of Kakamega Forest. Kokwaro (1988) recorded 147 species of woody plants and 227 species of herbaceous plants. Blackett (1994) recorded 132 tree species. Althof (2005) recorded 112 species of trees, 62 species of shrubs, 58 species of climbers and 165 species of herbaceous plants (including ferns).

Among the 212 woody species recorded in Kakamega Forest (Althof 2005), 41% were Guineo-Congolian origin, 33% were related to the Afromonatne forest system and 26% were transitional species. The Guineo-Congolian species include *Pouteria* (*Aningeria*) *altissima, Antiaris toxicaria, Argomuellera macrophylla, Artabotrys likimensis, Bequaertiodendron oblanceolatum, Blighia unijugata, Celtis gomphophylla, C. mildbraedii, Clerodendrom buchholzii, C. johnstoni, Coffea eugenioides, Craterispermum schweinfurthii, Culcasia falcifolia, Dracaena fragrans, D. laxissima, Entandophragma angolense, Ficus asperifolia, F. exasperate, F. vallis-choudae, Funtumia africana, Gouania longispicata, Harungana madagascariensis, Hippocratea africana, Jasminum* *fluminense, Landolphia buchananii, Maesopsis eminii, Monodora whitei, Premna angolensis, Pseuderanthenum ludovicianum, Rothmannia longiflora, Trichilia emetica, Uvariopsis congensis* and *Venronia conferta*.

The Afromontane species include *Albizia gummifera, Allophylus abyssinicus, Apodytes dimidiata, Cassipourea ruwensorensis, Chaetacme aristata, Chyrsophyllum albidum, C. viridifolium, Croton macrostachyus, C. megalocarpus, Deinbollia kilimandscharica, Diospyros abyssinica, Ekebergia capensis, Lepidotrichilia volkensii, Macaranga kilimandscharica, Neoboutonia macrocalyx, Nuxia congesta, Olea capensis, Oncoba spinosa, Oxyanthus speciosus, Polyscias fulva, Prunus africana, Rapanea melanophloeos, Ritchiea albersii, Stombosia scheffleri, Syzigium guineense, Teclea nobilis, Trichocladus ellipticus, Urera hypselodendron*, and *Vangueria apiculata*.

The transitional species include *Alangium chinense, Alchornea laxiflora, Bridelia micrantha, Clausena anisata, Clematis brachiata, Croton sylvaticus, Dalbergia lactea, Dombeya burgessiae, Dovyalis macrocalyx, Ehretia cymosa, Erythrococca atrovirens, Ficus natalensis, F. sur, F. thonningii, Flacourtia indica, Grewia similes, Kigelia africana, Maesa lanceolata, Margaritaria discoidea, Maytenus heterophylla, Morus mesozygia, Pavonia urens, Rawsonia lucida, Rothmannia urcelliformis, Sapium ellipticum, Stereospermum kunthianum, Strychnos usambarensis, Tinnea aethopica, Trema orientalis, Trilepisium madagascariense*, and *Vitex fischeri*.

Twenty-seven woody species recorded by Althof (2005) were not recorded in other parts of Kenya. These include *Acacia montigena, Achyrospermum parviflorum, Pouteria* (*Aningeria*) *altissima, Bequaertiodendron oblanceolatum, Cassipourea ruwensorensis, Chionanthus mildbraedii, Chrysophyllum albidum, Clerodendrum buchholzii, Craterispermum schweinfurthii, Dracaena fragrans, Entandophragma angolense, Illigera pentaphylla, Leea guineense, Maesopsis eminii, Monodora myristica, Oreobambus buchwaldii, Ouratea densiflora, Ouratea hiernii, Piper guineense, Premna angolensis, Pseuderanthenum ludovicianum, Rothmannia longiflora, Rothmannia sp., Uncaria africana, Uvariopsis congensis*, and *Vernonia conferta.* In addition, Althof (2005) recorded the endemic herb *Commelina albiflora* and 15 woody species for the first time in Kakamega Forest including *Agelaea pentagyna, Artabotrys likimensis, Basella alba, Connarus longistipitatus, Dregea abyssinica, Leptaspis cochleata, Meyna tetraphylla, Monanthotaxis buchananii, Smilax anceps, Suregada procera,* and *Turraea abyssinica.*

Althof (2005) described the plant communities Kakamega Forest based on the Braun-Blanquet method. In total, thirteen plant communities and subcommunities belonging to two alliances, i.e., *Antiaris toxicaria–Diospyros abyssinica* alliance representing the mature forest stage and *Harungana madagascariensis–Desmodium adscendens* alliance representing the young forest stage, were identified from the main forest block and fragments.

Plant communities and subcommunities of the *Antiaris toxicaria–Diospyros abyssinica* alliance:

1. *Trichocladus ellipticus* subcommunity is named from the differential species and is said to represent a climax stage of development in the near-primary Kisere forest.
2. *Ficus cyathistipula* subcommunity is characterized by the presence of *Ficus cyathistipula* and *F. bubu* and is localized in Ghostisland part of the Buyangu National Reserve.

3. *Uvariopsis congensis* community can be distinguished by the differential species *Uvariopsis congensis* and is restricted to the study sites at Kisere, Buyangu Hill, Colobus and Ghostisland.

4. cf. *Fernandoa magnifica* community occurs in places at Kisere, Buyangu Hill and Colobus and is characterized by the differential species cf. *Fernandoa magnifica* and *Rawsonia lucida* and *Strychnos usambarensis*. *Deinbollia kilimandscharica* and *Markhamia lutea* are the associated species in the shrub layer.

5. Degraded *Rapanea melanophloeos* community is found in a disturbed area along Isiukhu river. It is distinguished by the characteristic species *Rapanea melanophloeos* and *Nuxia congesta*.

6. Pure *Deinbollia kilimandscharica – Markhamia lutea* community is found in Buyangu Hill. It is a middle-aged secondary forest community characterized by *Rawsonia lucida*, *Strychnos usambarensis* and *Coffea eugenioides*.

7. *Deinbollia kilimandscharica – Markhamia lutea* transitional subcommunity is found in the Udo camp site and Vihiga area and is characteristic of young forests.

8. In *Suregada procera* subcommunity, *Suregada procera* is the differential species and the liana *Landolphia buchananii* is the characteristic species. The community is found in Yala and Ikuywa forests.

9. *Pseuderanthemum ludovicianum* subcommunity is found in parts of Salazar, Busambuli, Isecheno, Yala and Ikuywa and is described as a middle-aged secondary community.

10. *Strombosia scheffleri* community is a middle-aged secondary community and is found in parts of Isecheno forest.

11. In Pure *Celtis mildbraedii – Craibia brownii* community, *Celtis mildbraedii* and *Craibia brownii* are characteristic species in the tree layer and *Bequaertiodendron oblanceolatum* and *Chrysophyllum albidum* are the characteristic species in the shrub layer.

Plant community and subcommunity of the *Harungana madagascariensis–Desmodium adscendens* alliance:

1. *Maesa lanceolata* subcommunity is characteristic of a disturbed forest and is found in the forest around the Udo camp site. The community is characterized by the abundance of *Maesa lanceolata*, *Acanthus pubescens*, and *Pavonia urens*.

2. *Pittosporum viridiflorum* community is the youngest of all investigated succession stages in Kakamega Forest.

5.1.5 Fauna

Kakamega Forest is known for its animal diversity. It is home to five diurnal primate species: the Black and White Colobus (*Colobus guereza*)*,* the Red-tailed Monkey *(Cercopithecus ascanius*)*,* the Blue Monkey (*Cercopithecus mitis*)*,* the De Brazza's Monkey (*Cercopithecus neglectus*)*,* and *the Olive Baboon* (*Papio anubis*) (Fashing & Cords 2000). Other large mammals in the forest include the Bushbuck (*Tragelaphus scriptus*), the Waterbuck (*Kobus ellipsiprymnus*), the Bushpig *(Potamochoerus larvatus)*, the Blue Duiker (*Cephalophus monticola*), the Red Duiker (*Cephalophus harveyi*), and the Common Duiker (*Sylvicarpa grimmia*) (Blackett 2004).

The avifauna of Kakamega Forest is quite remarkable with a unique combination of central African lowland species and highland species, the lowland species being the dominat. Zimmerman (1972) shows that the avifaunal affinities of Kakamega Forest relate with the lowland Congo and western Uganda forests, as indicated by the 107 species they share in common. More than 350 species of birds are found in Kakamega Forest (KIFCON 1994). Sixty-two birds of Kenya are restricted to Kakamega Forest including Turner's Eremomela (*Eremomela turneri*) and Chapin's Flycatcher (*Muscicapa lendu*) which are globally threatened species (Sayer *et al*. 1992).

Kakamega Forest is rich in amphibians and reptiles. Many of the snakes in Kakamega Forest are from West Africa including the Forest Cobra (*Pseudonaje goldii*), the Black-lipped Cobra (*Naja melanoleuca*), Jameson's Mamba (*Dendroaspis jamesoni*), the Bush Viper (*Atheris squamigera*), the Rhinoceros-horned Viper (*Bitis nasicornis*) and the Gaboon Viper (*Bitis gabonica*). Veith (2004) recorded 28 species of frogs from Kakamega forest.

Insects, especially butterflies (Lepidoptera) are diverse in Kakamega Forest with a total of 515 species, representing 60% of the total butterfly species in Kenya (Häuser 2004). In addition, 71 species of dragonflies (Clausnitzer 2004) and more than 190 species of bees (Kraemer & Naumann 2004) have been recorded from the forest.

5.1.6. Management Status

Historical records (Mitchell 2004) indicate that the first forest boundary of Kakamega was physically established around 1908-1910. This boundary was later modified in1912-13 and in 1929-1932. During these periods, the forest used to be managed by the local people and village elders until its management was taken over by the Forest Department in 1931 (Mitchell 2004). In 1933, Kakamega Forest was first gazetted as a Trust Forest under Proclamation No. 14 and it was declared as a Central Forest in 1964 (Blackett 1994). In 1967, the Isecheno, Kisere and Yala Nature Reserves were established and gazetted. In 1986, the northern part of Kakamega Forest (Buyangu area) and Kisere forest were gazetted as Kakamega National Reserve and fell under management of the Kakamega Wildlife Reserve (KWS) which is a quasi-government body operating under the Ministry of Environment and Natural Resources. The southern part of the main forest block (Isecheno), and the fragments Malava, Yala, Ikuywa, and Kaimosi are managed by the Forest Department (FD) under the Ministry of Environment and Natural Resources.

The aim of the KWS is to conserve, protect and sustainably manage wildlife resources (Wass 1995). The areas under KWS managements are kept for conservation and tourism only and people are not allowed to collect any forest products. The aim of the FD is to enhance conservation and protection of indigenous forest, to improve the production of timber and fuelwood and to establish a framework for the long-term development forestry (Wass 1995). Cattle grazing, collection of dead firewood, medicinal plants and thatching grass are permitted in FD controlled area, while logging and charcoal burning is illegal (Glenday 2006).

5.1.7. Human Impact

Kakamega Forest is found in an area with one of the highest human population densities in Kenya (Tsingalia 1990) with an average of 600 people per square kilometer (Blackett 1994). Human settlement inside the forest was widespread until its gazettement. This high population density has led to considerable long-term human influence on the forest (Wass 1995). The local people have long used the forest for shamba system farming, as a thoroughfare for herding cattle to grasslands in the forest interior and as a source of charcoal, fuelwood, gold, honey, medicinal plants, timber, and construction materials and hunting of wild animals (Kokwaro 1988, Wass 1995, Mitchell 2004). The area surrounding the forest is used for growing maize, tea and sugar cane. Illegal logging, charcoal burning and grazing by domestic animals is prevalent in the forest (see Figs. 5.3 to Fig. 5.6). Bleher *et al*. (2005) conducted an assessment of human impact in Kakamega Forest and showed a high level of human impact throughout the forest with illegal logging and extraction of commercially valuable timber being most widespread.

Fig. 5.3 Cattle grazing in Kaimosi forest

Fig. 5.4. Firewood collection in Ikuywa forest

Fig. 5.5 Charcoal making place in Ikuywa

Fig. 5.6. Tee plantation near Isecheno forest

5.1.7.1 Fragmentation

Kakamega Forest is a highly fragmented and disturbed forest (Tsingalia 1990, Bleher *et al*. 2006) and what is known as Kakamega Forest at present consists of the main forest block with an area of 8,537 ha, surrounded by five forest fragments (Kisere, Malava, Yala, Ikuywa & Kaimosi) with area of 132 to 1,370 ha (Farwig *et al*. 2007).

To what extent the Kakamega Forest was extending and contiguous to the various fragments is debatable. Brooks *et al*. (1999) argued that at the time of British colonization of Kenya in 1895, Kakamega Forest was contiguous with what are now the peripheral fragments of Yala, Ikuywa, Kisere, and Malava, and eastwards up the Nandi Escarpment to the Nandi forest above 1800 m. According to these authors, Malava forest was isolated from Kakamega Forest between 1895 and 1917, Kisere forest was isolated around 1933, Yala forest was isolated at the beginning of 1970, and Ikuywa forest was isolated in 1976.

Mitchell (2004), who conducted a detail analysis on the fragmentation and disturbance history of Kakamega Forest, argued that Kakamega Forest was contiguous only with the forests of Yala and Ikuywa in the southern part and the forests of Malava, Kisere and North Nandi have always been separate from Kakamega Forest. The fragments Yala and Ikuywa have been separated from the main forest block since the early 1960s and Kaimosi was separated between 1913 and 1959 (Mitchell 2004).

5.1.7.2 Logging

Commercial logging in Kakamega Forest started after the gold rush of the 1930’s and its pit prop and fuel wood requirements (Mitchell 2004). Licenses for timber extraction were given to sawmills in 1933 and since then the forest was logged by clear-felling and selective logging. Clear-felling of indigenous forest to make way for fast-growing exotic tree and softwood plantations as well as for settlement and tea plantation was extensive under colonial forest service (Bleher *et al.* 2006). Clear-felling was officially halted in 1975 but selective logging for a wide range of species continued till the mid-1980’s when the exploitation of indigenous trees was banned by presidential decree (Mitchell 2004).

5.1.7.3 Plantation

Plantation of indigenous trees in Kakamega Forest started south of Isecheno around 1934 (Mitchell 2004). The trees planted include *Prunus africana, Olea capensis, Markhamia lutea, Croton megalocarpus, Spathodea campanulata, Zanthoxylum gillettii, Cordia africana, Funtumia africana* and *Maesopsis eminii*. Since the late 1940s, vast area of Kakamega Forest has been converted to forestry plantations including coniferous trees of *Pinus patula, P. caribaea,* and *Cupressus lusitanica* (Tattersfield et al. 2001). Blackett (1994) estimated 1,700 ha of plantations concentrated around Isecheno forest station whereas Mitchell (2004) estimated 1,700 to 2,400 ha of plantations in Kakamega Forest.

5.1.7.4 Change in land cover and forest area

As a result of the continuous human pressure in the previous century, Kakamega Forest has undergone a change in land cover resulting in a reduction of the indigenous forest cover. In addition, the observed difference in the floristic composition and structure within Kakamega Forest is partly attributed to the exploitation history of the forest (Kiama & Kiyiapi 2001, Althof 2005).

An assessment of land cover development trends since the early 1970’s (Glenday 2006, Lung & Schaab 2006) has revealed severe forest loss in the north-western and the southern parts of Kakamega Forest and succession in the north-eastern and north-central parts of the forest. Lung & Schaab (2006) reported a reduction of the near-natural and old secondary forests from 15,000 ha in 1972 to 12,200 ha in 2001, and an increase in bushland from 1,000 ha to 4,000 ha. Table 5.1 presents changes in areas of Kakamega main forest block and fragments for a period of 70 years since the forest was gazetted in 1933. Malava forest showed the highest forest loss with 73% of its forest area being lost in 70 years time. Kisere forest, on the other hand, had lost only 8.4% of its forest area. The main forest block, which also included Ikuywa and Yala forest during the time of forest gazettment, has lost 53% of its forest area.

Table 5.1 Area of Kakamega main forest block and fragments in 1933 and 2001 (Source: BIOTA East- Phase I Final Report)

Main forest block/fragment	**Area (ha) in 1933**	**Area (ha) in 2001**
Malava	703	190
Kisere	458	420
Kakamega main forest block	23,632 (including Yala & Ikuywa)	8,537
Ikuywa	Included in the main forest block	1,370
Yala	Included in the main forest block	1,199
Kaimosi	-	132

5.2 Study sites

Foliicolous lichens were collected from Kakamega main forest block (Colobus, Buyangu, Bukhaywa, Busambuli, Campsite, Isiukhu, Ghostisland, Salazar, and Isecheno) and from the surrounding forest fragments in the northern (Kisere and Malava) and southern (Yala, Ikuywa, and Kaimosi) part of Kakamega (Fig. 5.7). Table 5.2 presents the management regime, conservation status, forest type, disturbance history and plant community types of the study sites of Kakamega Forest.

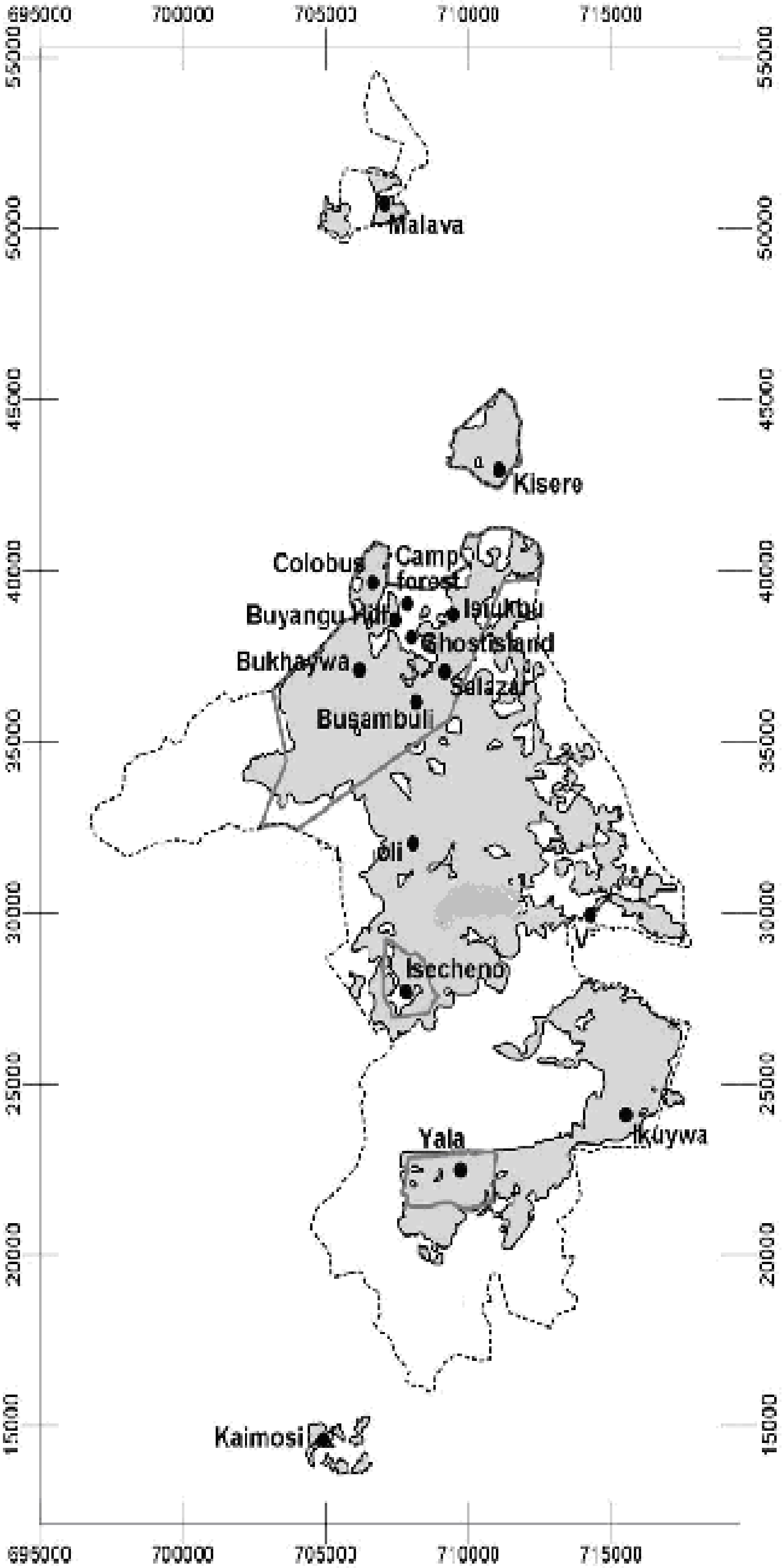

Fig. 5.7 Map of Kakamega forest and the location of the study sites

Table 5.2 Characterization of the study sites in Kakamega Forest

Study site	***Management regime/Protection status***	***Forest type/ Succession stage (Althof 2005)***	***Plant community (Althof 2005)***	***Disturbance history/level (Mitchell 2004, Althof 2005)***
Bukhaywa	*KWS/National Reserve*	*Middle-aged secondary*		*The forest is disrupted by several gaps. The heterogenous forest structure could be a result of selective logging. Disturbance high.*
Busambuli	*KWS/National Reserve*	*Middle-aged secondary*	*Pure* Celtis mildbraedii-Craibia brownii, Pseuderanthemum ludovicianum	*Small stature vegetation. Several gaps in the canopy and very young secondary forest sites present. Disturbance high.*
Buyangu	*KWS/National Reserve*	*Middle-aged secondary*	*cf.* Fernandoa magnifica, Uvariopsis congensis, Fernandoa magnifica	*Forest growth colonized much of the grassland areas since the early 20th century. Pitsawing of* Olea capensis, Cordia africana, Canthium schimperanum, Croton megalocarpus, Prunus africana, Funtumia africana *and* Croton sylvaticus *took place between1969 and mid 1970's. Disturbance intermediate.*
Camp site	*KWS/National Reserve*	*Young secondary*	Deinbollia kilimandscharica - Markhamia lutea transitional	*The vegetation is about 10 to 20 years old and the tree layer is up to 12 m high. Over 60 % of the canopy is closed, but only thin crown layers exist. Disturbance very high.*
Colobus	*KWS/National Reserve*	*Middle-aged secondary*	Uvariopsis congensis, Fernandoa magnifica	*It was with full forest in 1913/16. In the early 1920s part of the forest was cleared and converted to farmland. From 1943 sawmills cut timber mainly* Olea capensis, Cordia africana, Canthium schimperanum, Trichilia emetica, Premna angolensis, Celtis africana, Chrysophyllum albidum, Funtumia africana, Prunus africana, *and* Zanthoxylum gillettii. *Until 1989 there was a decrease in near-natural and secondary forest, but afterwards secondary forest expanded. Disturbance intermediate.*
Ghostisland	*KWS/National Reserve*	*Old secondary*	Ficus cyathistipula, Uvariopsis congensis	*It is a small forest island in the middle of a* Psidium guajava *and* Harungana madagascariensis – bushland. *Disturabnce intermediate*.
Ikuywa	*FD/Forest Reserve*	*Middle-aged secondary*	*Pure* Celtis mildbraedii-Craibia brownii, Strombosia scheffleri, Suregada procera, Pseuderanthemum ludovicianum	*Commercial logging started in late 1950s and continued in 1970s and 1980s. Main trees logged:* Prunus aficana, Cordia africana, Aningeria altissima, Zanthoxylum gillettii, Fagaropsis angolensis, Olea capensis, Cordia africana, *and* Trichilia emetica. *Disturbance low.*

Table 5. 2. contd.

Study site	***Management regime/Protection status***	***Forest type/ Succession stage (Althof 2005)***	***Plant community (Althof 2005)***	***Disturbance history/level (Mitchell 2004, Althof 2005)***
Isecheno	*FD/Forest Reserve*	*Middle-aged secondary*	*Pure* Celtis mildbraedii-Craibia brownii, Strombosia scheffleri, Pseuderanthemum ludovicianum	*In 1913/16 the forest west of Isecheno was seriously fragmented. In 1930s the forest was used for gold prospecting and subsequently logging to supply the gold mines with fuel and pit props. In 1940s part of the forest was group planted with* Olea capensis, Milicia excelsa, Acrocarpus fraxinifolius, Zanthoxylum gillettii *and* Khaya anthotheca. *Disturbance high.*
Kaimosi	*FD/Forest Reserve*	*Heavily logged and planted*	*Disturbed* Deinbollia kilimandscharica-Markhamia lutea	*The1913/16 map shows Kaimosi attached to Kakamega and Kapwaren forest. Between 1913 and 1959 the forest to the south-east gradually eroded. The 1950s maps show half of the forest deforested. In 1965 the local people were pitsawing* Olea capensis, Trichilia emetica, Zanthoxylum gillettii, Celtis mildbaredii, *and* Croton megelocarpus. *Disturbance high.*
Isiukhu	*KWS/National Reserve*	*Young secondary*	*Degraded* Rapanea melanophloeos–riverine community	*The forest is found along Isiukhu river. The tree layer is about 15 m high and a dense shrub layer exists. The plant community belongs to the middle-aged secondary forest, but species characteristic for disturbed and young stages also occur. Disturbance high.*
Kisere	*KWS/National Reserve*	*Near-primary*	Trichocladus ellipticus, Uvariopsis congensis, *cf.* Fernandoa magnifica	*Large-scale logging absent, only pitsawing of* Olea capensis, Prunus africana, Funtumia africana, Cordia africana *since 1960. Most part of the forest under near-natural and old secondary forest. Disturbance low.*
Malava	*FD/Forest Reserve*	*Heavily logged and planted*	*Disturbed* Deinbollia kilimandscharica-Markhamia lutea	*Heavy timber exploitation of Olea capensis and Prunus africana since 1940. Between 1945 and 1957 it has been intensively group planted with* Cordia africana, Prunus africana and O. capensis and exotic trees of Khaya anthotheca *and* Bischoffia javanica*. Disturbance high.*
Salazar	*KWS/Nature Reserve*	*Middle-aged secondary*	*Pure* Celtis mildbraedii-Craibia brownii, Pseuderanthemum ludovicianum.	*In 1913/16 part of the forest was covered by grassland with scattered trees. In 1977/78 logging of* Croton megalocarpus, Antiaris toxicaria, Celtis mildbraedii, Funtumia africana, Aningeria altissima, Olea capensis, Prunus africana, Cordia africana, Celtis mildbraedii, *and* Canthium schimperanum. *After 1989 secondary forest expanded. Disturbance low.*
Yala	*FD/Nature Reserve*	*Old secondary*	*Pure* Celtis mildbraedii-Craibia brownii, Pseuderanthemum ludovicianum, Suregada procera	*It became disconnected from indigenous forest on the northern half of its boundary in 1950s and 1960s. No large-scale logging but pit-sawing of a few species took place. It has a mature forest profile of a very low stem density. Disturbance low.*

5.3 Results

5.3.1 Floristic composition

A total of 146 taxa belonging to 41 genera and 17 families were recorded from Kakamega Forest. Out of these 137 species were fully identified to the species level. Eight taxa were identified to the genus level only. One species was further identified to a subspecies level and three species were further identified to a variety level. Five species new to science were discovered. For the sake of simplicity, in the subsequent presentation, all subgeneric taxa (species, subspecies and variety) will be treated as species. The full species list of Kakamega Forest is presented in Appendix 3.

Ninety-two per cent of the lichens recorded from Kakamega Forest were typically foliicolous, 5% were lichenicolous fungi growing on foliicolous lichens, 3% facultative foliicolous and 1% ubiquitous (Fig. 5.8)

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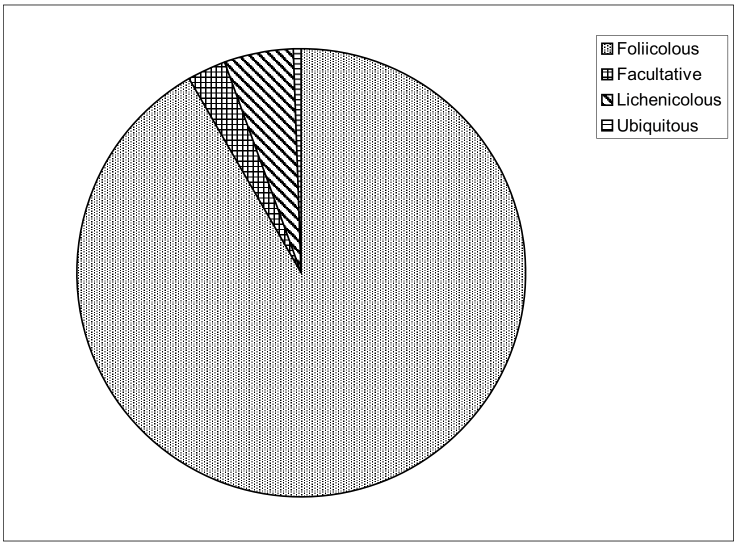


Fig. 5.8 Proportion of typical, facultative, ubiquitous foliicolous lichens and lichenicolous lichens

In Kakamega Forest, Pilocarpaceae was the dominant family both in terms of the number of genera (11) and species (30). The family Porinaceae was the second dominant in terms of the number of species (25) but with only two genera. The family Gomphillaceae comprised 7 genera and 19 species. The family Asterothyriaceae was represented by 3 genera and 12 species. The families Strigulaceae and Coenogoniaceae which have only one genus comprised 14 species and 12 species respectively.

Among the study sites, the highest number of families of foliicolous lichens were recorded from Kisere (14 families) followed by Buyangu, Isecheno, Isiukhu, and Salazar with 13 families each. Eleven families were recorded from Bukhayawa, Busambuli and Kaimosi. From Colobus and Ghostisland 9 families were recorded and the least family was recorded from Camp site (7 families). Fig. 5.9 shows the number of families, genera and species recorded in each forest part of Kakamega.

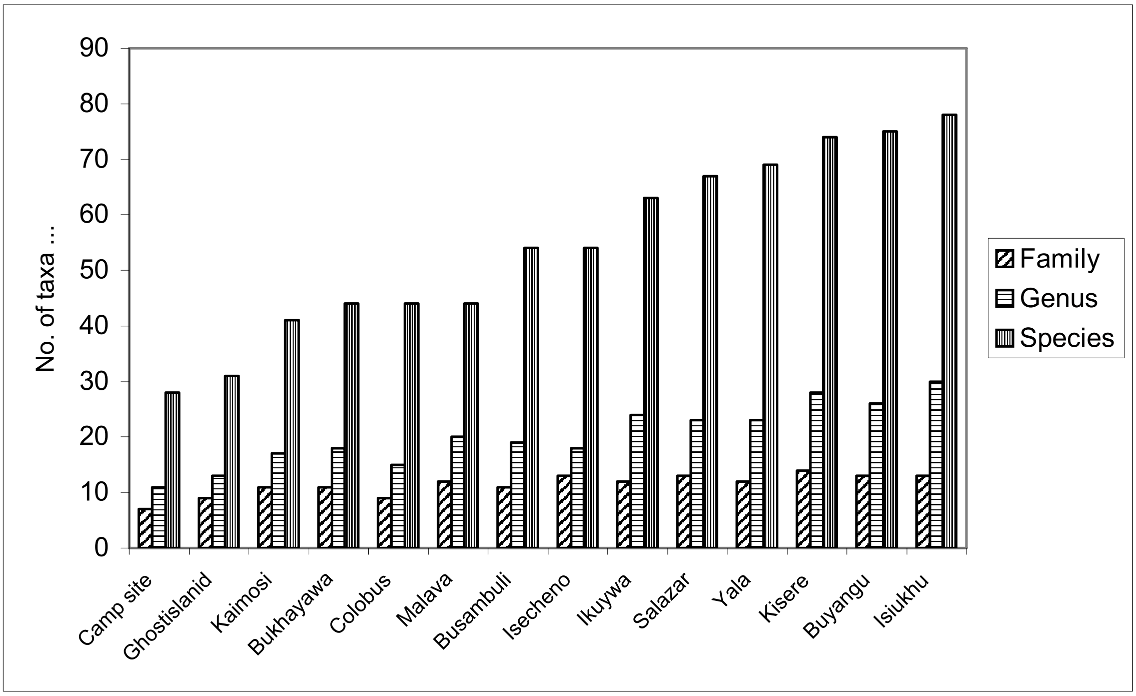


Fig. 5.9 Number of families, genera and species in the study sites of Kakamega Forest

The highest numbers of genera (30) were recorded from Isiukhu, followed respectively by Kisere (28 genera), Buyangu (26 genera), Ikuywa (24 genera), Salazar and Yala (23 genera each), Malava (20 genera), Busambuli (19 genera), and Bukhayawa and Isecheno (18 genera). The lowest number of genera were recorded from Colobus (15 genera), Ghostisland (13 genera) and Camp site (11 genera) (Fig. 5.11).

The highest numbers of species were recorded from Isiukhu (78 species), Buyangu (75 species) and Kisere (74 species). From Yala, Salazar, Ikuywa, and Busambuli, Isecheno 69, 67, 63, 54, and 54 species were recorded respectively. Forty-four species were recorded from Bukhayawa, Colobus, and Malava and the least number of species were recorded from Ghostisland (31 species) and Camp site (28 species).

Certain families of foliicolous lichens dominated both in the number of genera and species in the various study sites of Kakamega (see Figs. 5.10 & 5.11). In the number of species, the family Porinaceae was the most dominant in Bukhayawa, Buyangu, Colobus, Ghostisland, Isecheno, Salazar, Malava and Kaimosi. The family Pilocarpaceae was the most dominant in Busambuli, Kisere, Yala and Ikuywa. In Isiukhu both Porinaceae and Pilocarpaceae were equally dominant. In the Camp site forest, the family Asterothyriaceae was the most dominant.

The family Strigulaceae was the second dominant in Bukayawa, Busambuli, Ghostisland, Isecheno and Malava. In Buyangu and Kaimosi the family Pilocarpaceae was the second dominant. Gomphillaceae was the second dominant family in the Camp site, Isiukhu, and Ikuywa. In Colobus Coenogoniaceae and Strigulaceae were the second dominant while in Salazar Coenogoniaceae was the second dominant. In Kisere and Yala Porinaceae was the second dominant.

The distribution of species in the various forest parts of Kakamega is not uniform. Many species are restricted to some forest parts and not to others. Only seven species were common for the 14 forest parts. These species were *Calenia monospora, Gyalectidium filicinum, Porina epiphylla, P. nitidula, P. rubentior, Trichothelium pauciseptatum* and *Strigula smaragdula.* Seven species recorded from 13 forest parts were *Calopadia fusca, C. puiggarii, Porina cupreola* var. *cupreola, P. subpallescens, Strigula phyllogena* (all absent from Camp site), *Strigula microspora* (absent from Kaimosi), and *S. nitidula* (absent from Ghostisland). *Coenogonium geralense, Byssoloma leucoblepharum, Strigula macrocarpa*, and *Strigula schizospora* were recorded from 12 forest parts, all being absent from Camp site, the first three were absent from Kaimosi and the last species was absent from Bukhayawa. Six species recorded from 12 study sites were *Calenia aspidota* (not recorded from Bukhayawa, Camp site & Malava), *Lyromma nectandrae* (not recorded from Busambuli, Camp site, & Malava), *Bacidina apiahica* (Isecheno, Isiukhu & Yala), *Opegrapha phylloporinae* (not recorded from Camp site, Ghostisland and Salazar), *Strigula obducta* (not recorded from Camp site, Ghostisland and Kaimosi) and *Chroodiscus verrucosus* (not recorded from Bukhayawa, Colobus and Kaimosi).

Twenty-eight species were recorded from one study site only. *Fellhanera parvula, Arthonia flavoverrucosa, Arthonia fuscocyanea, Musaespora kalbii, Porina lucida* var. *lucida* (all recorded from Buyangu only). *Asterothyrium septemseptatum* ssp. *africanum, Asterothyrium* sp., and *Psorotheciopsis gyalideoides* were recorded from Camp site only. *Fellhanera encephalarti, Strigula janeriensis*, and *Chroodiscus australiensis* were recorded from Ikuywa. *Eremothecella calamicola, Aspidothelium geminiparum, A. scutelicarpum, Aderkomyces dilatatus, Aulaxina opegraphina, Calenia* sp., *C. thelotremela, Gyalideopsis cochlearifer*, and *Porina atrocoerulea* were recorded from Isiukhu only. *Arthonia atropunctata, Aspidothelium hirustum* sp. nov., *Byssolecania hymenocarpa* and *Tapellaria nigrata* were recorded from Kisere only. *Lichenopeltella epiphylla* and *Porina pallescens* were recorded from Salazar. *Porina kamerunensis* and *Bacidia medialis* was recorded from Colobus and Malava respectively.

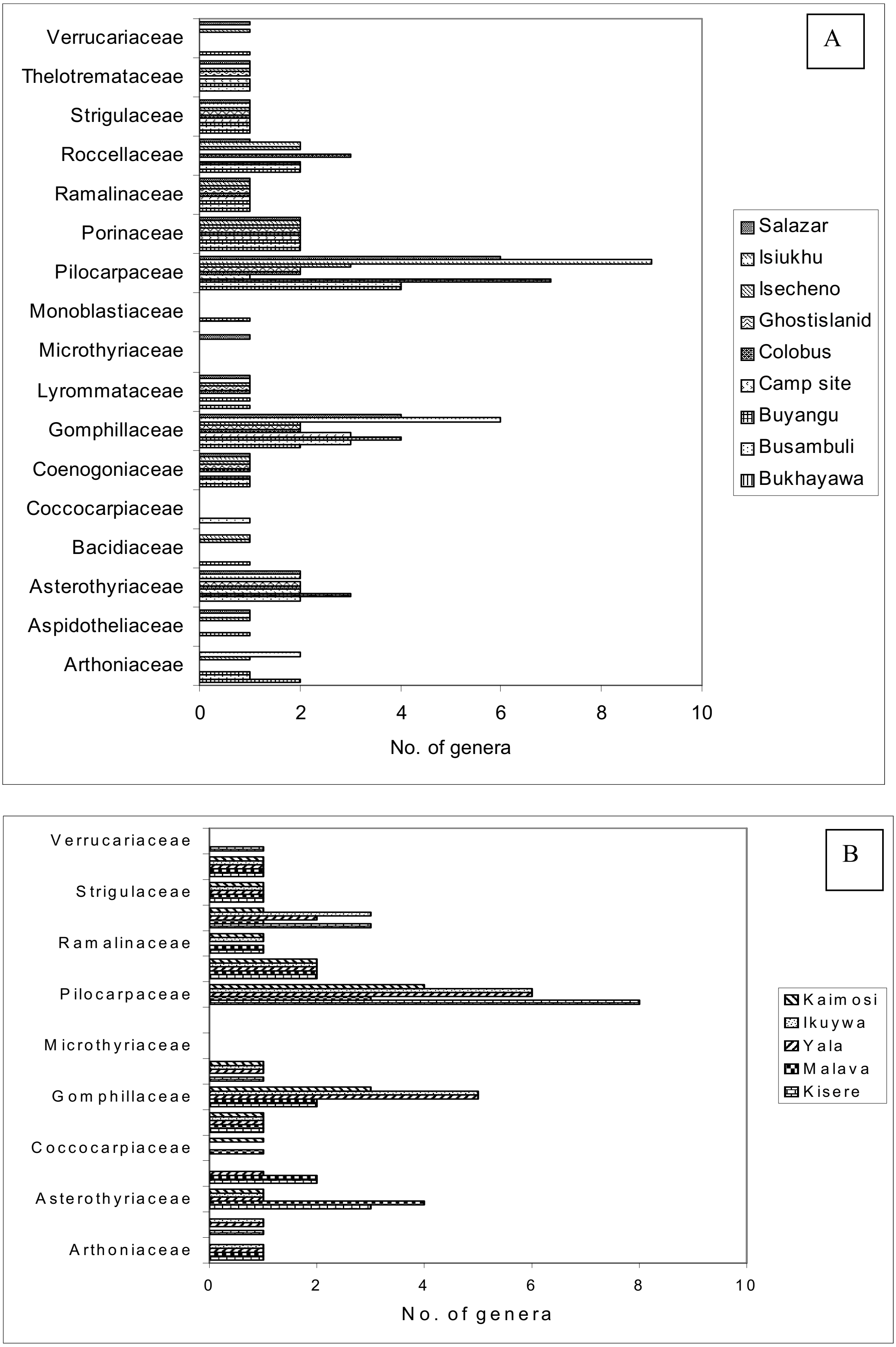
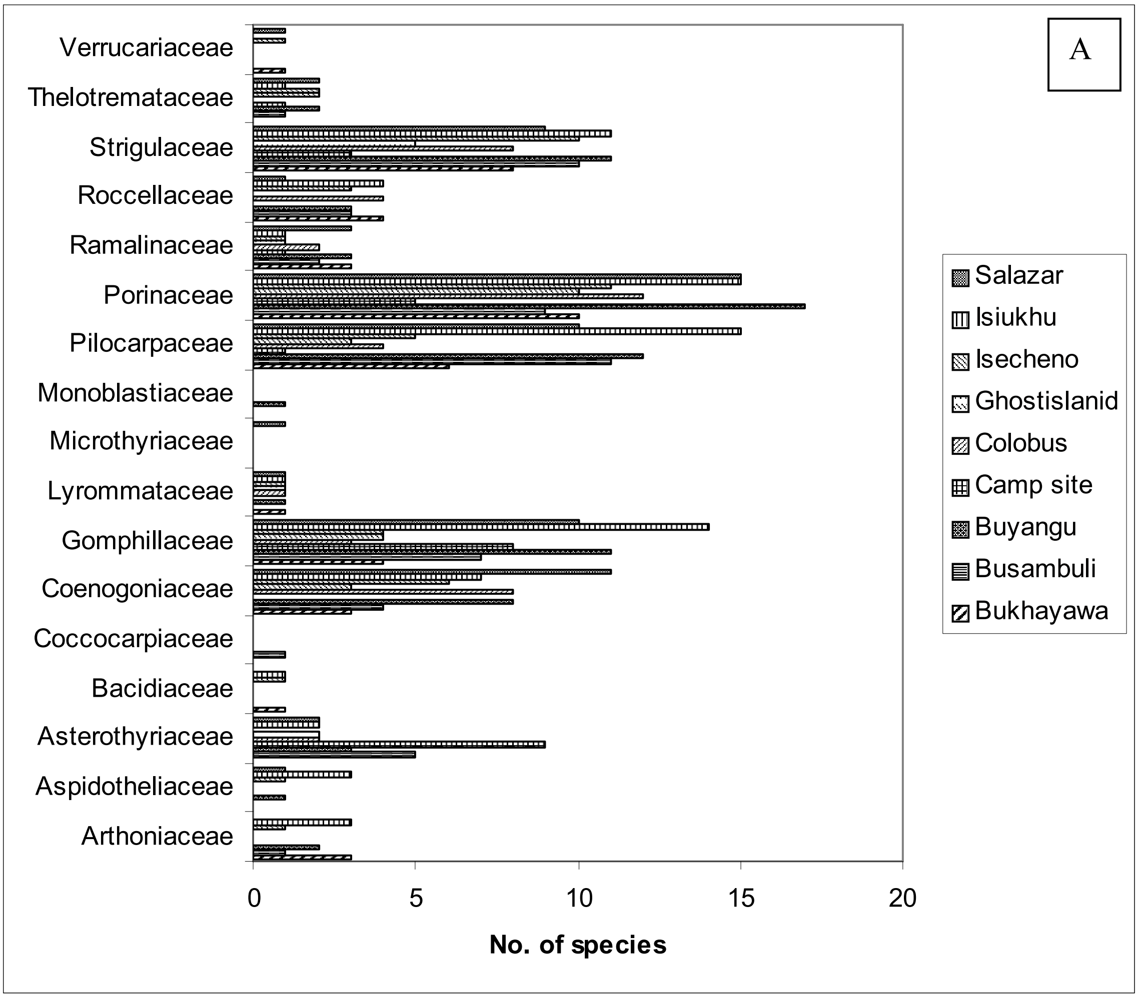


Fig. 5.10 Number of genera per family in the main forests (A) and fragments (B) of Kakamega



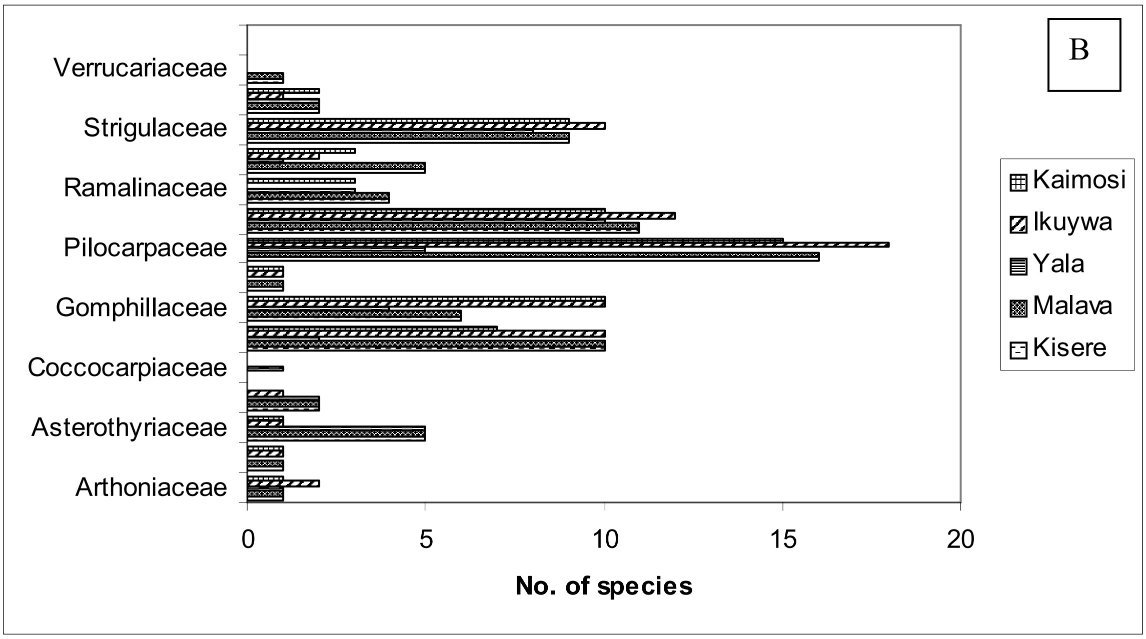


Fig.5.11 Number of species per family in the main forest parts (A) and fragments (B) of Kakamega

5.3.2 Species frequency

The frequency of occurrence of species in the various study sites of Kakamega is presented in Fig. 5.12. In all study sites except in Isecheno, Ghostisland and Kaimosi, species classified as rare constituted the highest proportion. The highest proportion of rare species was recorded from Buyangu (80%). In Isecheno species classified as occasional constituted the highest proportion (31%) and rare species constituted 25% of the whole species. In Ghostisland and Kaimosi, species classified as rare are absent and occasional species have the highest proportion. Species classified as occasional constituted the second largest proportion in Busambuli, Bukhayawa, Camp site, Colobus, Isiukhu, Kisere, Malava and Salazar. Dominant species constituted the second highest proportion only in Bukhayawa.

Porina nitidula is the dominant species in all study sites except in the camp site forest. *Porina epiphylla* is the dominant species in Bukhayawa, Busambuli, Buyangu, Colobus, Isecheno, Isiukhu, Kaimosi, Kisere, Malava, Slazar and Yala. Except in Busambuli, Camp site, Ghostisland, and Kaimosi, *Porina rubentior* is the dominant species in the remaining study sites. *Porina cupreola* var. *cupreola* is the dominant species in Bukhayawa, Ghostisland, Ikuywa, Isiukhu, Kisere, Malava, Salazar and Yala.

Species which are dominant in only one study site were *Asterothyrium rotuliforme* in Camp site, *Bacidina apiahica* and *Coenogonium lisowski* in Malava, *Calenia aspidota, Strigula antilarum* and *S. microspora* in Busambuli, and *Strigula obducta* and *Calopadia puigarii* in Bukhayawa. *Coenogonium geralense* is the only species which became dominant in two forests, in Bukhayawa and Isecheno. The frequency occurrences of all species in the study sites of Kakamega are presented in Appendices 15.

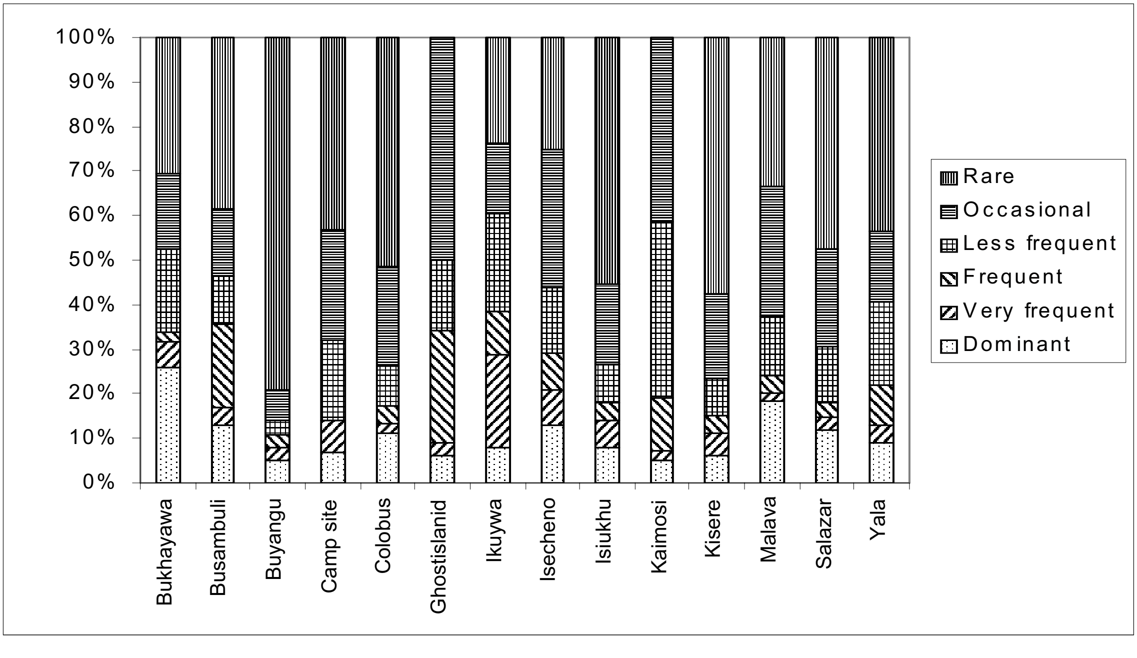


Fig. 5.12 Proportion (%) of species in the various frequency classes in the study sites of Kakamega

5.3.3 New and interesting records and new species of foliicolous lichens

In the course of the present study many new species and new records of foliicolous lichens were discovered. Among the total list of foliicolous lichens and lichenicolous fungi of this study, 5 species are new to science and 75 species are new records for Kenya. In addition three specimens belonging to the genera *Asterothyrium, Calenia* and *Fellhanera* seem to be new to science. However, further collection is needed to verify their identity.

5.3.3.1 Species new to science

1. *Aspidothelium hirsutum* sp.nov. (Aspidotheliaceae)

This new species is described from Godere Forest. The second record of this species was collected from Kakamega Forest. See Fig. 3.9 for pictures of the species.

2. *Chroodiscus kakamegensis* sp.nov. (Thelotremataceae)

Several specimens of this facultative lichenicolous species were collected from Godere, Budongo and Kakamega forests. For the description of the species see section 3.3.3.1.

Specimens examined: Malava fragment of Kakamega Forest, 00^{0}27’.072’’ N and 034^{0}51’542’’, 1630 m, on living leaves of *Peddiea fischeri* Engl., *Strychnos usambarensis* Gilg; 18.8.2006, Kumelachew 433, 434, 436, 438 (KOBL); Kaimosi fragment of Kakamega Forest, 00^{0}07’.743’’ N and 034^{0}50’.458’’ E, 1630 m, on living leaves of *Hippocratea* sp., 19.8.2006, Kumelachew 447 (KOBL); Ghostisland, Kakamega Forest, 00^{0}21’.057’’ N and 034^{0}51’.668’’ E, 1600 m, on living leaves of *Chrysophyllum albidum* G. Don., Kumelachew 477 (KOBL); Isecheno site of Kakamega Forest, 00^{0}14’.522 N and 034^{0} 51’.959’’E, 1580 m, on living leaves of *Heinsenia diervilleoides* K.Schum. and *Dracaena fragrans*, Kumelachew 489 & 491 (KOBL); Kisere fragment of Kakamega Forest, 00^{0}23’.151’’ N and 034^{0}53’.595’’ E., 1580 m, on living leaves of *Diospyros abyssinica*, Kumelachew 541 (KOBL); Salazar, Kakamega Forest, 00019’.935’’ N and 034052.649’’, 1560 m, on living leaves of *Cassipourea ruwensorensis* (Engl.), Kumelachew 578 (KOBL).

3. *Enterographa fellhaneroides* sp. nov. (Roccellaceae) Fig. 5.13A

This new species is closely related to *Enterographa perez-higaredae* described from Mexico (Herrera-Campos & Lücking 2002) in having shortly lirelliform ascomata, excipuloid tissue and hypothecium filled with grayish crystals and hypothecial socle. They differ in the size of apothecia, number of ascospore septa and size of ascospores and asci. Morphologically, *E. fellhaneroides* looks similar to *E. seawardii*, a foliicolous species described in Sparrius (2004) from the Seychelles Islands, because of similar prominent, open, angular-rounded to shortly lirellate ascomata with pale orange discs.

Specimens examined: Kakamega Forest, Kisere fragment, 00^{0}22’.966 N, 034^{0}53’.751 E, 1594 m, on living leaves of *Chrysophyllum albidum* G.Don., 15. 08. 2006, Kumelachew 373 (KOBL); Kisere fragment, 00^{0}23’.151 N, 034^{0}53’.595 E, 1580 m, on living leaves of

Teclea nobilis Del., *Dracaena fragrans* and *Cassipourea ruwenzorensis* (Engl.) Alston, 24 August 2006, Kumelachew 538, 539 & 537 (KOBL); Kakamega Forest, Isecheno, 00^{0}14’.522 N, 034^{0}51’.959 E, 1580 m, on living leaves of *Cassipourea ruwenzorensis*, 21. 08. 2006, Kumelachew 484 & 493 (KOBL).

4. *Enterographa meklitiae* sp. nov. (Roccellaceae) Fig. 5.13B

This new species of *Enterographa* is different from the other species of the genus by the presence of punctiform ascomata arranged in groups in pseudostromata. In the genus this type of ascomata is so far recorded from the lichenicolous fungi *Enterographa epiphylla* (Ertz *et al*. 2005).

Specimen examined: Kakamega Forest, Isecheno, 00^{0}14’.522 N, 034^{0}51’.959 E, 1580 m, on living leaves of *Cassipourea ruwensorensis*, 21 08. 2006, Kumelachew 484 (KOBL).

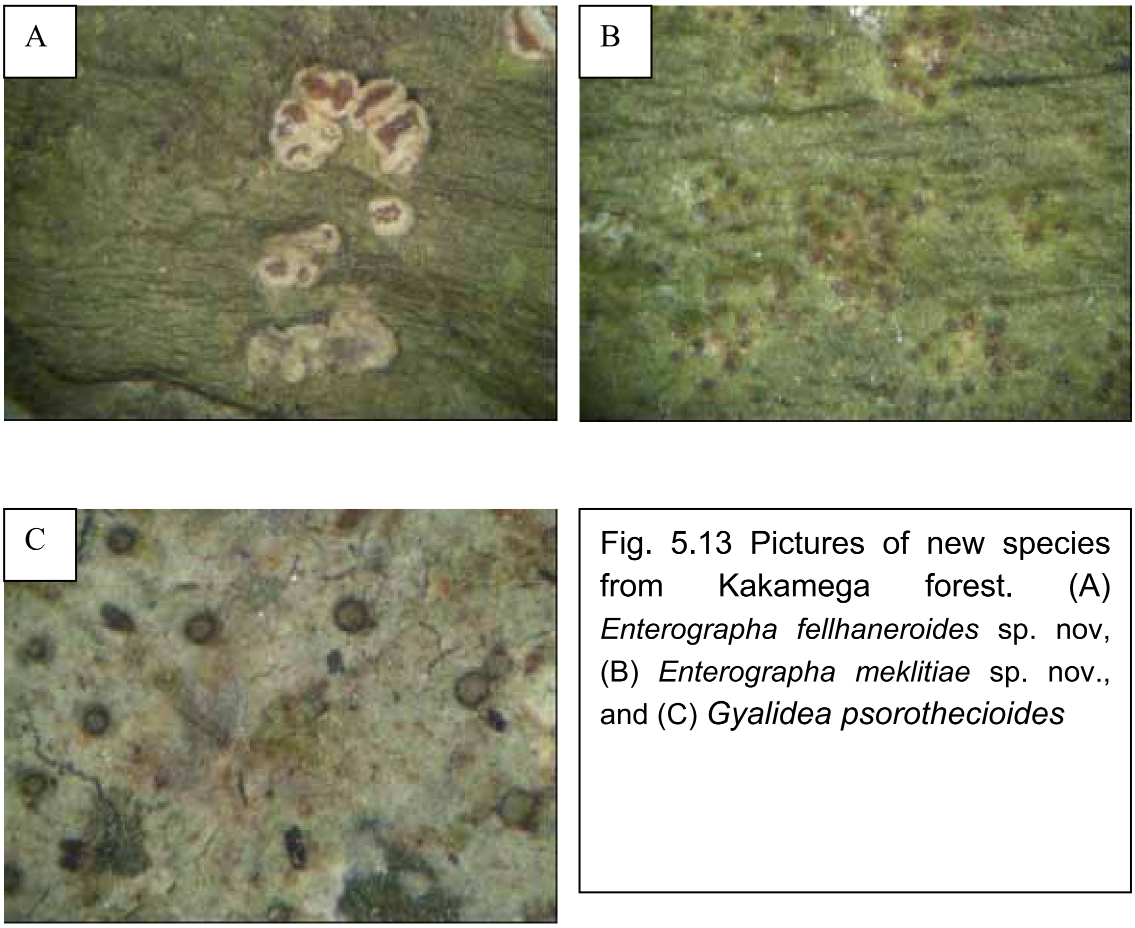


Fig. 5.13 Pictures of new species from Kakamega forest. (A) *Enterographa fellhaneroides* sp. nov, (B) *Enterographa meklitiae* sp. nov., and (C) *Gyalidea psorothecioides*

5. *Gyalidea psorothecioides* sp. nov. (Asterothyriaceae) Fig. 5.13C

This new species is characterized by marginally black apothecia and 1-septate ascospores. The two foliicolous *Gyalidea* (*Gyalidea epiphylla* & *G. phyllophila*) hitherto described have apothecial margin concolorous with the disc and ascospores are 3(4-5)-septate in *G. epiphylla* and 3-6 septate in *G. phyllophila*. The presence of black apothecia margin makes this new species similar to *Psorotheciopsis* (Asterothyriaceae) but unlike the later genus, this new species has no cellular cortex.

Specimen examined: Kakamega Forest (Colobus, Mukangu trail) 00^{0}21’276’’ N and 034^{0}51’519 E, 1609 m, 14.08.2006, on living leaves on *Tiliacora funifera* (Miers) Oliv., Kumelachew 350 (KOBL, holotype).

5.3.3.2 Interesting records of foliicolous lichens

In addition to the above five foliicolous lichen species described as new to science, certain specimens belonging to the genera *Asterothyrium, Calenia, Fellhanera, Strigula* were found to be interesting records which require further collection to identify their taxonomic status.

1. *Asterothyrium* sp. (Asterothyriaceae) Fig. 5.14A

The specimen cited below is an unknown taxon of the genus *Asterothyrium* having a green thallus, typical cortex, 1-septate spores. I presume it is new to science, but the material is scanty to describe it as new species.

Specimen examined: Kakamega Forest, camp site, 00^{0}21.134 N, 034^{0}51.923 E, 1581 m, 20.08.06, Kumelachew 458, (KOBL)

2. *Calenia* sp. (Gomphillaceae) Fig. 5.14B

Thallus is pale green, non dispersed, slightly applanate verrucae, apothecia medium sized, marginally slightly raised, with triangular lobules towards the center, disc grayish, slightly pruinose; ascospores 5-9 septate, 30-40 x 8-10 µm, 4-8 per ascus. The specimen looks like *Calenia obtecta* or *Calenia pernambucensis* to be described by Robert Lücking in Flora Neotropica (Lücking 2008).

3. *Fellhanera* aff. *bouteillei* (Pilocarpaceae) Fig. 5.14C

Fellhanera bouteillei is a ubiquitous species having a bluish white to bluish gray thallus, apothecia disc pale flesh-coloured to yellowish, margin indistinct and ascospores 10-15(-18) x 3-5(-6) µm (Santesson 1952). The specimens cited below are close to *Fellhanera bouteillei* but with some differences. Thallus green, rather coherent, apothecia medium sized, pale orange to brownish orange, with a thin but distinct margin, spores 1-septate, 18-25 x 4-4.5 µm.

Specimens examined: Kakmega forest, Ikuywa, 00^{0}12.628 N, 034^{0}55.931 E, 1550 m, epiphyllous on *Dracaena fragrans* and *Teclea nobilis*, 23.08.06, Kumelachew 190 & 192 (KOBL).

4. *Sporopodium* sp. (Pilocarpaceae) Fig. 5.14D

Three collections from Kisere and Isiukhu forests of Kakamega were close to *Sporopodium leprieurii* but the thallus of these specimens are smooth.

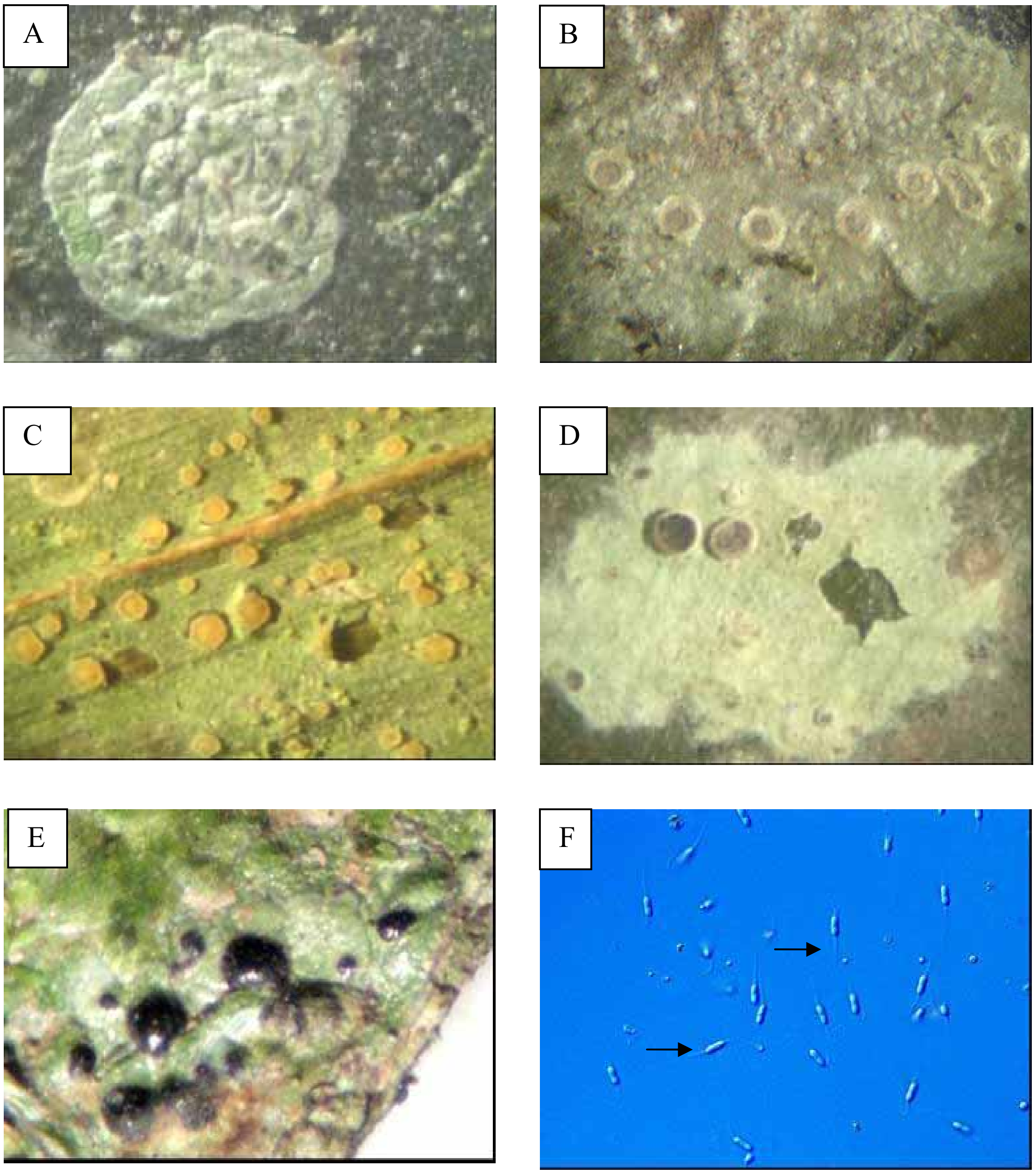


Fig. 5.14 Some interesting species of foliicolous lichens from kakamega forest. (A) *Asterothyrium* sp., (B) *Calenia* sp., (C) *Fellhanera* aff. b*outeillei,* (D) *Sporopodium* sp., (E) *Strigula microspora,* (F) Conidia with appendages (arrows) of *Strigula microspora*

5. Strigula microspora **(Strigulaceae) Fig. 5.14E & Fig. 5.15F**

The specimen of *Strigula microspora* cited below has got microconidia with long appendages on both ends. Like the typical species, the microconidia are 1-septate, bacilliform, 5 x 1.5 µm. Ascospores are 10-12 x 2.5-3 µm. In the description of *Strigula microspora* by Lücking (1991), there is no mention of presence of appendages on conidia.

Specimen examined: Kakamega Forest, Kisere, $00^0$23.053 N, $034^0$53.562 E, 1580 m, epiphyllous on *Rawsonia lucida*, 24.08.06, Kumelachew 547 (KOBL).

5.3.2 Alpha diversity

5.3.2.1 Mean species number

Species richness per sample of the various forest parts of Kakamega is variable ranging from a mean of 5.1 species to a mean of 17.4 species. The mean species number per sample is highest in Ikuywa and lowest in Camp site (Fig. 5.15). Kruskall-Wallis test of analysis of variance showed the presence of significant difference among the medians of species number among the various forest parts (Kruskall-Wallis Chi-square =61.8, P<0.05). To determine which medians were significantly different from which others, the Kruskal-Wallis multiple comparison test was performed. The result of this analysis is presented in Table 5.3.

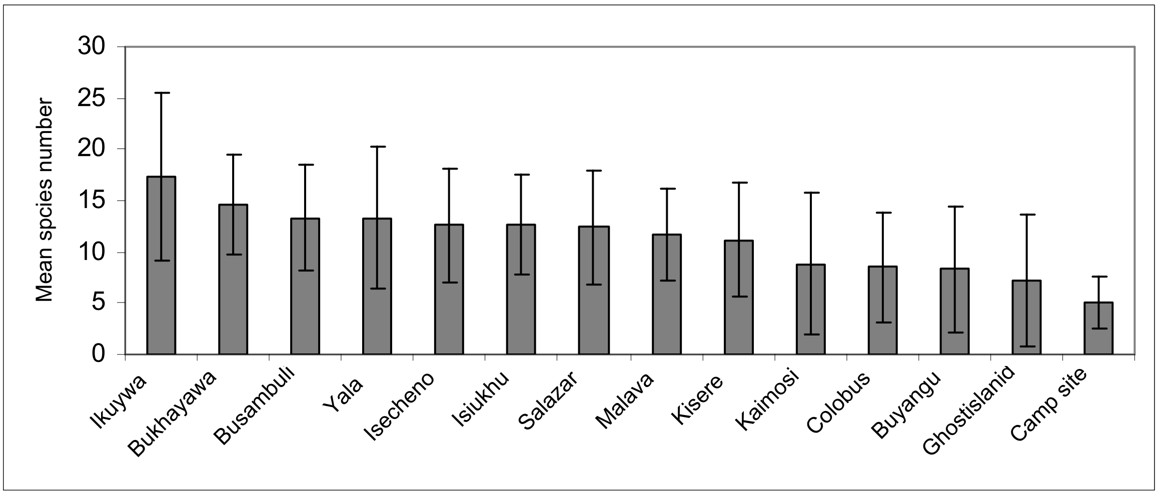


Fig. 5.15 The mean species number per study site in Kakamega Forest (values are mean ± SD).

Except with Ghostisland and Kaimosi, the mean species number of Camp site forest is significantly different from the mean of the other forest parts. Buyangu is significantly different from Ikuywa, Bukhayawa, Busambuli, Yala, Isecheno, Isiukhu, Salazar, Malava, and Kisere. Colobus is significantly different from Ikuywa, Bukhayawa, Busambuli, Yala, Isecheno, Isiukhu, and Salazar. Ghostisland is significantly different from Ikuywa, Yala, Isecheno, Isiukhu, Salazar, and Malava. Isiukhu, Kaimosi and Kisere are significantly different from Ikuywa.

Table 5.3 Kruskal-Wallis Multiple-Comparison test between medians of species numbers of the study parts of Kakamega Forest. * significant (P<0.05), ns= not significant

	Bukhayawa	*Busambuli*	*Buyangu*	*Camp site*	*Colobus*	*Ghostisland*	*Ikuywa*	*Isecheno*	*Isiukhu*	*Kaimosi*	*Kisere*	*Malava*	*Salazar*
Busambuli	ns	-											
Buyangu	*	*	-										
Campsite	*	*	*	-									
Colobus	*	*	ns	*	-								
Ghostisland	*	*	ns	ns	ns	-							
Ikuywa	ns	ns	*	*	*	*	-						
Isecheno	ns	ns	*	*	*	*	ns	-					
Isiukhu	ns	ns	*	*	*	*	*	ns	-				
Kaimosi	*	*	ns	ns	ns	ns	*	ns	ns	-			
Kisere	*	ns	*	*	ns	ns	*	ns	ns	ns	-		
Malava	ns	ns	*	*	ns	*	ns	ns	ns	ns	ns	-	
Salazar	ns	ns	*	*	*	*	ns	ns	ns	ns	ns	ns	-
Yala	ns	ns	*	*	*	*	ns	ns	ns	ns	ns	ns	ns

5.3.2.2 Species accumulation curve

Species accumulation (rarefaction) curves were plotted for the foliicolous lichens observed from each study site in Kakamega Forest (Fig. 5.16). The curves show the mean number of species for each sample accumulated. Since the unit of the x-axis is number of samples, the resulting rarefaction curves are measures of species density (Gotelli & Colwell 2001). The 95% confidence intervals of the respective curves allow to test if there is significant difference in species richness among the study sites (Table 5.4).

Foliicolous lichen species richness is significantly higher in Isiukhu, Kisere, Buyangu, Yala and Salazar than the remaining study sites. However, Ikuywa is not significantly different from Isiukhu and Yala. Species richness is significantly higher in Ikuywa than in Bukhayawa, Busambuli, Isecheno, Kaimosi, Malava and Colobus. Similarly, there is significantly higher species richness in Isecheno and Bukhayawa than in Colobus and Ghostisland. Species richness is also significantly higher in Kaimosi than in Ghostisland. The foliicolous lichen species richness of Camp site is significantly lower than all the other study sites.

Table 5.4 Significance of species richness differences at 95% confidence limit. ns = not significant, * = significant difference in species richness

	Bukhayawa	Busambuli	Buyangu	Camp site	Colobus	Ghostisland	Ikuywa	Isecheno	Isiukhu	Kaimosi	Kisere	Malava	Salazar
Busambuli	ns	-											
Buyangu	ns	ns	-										
Camp site	*	*	*	-									
Colobus	*	*	ns	*	-								
Ghostisland	*	*	ns	*	ns	-							
Ikuywa	*	*	*	*	*		-						
Isecheno	ns	*	ns	*	*	*	*	-					
Isiukhu	ns	ns	ns	*	*	*	ns	*	-				
Kaimosi	ns	ns	ns	*	ns	*	*	ns	*	-			
Kisere	ns	ns	ns	*	*	*	*	ns	ns	*	-		
Malava	ns	*	ns	*	ns	ns	*	ns	*	ns	ns	-	
Salazar	ns	ns	ns	*	*	*	*	ns	ns	*	ns	ns	-
Yala	ns	ns	ns	*	*	*	ns	ns	ns	*	ns	*	ns

The species accumulation curves could be used to compare the observed species richness of sites at similar sample size (usually the smallest). Comparison of the expected species richness of the study sites of Kakamega by the rarefaction curve after 9 samples (the sample size of Ghostisland and Kaimosi) provided a mean species richness of 56.3 for Ikuywa, 49.8 for Isiukhu, 49.5 for Yala, 46.8 for Busambuli, 43.3 for Salazar, 42.3 for Kisere, 41.6 for Bukhayawa, 41 for Kaimosi, 39.7 for Isecheno, 37.5 for Buyangu, 35.7 for Malava, 32.5 for Colobus, 32 for Ghostisland and 20.7 for Camp site forest.

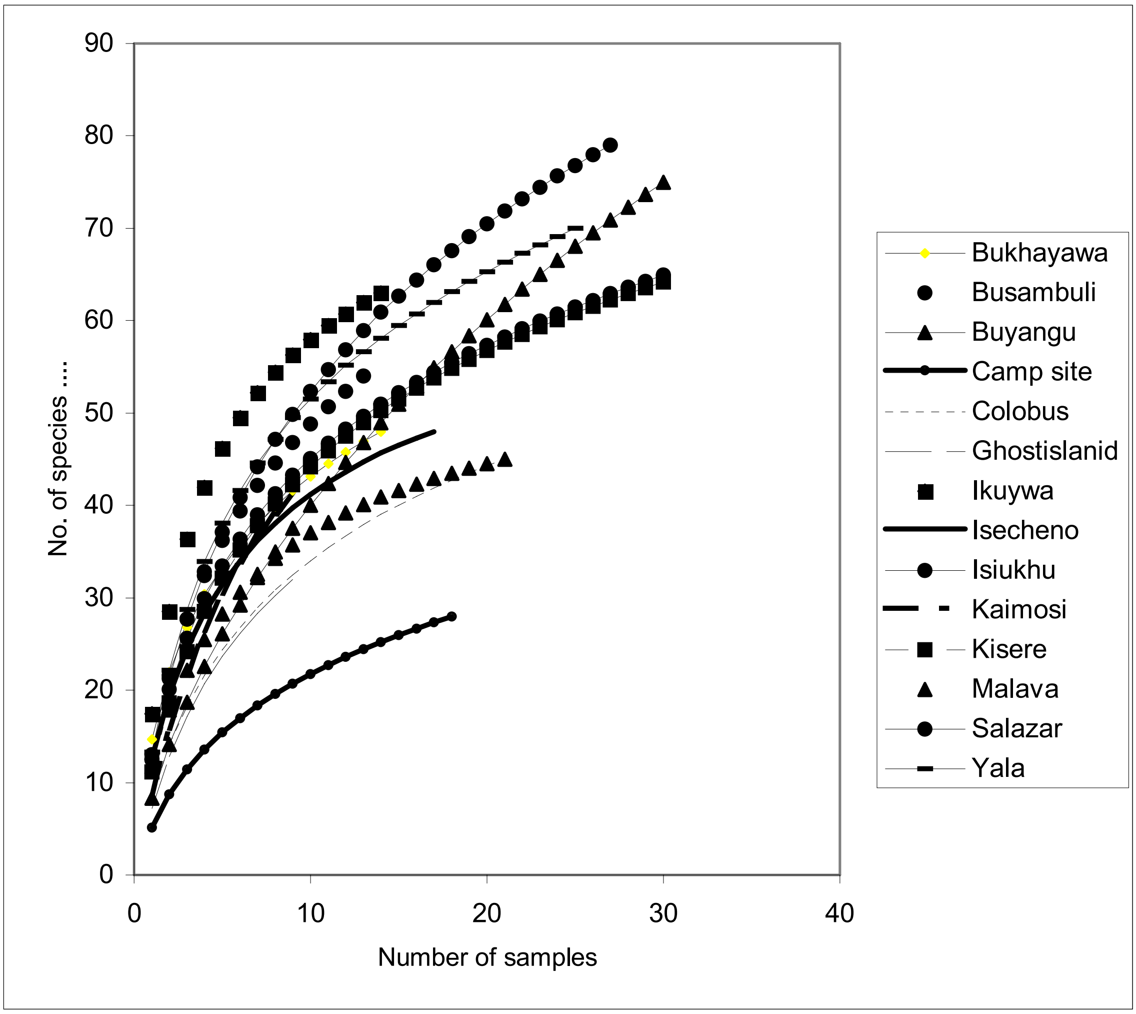


Fig. 5.16 Species accumulation curve (rarefaction) of the foliicolous lichens in the study sites of Kakamega Forest.

5.3.2.3 Estimation of species richness

The various non-parametric species richness estimators for incidence data provided different values for the estimate of the species richness of the study sites of Kakamega Forest (Table 5.5). In Bukhayawa, Busambuli, Camp site, Colobus, Ghostisland, Ikuywa, Isecheno, Isiukhu, Kaimosi, Malava, Salazar and Yala, the second order Jackknife estimator provided the highest estimate of species richness. In Buyangu and Kisere the ICE and Chao 2 provided the highest estimate respectively. The Bootstrap estimator provided the lowest estimate of species richness for Bukhayawa, Busambuli, Buyangu, Camp site, Colobus, Ghostisland, Ikuywa, Isiukhu, Malava and Yala. In Isecheno both the Bootstrap and Chao 2 estimators provided the lowest estimation and the Michalis-Menten Mean provided the lowest estimate of species richness for Kisere and Salazar. The difference between the highest and lowest richness estimator varied from 11.5 species (in Isecheno) to 52 species (in Kisere). The highest difference for Kisere is due to the very high Chao 2 estimate.

Table 5.5 Number of samples, number of individuals and species richness (with standard deviation for some) estimate values for the study sites of Kakamega

	No. of samples	No. of individuals	S_{obs}	MMMeans	Chao 2	Jack 1	Jack 2	Bootstrap	ICE	Degree of collection (%)
Bukhayawa	14	204	48	56	62.1±9.6	61.9±4.4	68.5	54.5	63.8	70 –88
Busambuli	13	173	54	71.1	81.6 ±16.4	73.4±6.2	85	62.3	75.4	64 –87
Buyangu	30	249	75	100.2	136.6 ±27.1	113.7 ±12.4	139.3	91.4	148.7	50 –82
Camp site	18	92	28	36.7	52±20.2	39.3±3.6	47.5	32.8	43.9	54 –85
Colobus	21	177	45	56	59.1±9.6	59.3±4.6	66	51.7	60.2	68- 87
Ghostisland	9	65	32	55.5	49.8±12	46.2±5.9	55.3	38.3	50	58-84
Ikuywa	14	243	63	78.3	71.9±6.2	76.9±4.6	81.9	69.8	72.3	77-90
Iaecheno	17	214	48	57.2	53.7±4.5	59.3±3	61.6	53.7	57	78-89
Isiukhu	27	339	79	95.2	107±13.7	106.9±4	120.4	91.7	113	70 –86
Kaimosi	9	79	41	77.2	48.1±4.8	56.1±5.6	58.4	48.7	55.9	53 -85.2
Kisere	55	613	77	81.5	181.2 ±73.9	101.6 ±6.1	122.8	86.9	101.4	43-95
Malava	21	246	45	54.1	52.1±6.1	54.5±2.6	59.3	49.6	51.3	76-91
Salazar	37	461	69	75.3	91.2 ±13.3	88.5±5.1	99.1	77.7	87.7	70-92
Yala	25	332	70	82.3	96.9 ±15.5	91.1±5.6	103.4	79.4	89.2	68-88

5.3.2.4 Shannon-Wiener diversity

The Shannon-Wiener diversity and evenness values for the study sites of Kakamega Forest is presented in Table 5.6. Analysis of variance (ANOVA) of the Shannon diversity index values of the study sites confirmed the presence of significant differences (F=2.91, $p<0.001$). Fischer's least significant difference *post hoc* test (Table 5.7) showed that Shannon diversity of Camp site (H'=2.97) is not significantly different from Colobus (H'=3.42), Ghostisland (H'=3.29) and Malava (H'=3.42) but significantly lower than the Shannon diversity of the other forest parts. The highest value of Shannon diversity is computed for Isiukhu but it was not significantly different from Bukhayawa, Busambuli, Buyangu, Ikuywa, Isecheno, Kaimosi, Kisere, Salazar, and Yala. Shannon diversity of Colobus is significantly lower than those of Ikuywa, Isiukhu, Kisere and Yala. Similarly Shannon diversity of Ghostisland is significantly lower than those of Ikuywa, Isiukhu, and Yala. Shannon diversity of Malava is also significantly lower than the diversity of Ikuywa, Isiukhu, Kisere and Yala.

Table 5.6 Shannon diversity (H') and evenness (J') values of the study sites

	Shannon index (H')	Shannon evenness index (J')
Bukhayawa	3.53	0.91
Busambuli	3.69	0.93
Buyangu	3.71	0.86
Camp site	2.97	0.89
Colobus	3.42	0.89
Ghostisland	3.29	0.94
Ikuywa	3.93	0.95
Isecheno	3.52	0.91
Isiukhu	3.92	0.89
Kaimosi	3.57	0.96
Kisere	3.8	0.88
Malava	3.42	0.89
Salazar	3.73	0.88
Yala	3.87	0.91

Table 5.7 Fischer's least significant difference (LSD) multiple comparison of Shannon diversity index values among the study sites. ns= not significant, * = significant ($p<0.001$)

	Bukhayawa	Busambuli	Buyangu	Camp site	Colobus	Ghostisland	Ikuywa	Isecheno	Isiukhu	Kaimosi	Kisere	Malava	Salazar
Busambuli	ns	-											
Buyangu	ns	ns	-										
Camp site	*	*	*	-									
Colobus	ns	ns	ns	ns	-								
Ghostisland	ns	ns	ns	ns	ns	-							
Ikuywa	ns	ns	ns	*	*	*	-						
Isecheno	ns	ns	ns	*	ns	ns	ns	-					
Isiukhu	ns	ns	ns	*	*	*	ns	ns	-				
Kaimosi	ns	ns	ns	*	ns	ns	ns	ns	ns	-			
Kisere	ns	ns	ns	*	*	ns	ns	ns	ns	ns	-		
Malava	ns	ns	ns	ns	ns	ns	*	ns	*	ns	*	-	
Salazar	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	-
Yala	ns	ns	ns	*	*	*	ns	ns	ns	ns	ns	*	ns

5.3.3 β-diversity and similarity in species composition

Total β-diversity measured by Whittaker's index of β-diversity (β_w) for the study sites of Kakamega is presented in Table 5.8. This index of β-diversity is a measure the degree of turnover or species changes. The highest species turnover is seen in Buyangu (β-diversity=9). The next highest species turnover is found in Kisere (β-diversity = 6.9) and Isiukhu (β-diversity = 6.3) respectively. The lowest turnover is registered in Bukhayawa (β-diversity = 3.3).

Table 5.8 Total β-diversity values along the study sites of Kakamega

	Number of species (a)	Mean species number per sample (b)	β-diversity (a/b)
Buyangu	75	8.3	9.0
Kisere	77	11.2	6.9
Isiukhu	79	12.6	6.3
Salazar	69	12.4	5.6
Camp site	28	5.1	5.5
Yala	70	13.3	5.3
Colobus	45	8.5	5.3
Kaimosi	41	8.8	4.7
Ghostisland	32	7.2	4.4
Busambuli	54	13.3	4.1
Isecheno	48	12.6	3.8
Malava	45	11.7	3.8
Ikuywa	63	17.4	3.6
Bukhayawa	48	14.6	3.3

Analysis of β-diversity among the study sites based on Sørensen index of similarity is presented in Table 5.9. The values of the Sørensen index varied from 0.27 to 0.81 indicating variation in β-diversity among the study sites. High similarity, and thus low β-diversity, is observed between forests of different succession stages like the middle-aged secondary and the old secondary forest sites e.g. Salazar and Yala (S_s=0.81) and Ikuywa and Yala (S_s=0.78); the near-primary forest of Kisere and the old secondary forest of Yala (S_s=0.69). High similarity (low β-diversity) is also observed between forests of similar development stages, e.g. between the middle-aged secondary forests of Salazar and Buyangu (S_s=0.72) and Salazar and Ikuywa (S_s=0.7). Low β-diversity could also be seen between the young secondary forest of Isiukhu and middle-aged secondary forest of Buyangu (S_s=0.69). The lowest similarity in species composition, and thus high β-diversity is observed between the young secondary Camp site forest and the middle-aged secondary forest of Salazar (S_s=0.27) as well as between the young secondary forests of Camp site and Isiukhu (S_s=0.28). In general, the Camp site forest shows the least similarity with all other forest sites.

Table 5.9 Values of Sørensen index of similarity among the study sites

	Bukhayawa	Busambuli	Buyangu	Camp site	Colobus	Ghostisland	Ikuywa	Isecheno	Isiukhu	Kaimosi	Kisere	Malava	Salazar
Busambuli	0.61	-											
Buyangu	0.55	0.56	-										
Camp site	0.37	0.46	0.37	-									
Colobus	0.69	0.59	0.53	0.30	-								
Ghostisland	0.53	0.51	0.54	0.50	0.62	-							
Ikuywa	0.58	0.63	0.65	0.40	0.63	0.55	-						
Isecheno	0.63	0.53	0.55	0.29	0.66	0.63	0.63	-					
Isiukhu	0.54	0.59	0.69	0.28	0.55	0.40	0.62	0.55	-				
Kaimosi	0.47	0.57	0.52	0.38	0.56	0.58	0.58	0.58	0.43	-			
Kisere	0.62	0.6	0.62	0.32	0.66	0.51	0.66	0.67	0.60	0.53	-		
Malava	0.67	0.65	0.53	0.49	0.62	0.65	0.59	0.65	0.45	0.56	0.62	-	
Salazar	0.56	0.54	0.72	0.27	0.6	0.53	0.7	0.68	0.61	0.56	0.67	0.53	-
Yala	0.54	0.58	0.65	0.29	0.57	0.49	0.78	0.66	0.64	0.52	0.69	0.52	0.81

5.3.4 Ordination

The PCA ordination of the forest sites of Kakamega Forest is presented in Fig. 5.17. The first four axes of PCA explain 51.6% of the total variation in species composition. The first two axes explain 32.4% of the total variation. The first axis alone contributes to 18.9% of the total variation. Therefore, the highest variation is explained by the first PCA axis.

In the ordination diagram, forest sites that are close to each other are more related in species composition. Forest sites with high species diversity are positively correlated with the first PCA axis and sites with low diversity are negatively correlated with this axis. Forest sites with high disturbance are positively correlated with the second PCA axis and sites with low disturbance are negatively correlated with this axis. The ordination diagram shows that the Camp site and Isiukhu forest sites are different from the other forest sites and explain much of the variation in the data set. Like Yala, Salazar, Ikuywa, Kisere and Buyangu forest sites, Isiukhu has high species diversity and is positively correlated with the first PCA axis. Like the Camp site forest site, it is a disturbed forest and is positively correlated with the second PCA axis.

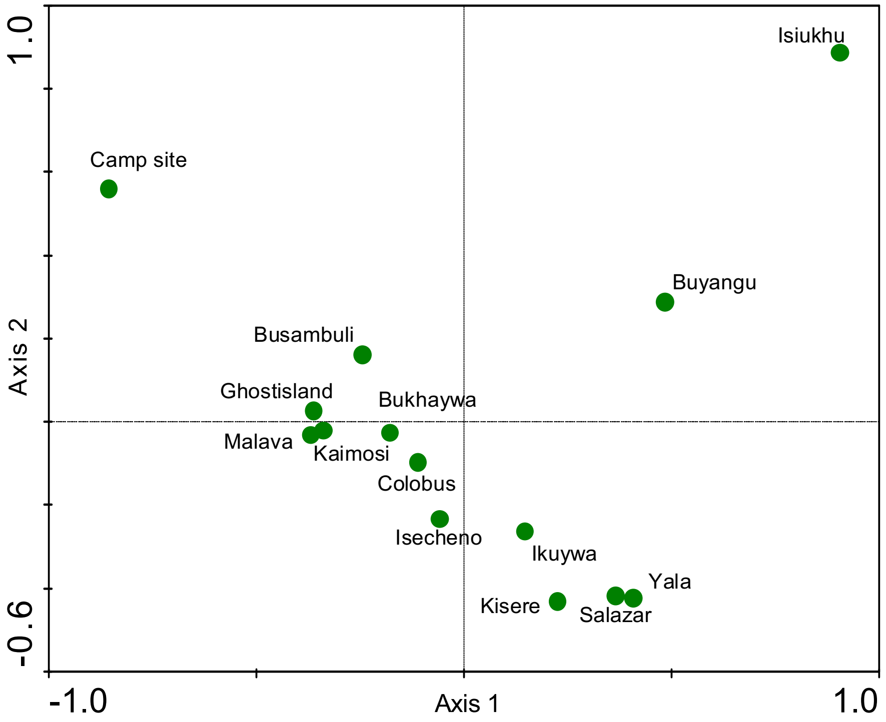


Fig. 5.17 PCA ordination of the study sites of Kakamega Forest.

5.4 Discussion

5.4.1 Sufficiency of sample size

Complete enumeration of all species of a given community is difficult for many organisms. Therefore, the most important question in sampling is the sufficiency of sample size. This is evaluated in this study with the help of a species accumulation curve and comparison with the species richness estimated by the various non-parametric richness estimators. Except for the species accumulation curves for Buyangu and Isiukhu which are rising as more samples are pooled, the curves for the other forests are leveling off and the rate of species accumulation as samples are successively pooled is highly reducing.

One of the reasons for estimating species richness is to know how much of the species richness estimated were observed in the sampling, i.e. how much is the degree of collection of a site. Accordingly, on average 64 up to 88% of the foliicolous lichens estimated by the various richness estimators have been collected from the study sites of Kakamega. Heck *et al.* (1975) reported that collection of 50% to 75% of the total number of species known to occur in a given area is satisfactory. In Kisere only 42.5% of the maximum estimated species richness was collected. However 94.5% of the minimum estimates species richness was collected.

5.4.2 Alpha-diversity

Lücking and Kalb (2002) reported 92 species of foliicolous lichens and 5 species of lichenicolous fungi from Kenya. In the present study, 53 of the species already reported have been encountered in Kakamega Forest. In addition, 77 new records of foliicolous lichens including 3 lichenicolous fungi and 5 species new to science are reported from this study, raising the number of foliicolous lichens of Kenya to 171 and the number of lichenicolous fungi to 8. As far as my knowledge is concerned, this is the highest number of foliicolous lichens so far recorded for a single country in tropical Africa. Reported numbers of foliicolous lichens include 161 species from Ivory Coast, 124 species from Guinea, 124 species from DR Congo (Santesson & Lücking 1999) and 144 species from Tanzania (Pócs 1978, Farkas 1987, Farkas & Vězda 1987, Farkas 1991, Farkas & Vězda 1993, Feuerer 2007)

High family, generic and species diversity was mostly observed in the forests with low level of disturbances in both the near-primary (Kisere), old aged secondary forest site (Yala) and middle-aged secondary forest sites (Ikuywa, Salazar and Buyangu). In addition high diversity was also recorded in the disturbed forest site of Isiukhu. Low diversity, on the other hand, was observed in the old secondary forest of Ghostisland, the middle-aged secondary forest of Colobus, the logged and planted forests of Kaimosi and Malava and the disturbed young secondary forest of Camp site. Forest sites where high species diversity were recorded have relatively closed canopy (e.g. Yala, Buyangu, Kisere) and forest sites with lower diversity have open or semi-open canopy (e.g. Malava, Kaimosi). The high diversity at Isiukhu is due to the existence of both semi-open and closed canopy forests.

The observed species number of a community is mostly biased (Brose *et al.* 2003) and excludes rare species, underestimating the true species richness (Palmer 1990, Baltanás 1992). Species accumulation curves and non-parametric estimators reduce this bias (Soberón &Llorente 1993, Colwell & Coddington 1994). The estimation of the expected species richness of the study sites by rarefying all study sites down to the smallest sample size indicated high species richness in forests of different seral and/or disturbance stages. High species richness was respectively estimated for Ikuywa, Isiukhu, and Yala (Fig. 5.24). Low richness was respectively estimated for Colobus, Ghostisland and Camp site. In general, the species accumulation curves estimated high foliicolous lichen species richness for forest sites with low level of disturbance and low species richness for forest sites with high level of disturbance. Isiukhu is the only forest with high level of disturbance but with high expected species richness.

Various studies (Sérusiaux 1989, Lücking 1992b, Aptroot 1997, Lücking 1998b) have reported high foliicolous lichen diversity in undisturbed primary forests and low diversity in disturbed and secondary forests. In the present study high foliicolous lichen species diversity was recorded both in a near-primary, slightly disturbed forest site of Kisere; old secondary, slightly disturbed forest site of Yala; middle-aged secondary, slightly disturbed forest sites of Salazar and Ikuywa; middle-aged, intermediately disturbed site of Buyangu and a highly disturbed young secondary forest site of Isiukhu. Although Isiukhu is a disturbed forest, there are parts with closed forest creating shady understorey and light gap microsite conditions. In addition, the riverine atmosphere and the relatively high humidity inside the forest provide suitable microclimatic conditions for many foliicolous lichens. As a result characteristic foliicolous lichens of the various light regimes are well represented in Isiukhu making this forest type one of the highest in foliicolous lichen diversity in Kakamega. In the Buyangu study site forests with closed canopy and semi-open canopy have been observed. As a result of diversity of microsites in this forest, the species diversity is also high. Low species diversity was observed in forest sites with relatively high disturbance (Camp site, Malava, Kaimosi) and in Ghostisland. Although Ghostisland is said to be an old secondary forest with little disturbance (Althof 2005), signs of human disturbance and canopy openings were seen in several places.

The results from this study show that the effect of disturbance on foliicolous lichen diversity is dependent on the type, frequency and intensity of disturbance (Petraitis *et al.* 1989). The diversity of foliicolous lichens is dependent on the availability of different microsite conditions (Lücking 1997d). If disturbance maintains or enhances the whole microsite gradient of a forest (e.g. Isiukhu) then there would be high foliicolous lichen diversity. Contrarily, if disturbance results severe change in microclimatic conditions and loss of microsites (e.g. Camp site) then diversity of foliicolous lichens would be reduced. Due to an open canopy in the Camp site forest, the intensity of light reaching the understorey is high and this reduces the humidity inside the forest. Althof (2005) recorded the lowest humidity (21.7%) in this forest type. The most affected by the increased light intensity and reduced atmospheric humidity are shady understorey species. Many of the foliicolous lichens recorded from the understorey of Camp site forest are canopy specialists which have made use of the increased light condition. In Kaimosi, Bukhayawa, Busambuli, and Malava because of high disturbance, the forest canopy is open in many places affecting shady understorey species. In these forests light gap species constituted the highest proportion.

5.4.3 Non-parametric species richness estimators

The speed with which the species accumulation curve of an estimator reaches an asymptote as sample sizes increases indicates the usefulness of an estimator (Colwell & Coddington 1995). The Michaelis-Menten Means is the only estimator that appeared to reach an asymptote (curves not shown). The curves of Jack 1 and Bootstrap estimators, though not clearly approaching an asymptote, are leveling off and predicted comparable species number to the MMMeans. The Chao 2 and ICE estimators did not seem to be a good estimator as they estimated high species richness when fewer samples were pooled and the curves did not stabilize. The curve for the second order Jackknife estimator is rising as more samples were accumulated. Except the Bootstrap estimator, all the other estimators of Buyangu predicted high species richness than the observed species. This is due to the high number of uniques (species restricted to one sample only) which constituted 53% of the whole species.

The variation in the number of species estimated by the species richness estimators is due to the dependence of the non parametric estimators on rare species (uniques and doubletons). In Kisere, for example, based on 77 observed species, the estimators estimated as low as 82 species and as high as 181 species. Based on the highest estimate 2.4 times more species is expected from this forest site, which is an unreliable estimate. This is due to the high number of uniques which accounted for 32.5% of the whole species. Therefore, for the comparison of species richness of forest sites the rarefaction method is more reliable than the species richness estimators.

5.4.4 β-diversity

Total β-diversity, computed by dividing the observed number of species of a study site by the mean number of species, is generally low suggesting low species turnover in the study sites of Kakamega. A relatively high turnover could only be seen for Buyangu (β-diversity = 9.0).

There is a wide variation in the values of Søresnson's index (S_s =0.27-0.81), indicating variation in species composition (β-diversity). The lowest species similarity and thus highest β-diversity is to be observed between Camp site forests and the remaining forests. Since the camp site forest is very disturbed having open canopy, many species which are restricted to canopy of closed forests have grown in the understorey. Furthermore, shady understorey species which are abundant in the other forest types are scarcely represented in the understorey. Foliicolous lichen similarity is high between forests of different seral stages (e.g. Yala vs. Salazar, Yala vs. Ikuywa, Buyangu vs. Isiukhu) as well as between forests of similar seral stages (e.g. Buyangu vs. Salazar, Salazar vs. Ikuywa). These results showed no uniform pattern of change in species composition along succession gradient.

5.5 Conclusion

Kakamega Forest, as the only Guineo-Congolian transitional rainforest in Kenya, is naturally expected to be the best habitat for foliicolous lichens. Due to various levels of disturbance and fragmentation, the vegetation of Kakamega Forest consists of a mosaic of forests of different seral stages, anthropogenic vegetation, and grasslands, with differing impact on the diversity of organisms. From the result of this study it can be concluded that:

- The overall diversity of foliicolous lichens in Kakamega Forest is considerably high.

- Differences in diversity of foliicolous lichens among the various forest types have been shown to depend on the level of disturbance rather than on the seral stage of forest development.
- Forest sites with similar seral stages have been shown to differ in their foliicolous lichen diversity (e.g. Yala vs. Ghostisland, Isiukhu vs. Camp site, Colobus vs. Ikuywa).
- Forest sites with closed canopy have high diversity and sites with semi-open and open canopy have low diversity. Canopy openness in Kakamega Forest is related to the level of disturbance.
- Foliicolous lichen diversity has been found to be high in the forest sites of Yala, Isiukhu, Kisere, Salazar, Buyangu and Ikuywa.

Chapter 6. DIVERSITY OF FOLIICOLOUS LICHENS ALONG DISTURBANCE GRADIENT: A COMPARATIVE ANALYSIS OF GODERE, BUDONGO AND KAKAMEGA FORESTS

6.1 Introduction

Due to over exploitation by the local people, and state and private enterprises, the natural forests of Ethiopia, Uganda and Kenya have declined both in size and quality. The most serious threats to the natural forests come from forest clearance due to an increasing human population which require new land for agriculture and settlement, and from forest degradation due to timber logging and other unsustainable exploitative activities. As a result, most of the natural forests in these countries are secondary with different level of disturbances.

Forest destruction and degradation has an obvious, deleterious effect on biodiversity and environment. If the present trends of deforestation continue, then many plant and animal species could locally be extinct. Since tropical biodiversity is not fully explored, many undiscovered taxa could have been or will be lost even before we discover and name them. The situation is more serious for some organisms whose diversity and distribution are not known. In order to curb some of these problems, natural forest should be conserved and managed. Under the present trend of human population growth and socio-economic situations which have resulted in intense competition for land for subsistence and commercial agriculture as well as for industrial development, protection of the whole natural forests of an area is not feasible. However, some areas could be selected and designated as conservation sites. Biodiversity is one of the useful parameter used for the selection of sites for the purpose of conservation (Goldsmith 1987). Biodiversity includes species diversity, genetic diversity and ecosystem diversity. Species diversity is the most obvious and frequently used measure of biodiversity. Species diversity in tropical forests, however, is not fully understood and this necessitates their immediate documentation.

The vascular plant floras of Ethiopia, Uganda and Kenya are relatively well known due to the publications of the Flora of Tropical East Africa and Flora of Ethiopia and Eritrea. Documentation of the cryptogamic flora of these countries is at its infancy stage. Lichens in general and foliicolous lichens in particular are among the least studied (or unstudied) organisms in these countries as well as in tropical Africa.

In order to include foliicolous lichens in the forest conservation program and to use them, as component of biodiversity, in the selection of forest sites for the purpose of conservation, their diversity and distribution should be documented. Since the monographic work of Santesson (1952), there has been an increasing attention on the systematics of foliicolous lichens. However, very little is known about their ecology and the impact of forest disturbance on their diversity, especially in the forests of tropical

Africa. In this study, comparison of the diversity of foliicolous lichens along disturbance gradient from Budongo (comparatively least disturbed) to Kakamega (comparatively medium disturbance) and Godere (comparatively more disturbed) is presented with the following objectives.

- To describe the species composition of the foliicolous lichens of the three forests
- To compare the α- and β-diversity of foliicolous lichens of the three forests
- To compare the similarity in foliicolous lichen species composition of the three forests
- To analyse the foliicolous lichen species diversity along disturbance gradient
- To identify foliicolous lichen species that could be used as bioindicator of forest types
- To analyse the biographical distribution of the foliicolous lichens of the study area.

6.2 Study area

A detailed description of Godere, Budongo and Kakamega forests are presented in Chapters 3, 4 and 5. The three forests selected for the study of the diversity of foliicolous lichens share several topographic, and physiognomic and climatic characters (Table 6.1). They are situated on flat terrains with gentle slope, at medium altitudes and in similar climatic conditions. Godere and Kakamega forests are composed of a mixture of afromontane and Guineo-Congolian floral elements as well as transitional species. Budongo Forest is a Guineo-Congolian rainforest. Most of the canopy species in both forests are deciduous. Climatically, the three forests are located in high rainfall areas of the respective countries.

Due to the different socio-economic conditions where the three forests are found, the management regime, degree of anthropogenic disturbance and the land use are substantially different. Forest management in Budongo and Kakamega is much better than in Godere where no forest management plan is in place. Due to different management and exploitation history, the three forests are now found in a different disturbance conditions.

Among the three forests, Budongo is the least disturbed with undisturbed primary and disturbed secondary forests located in close proximity. Timber has been selectively extracted from the forest since 1910. In 1957 clear-cutting was promoted and enrichment planting of mahoganies (*Khaya* and *Entandrophragma*) and *Maesopsis* was established in plantations (Paterson 1991). In addition, arboricide treatment was applied to remove trees which did not have commercial value.

Kakamega Forest has a long history of exploitation (Mitchell 2004) and at present forests of different physiognomic, successional and disturbance levels are found. Most of the forests in Kakamega are middle-age secondary which are managed by the Kenya Wildlife Service or the Forest Department. Forests of early seral stages with high level of disturbance and indigenous and exotic plantations are also the features of Kakamega

Forest. Undisturbed primary forest is absent in Kakamega, though some forests areas received greater protection and experienced little disturbance.

Godere is the most disturbed among the three. The major disturbance in the forest is selective cutting by timber industries, shifting cultivation by the indigenous people, commercial coffee plantation by state and private enterprises and semi-forest coffee management by the indigenous people and settlers. Therefore, the forest in Godere is secondary with different level of anthropogenic disturbances. While closed forest are absent in Godere, most of the remaining natural forests are semi-open, so maintained for the growth of *Coffea arabica* under the system of semi-coffee forest management. Under such system, competing trees, shrubs and lianas are removed (Senbetta & Denich 2006) while shade species are maintained.

Table 6.1 Some climatic and physiognomic characters of Godere, Budongo and Kakamega forests

	Godere	Budongo	Kakamega
Altitude (m a.s.l.)	1000-1500	950-1200	1460-1765
Mean annual rain fall (mm)	>1500	1200-1800	1343-2638
Mean annual temperature (^{0}C)	15-25	17-29	10.6-27.7
Forest type	Transitional rainforest (Friis 1992)	Semi-deciduous tropical rainforest (Reynolds 2005)	Dry perpipheral semi-evergreen Guineo-Congolian transitional rainforest (Althof 2005)
Floral elements	Afromontane, Guineo-Congolian, Transitional	Guineo-Congolian	Afromontane, Guineo-Congolian, Transitional
Major disturbance history (type)	Selective logging, shifting cultivation, semi-forest coffee management, commercial coffee plantation	Selective logging, silvicultural treatment	Logging (clear felling & selective), exotic tree plantation

6.3 Methodology

The methodology followed for foliicolous lichen collection and identification is presented in Chapter 2. In order to make comparison of α- and β-diversity of the three forests simple, only taxa identified to species and subspecific level were considered. Exception to this is *Opegrapha* sp. since it occurs in the three forests and all the specimens are expected to belong to the same species. Alpha diversity of foliicolous lichens is analysed from the observed species richness, species accumulation curves, non-parametric species richness estimators (Colwell 2006) and Shannon-Wiener diversity and evenness indices (Magurran 1988). Beta diversity is computed with Whittaker index (Whittaker 1960) and Sørenson's index of similarity (Sørenson 1948). The frequency occurrences of species in the samples of Godere, Budongo and Kakamega forests were analysed based on a six-scale frequency classes (see section 2.3.1). Statistical analyses were done in order to look for significant differences in α-diversity using Statigraphics version 5 software (Statistical Graphics Corporation).

Ordination of the forest sites and species of the three forests was made using Principal Component Analysis (PCA) using the software CANOCO (ter Braak & Šmilauer 2002). PCA is selected for ordination since the initial correspondence analysis provided a gradient length of less than 3 indicating a linear response of species distribution. In the PCA ordination centering by species was selected.

The PCA biplot is used to identify characteristic foliicolous lichen species that can be used as indicator of forest types of different disturbance regimes. Species that have high fidelity to a particular forest type with high frequency of occurrence were then used as indicators of that forest type (disturbance regime). Only species which occurred on all or most of the forest sites of a particular disturbance regime are selected as indicator species. Dufrene and Legendre (1997) called these species as symmetrical indicators whose presence contributes to the habitat specificity.

In order to establish the biogeographical distribution of the typically and facultatively foliicolous lichen species of Ethiopia, Uganda and Kenya, data from the present study as well as additional data for Kenya (Lücking and Kalb 2002) and Uganda (Feuerer 2007) were utilized. Information on the distribution types of the foliicolous lichens were obtained from Lücking *et al.* (2000), Lücking & Colin (2004), and the observation of the present study. The biogeographical distribution of foliicolous lichens is analysed based on the lichenogeographical regions of Lücking (2003). The similarity in foliicolous lichens of Godere, Budongo and Kakamega forests and Taï National Park in Ivory Coast is determined using Sørensen similarity index (Sørensen 1948).

6.4 Results

6.4.1 α-diversity

6.4.1.1 Family, generic and species richness

A total of 16 families of foliicolous lichen were recorded from the three forests (Fig. 6.1). All of these families were represented in Kakamega while only 15 families were recorded from Godere and Budongo. The family Monoblastiaceae was not represented in Budongo and Microthyriaceae was not represented in Godere.

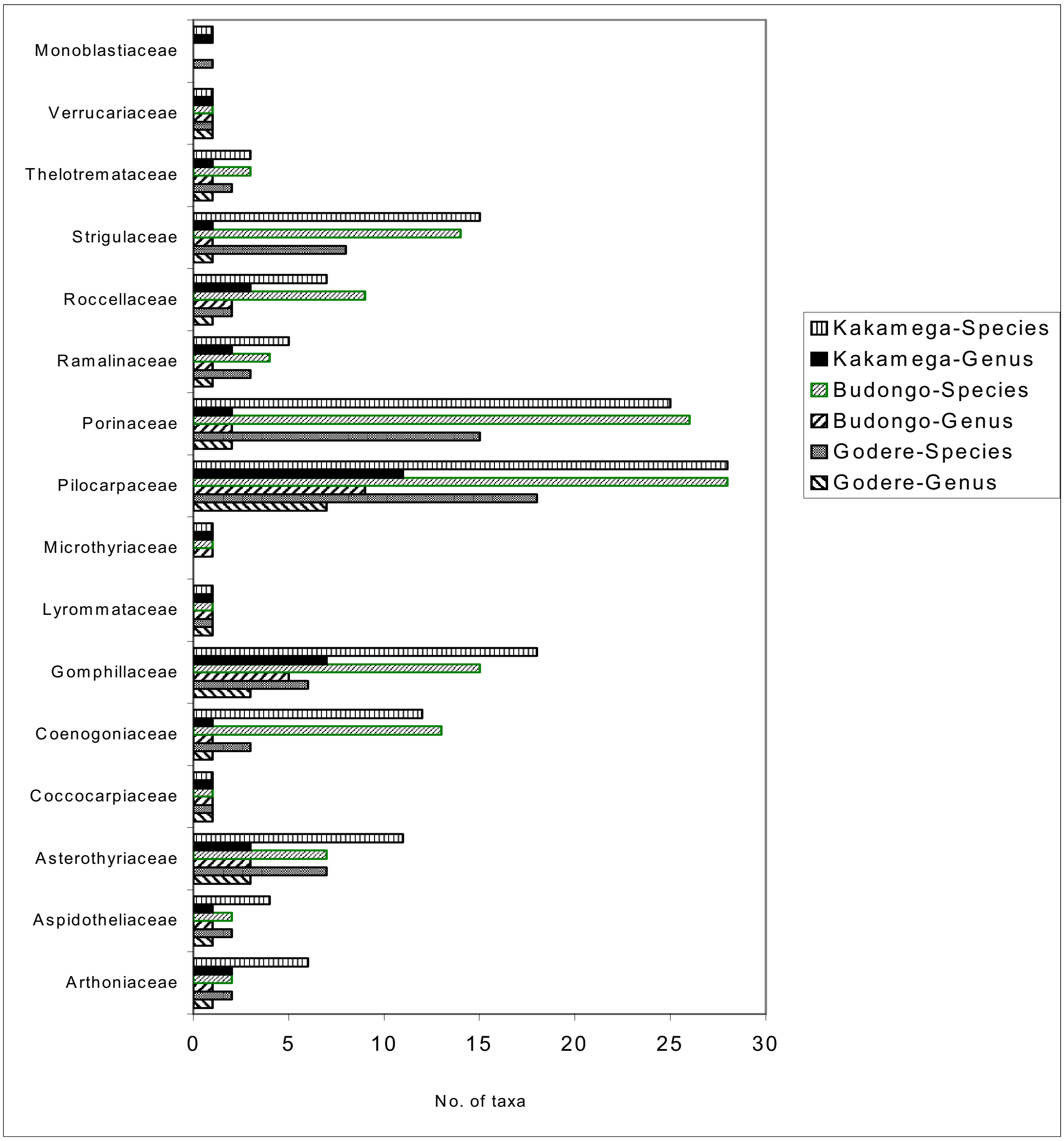


Fig. 6.1 Number of genera and species per family in Godere, Budongo and Kakamega forests.

Forty-one genera were recorded from the three forests. Generic diversity is highest in Kakamega (39 genera), the genera *Caprettia* and *Eugeniella* being absent. Thirty-three genera were recorded from Budongo, the genera *Aderkomyces, Badimia, Caprettia, Enterographa, Eremothecella, Gyalideopsis, Lasioloma,* and *Musaespora* being absent. Godere ranks the least in generic diversity (27 genera). The genera *Aderkomyces, Aulaxina, Badimia, Bapalmuia, Eugeniella, Enterographa, Eremothecella, Gyalideopsis, Lasioloma, Lichenopeltella* (lichenicolous fungi), *Loflammia, Mazosia*, *Musaespora,* and *Tricharia* were not recorded from Godere.

In terms of species diversity, Kakamega and Budongo forests have higher number of foliicolous lichen species diversity than Godere. The observed number of species from Godere is 70, 125 from Budongo and 137 from Kakamega.

The mean number of species per sample in Godere Forest is 9.8, 10.7 in Budongo and 11.1 in Kakamega (Fig. 6.2). Kruskal-Wallis one way ANOVA was performed to see if there is significant difference among the three medians. The result indicated absence of significant difference (Chi square = 4.08, p-value = 0.1298) at 95% confidence level.

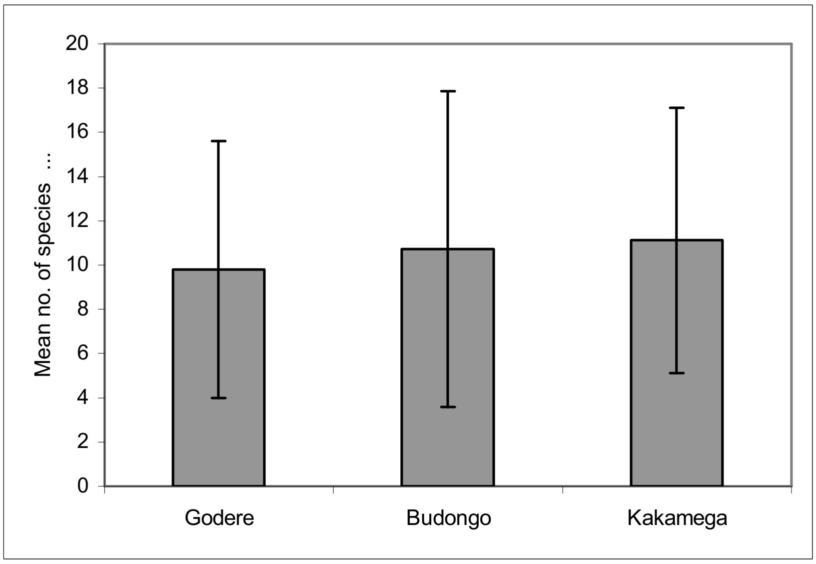


Fig. 6.2 Mean (±SD) number of species per sample in Godere, Budongo and Kakamega forests

The estimated number of species for Godere, Budongo and Kakamega by the non-parametric species richness estimators is presented in Table 6.2. The second order and first order Jackknife estimators respectively predicted the highest richness for both forests and the Michaelis-Menten Means (MMMeans) predicted the lowest species richness. The difference between the highest and the lowest estimates is 13.3 species for Godere, 18.9 species for Budongo and 37.3 species for Kakamega. The Michaelis-Menten Means estimator was not found to be a good estimator for Kakamega as its estimate (135.6 species) is below the observed number of species (138). According to these estimators more than 80% of the foliicolous lichen species predicted were collected from Godere, Budongo and Kakamega forests.

For Godere the species accumulation curves (not shown) of MMMeans and Jack 2 estimators seemed to approach an asymptote, the curves for the others either did not approach an asymptote or did not stabilize. For Budongo, the species accumulation curves of Jack 2 and MMMeans estimators approached a horizontal asymptote. The curves for the other estimators did not approach an asymptote. Therefore, for Godere and Budongo the estimates of MMMeans could be considered as the lower limit of species richness and the Jack 2 estimates as the upper limit. For Kakamega the curves for Jack 1 and Chao 2 estimators seem to approach an asymptote. Accordingly the estimate of Chao 2 could be considered as the lower limit of species richness and that of Jack 1 as the upper limit.

Table 6.2 Species richness estimates and other summary values for foliicolous lichen species in Godere, Budongo and Kakamega forests

	Godere	Budongo	Kakamega
No. of samples	64	194	304
No. of individuals	626	2068	3380
S_{obs}	71	126	138
MMMeans	75.6	128.1	135.6
Chao 2	78.95 ± 5.5	135.5 ± 5.8	159±11.6
Jackknife 1	85.8 ±4.4	144.9±4.4	169.9±6.1
Jackknife 2	88.9	146.97	172.9
ICE	82.6	138.8	156.4
Bootstrap	78.6	135.6	148.6
Collection degree (%)	80-94	86-98	80-102

6.4.1.2 Shannon diversity

Table 6.3 presents the Shannon diversity and evenness indices for the foliicolous lichen species of Godere, Budongo and Kakamega forests. ANOVA followed by Fischer's least significant difference (LSD) *post hoc* test indicated significant difference (F-value = 69.04, $p<0.05$) in Shannon diversity between Godere and Budongo as well as Godere and Kakamega. There is no significant difference between Budongo and Kakamega. Diversity of foliicolous lichens, as measured by Shannon index, is therefore significantly higher in Budongo and Kakamega than in Godere. The Shannon evenness is similar in Godere and Budongo but is slightly lower in Kakamega.

Table 6.3 Shannon diversity and evenness of foliicolous lichens in Godere, Budongo and Kakamega forests.

	Godere	Budongo	Kakamega
Shannon diversity index (H')	3.66	4.14	4.09
Shannon evenness index (J')	0.86	0.86	0.83

6.4.2 Beta diversity

Beta diversity of foliicolous lichens, expressed as the number of species observed divided by the mean number of species, is high in Kakamega and Budongo and low in Godere (Table 6.4). As this index of β-diversity is a measure of the species turnover or the degree of change in species composition, species turnover is high in Kakamega and Budongo and low in Godere.

Table 6.4 Total β-diversity in Godere, Budongo and Kakamega forests

	Total species number (a)	Mean number of species per sample (b)	β-diversity (a/b)
Godere	71	9.8	7.2
Budongo	126	10.7	11.8
Kakamega	138	11.1	12.4

The similarity in species composition, measured by Sørensen similarity index, shows high foliicolous lichens similarity between Budongo and Kakamega than between these forests and Godere (Table 6.5).

Table 6.5 Sørensen similarity index values for Godere, Budongo and Kakamega

	Godere	Budongo
Godere	-	
Budongo	0.59	-
Kakamega	0.61	0.77

6.4.3 Species frequency

In Godere, Budongo and Kakamega forests rare species constituted 62%, 74.6% and 77.5% of the total species respectively (Fig. 6.3). Occasional species constituted the next highest proportion. The species which fall in the other frequency classes constituted very small proportion.

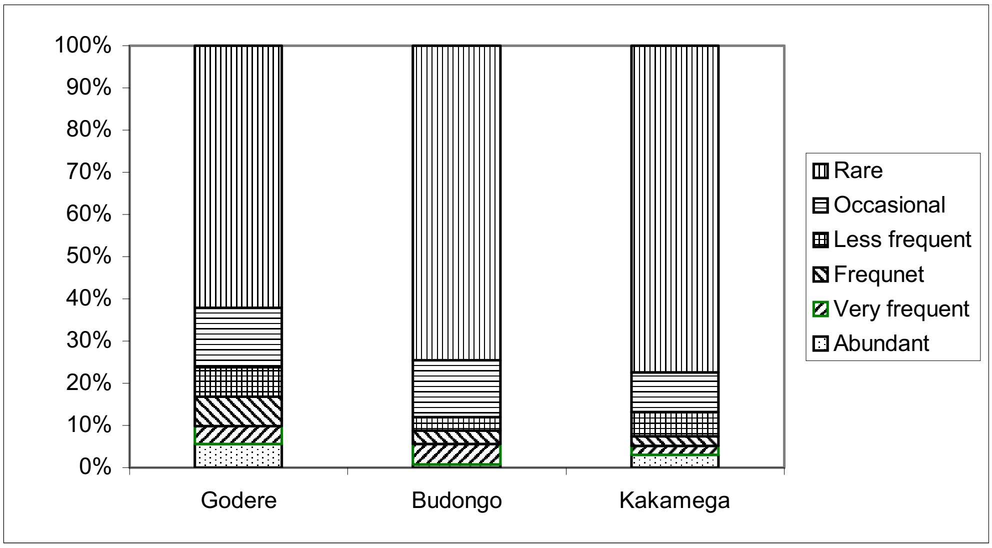


Fig. 6.3 Proportion (%) of species in the various frequency classes in Godere, Budongo and Kakamega forests

In Godere, *Porina epiphylla, P. nitidula, P. subpallescens,* and *P. rubentior* were the dominant species. *Strigula phyllogena, Bacidina apiahica,* and *Calopadia puiggarii* were the very frequent species. Species classified as frequent were *Calopadia fusca, Gyalectidium filicinum, Porina cupreola* var. *cupreola, P. leptosperma,* and *Strigula smaragdula*. *Fellhanera paradoxa, Gyalidea epiphylla, Calenia monospora, Lyromma nectandrae*, and *Trichothelium africanum* constituted the less frequent class. The species classified as occasional were *Aspidothelium fugiens, Brasilicia foliicola, Byssolecania hymenocarpa, Coccocarpia stellata, Fellhanera bouteillei, Gyalectidium imperfectum, Strigula nemathora var. hypothelia, Strigula nitidula, Trichothelium pauciseptatum* and *Trichothelium minutum* The remaining 44 species were rare.

In Budongo Forest, only *Porina epiphylla* fall into the dominant frequency class. Species classified as very frequent were *Porina nitidula, P. radiata, P. rubentior, Strigula phyllogena, S. smaragdula,* and *Coenogonium dilucidum*. The frequent species were *Mazosia rotula, M. melanopthalma, Strigula nemathora* var. *hypothelia* and *S. nitidula*. *Porina sphaerocephala, P. alba*, *P. semicarpi* and *Strigula microspora* constituted the less frequent frequency class. *Byssolecania deplanata, Bacidina apiahica, Brasilicia foliicola, Byssolecania hymenocarpa, Echinoplaca pellicula, Fellhanera submicrommata, Gyalectidium filicinum, Lyromma nectandrae, Porina conica, Porina cupreola* var.

cupreola, P. epiphylloides, P. kamerunensis, P. leptosperma, P. rubescens, Sporopodium leprieurii, Strigula multipunctata, and *S. obducta* were the species classified as occasionals. The remaining species were classified as rare.

In Kakamega Forest *Porina nitidula, P. epiphylla, P. rubetior,* and *P. cupreola* var. *cupreola* were the dominant species. The very frequent species were *Strigula phyllogena, S. amaragdula* and *Porina subpallescens. Gyalectidium filicinum, Strigula nitidula* and *Byssoloma leucoblepharum* were the species classified as frequent. Species classified as less frequent were *Coenogonium geralense, C. subluteum, Lyromma nectandrae, Calopadia puiggarii, Calenia monospora, Strigula macrocarpa,* and *Trichothelium pauciseptatum. Bacidina apiahica, Chroodiscus verrucosus, Coenogonium lisowskii, Coenogonium pocsii, C. siquirrense, Fellhanera bouteillei, Gyalectidium caucasicum, Mazosia melanopthalma, Porina epiphylloides, P. rubescens, Strigula microspora, S. nemathora* var. *hypothelia and S. obducta* were the species classified as occasional. The remaining species were rare.

6.4.4 Ordination

Principal component analysis (PCA) biplot of the species by forest sites data matrix of Godere, Budongo and Kakamega forests is presented in Fig. 6.4. The first four axes of the PCA ordination explain 50.6% of the total variation in the species data. The first and second axes of PCA ordination explain 21.7% and 13.8% of the total variation respectively; therefore most of the variation in species composition is explained by the first axis. In the PCA biplot species are represented by arrows and forest sites by dots. The direction of the arrow indicates the direction in which the abundance of a species increases most rapidly. The length of the arrows indicates the rate of change in abundance in that direction. A long arrow indicates gradual rate of change in abundance, while a short arrow represents very rapid change.

The distribution of the forest sites in the PCA biplot shows a clear pattern, with the primary, swamp, old secondary and young secondary forests of Budongo showing a strong positive correlation with the first axis but negative correlation with the second axis. The forest sites of Isiukhu, Yala, Ikuywa, and Salazar are positively correlated with both the first and the second axes but the correlation with the second axis is stronger. The forest site of Buyangu is slightly positively correlated with both axes while Kisere is slightly negatively correlated with the first axis and positively correlated with the second axis. Isecheno, Bukhaywa, Busambuli and Colobus forest sites of Kakamega are negatively correlated with the first axis and positively with the second axis. The forest sites of Dushi, Bishan Waka, Kaimosi, Malava, Ghostisland and Camp site are negatively correlated both with both the first and the second axes. The distribution of the study sites along the first PCA axis seems to depend on the level of forest disturbance. Therefore, forest sites with a strong positive correlation with the first PCA axis are undisturbed or slightly disturbed, while forest site negatively correlated with the first axis are more disturbed.

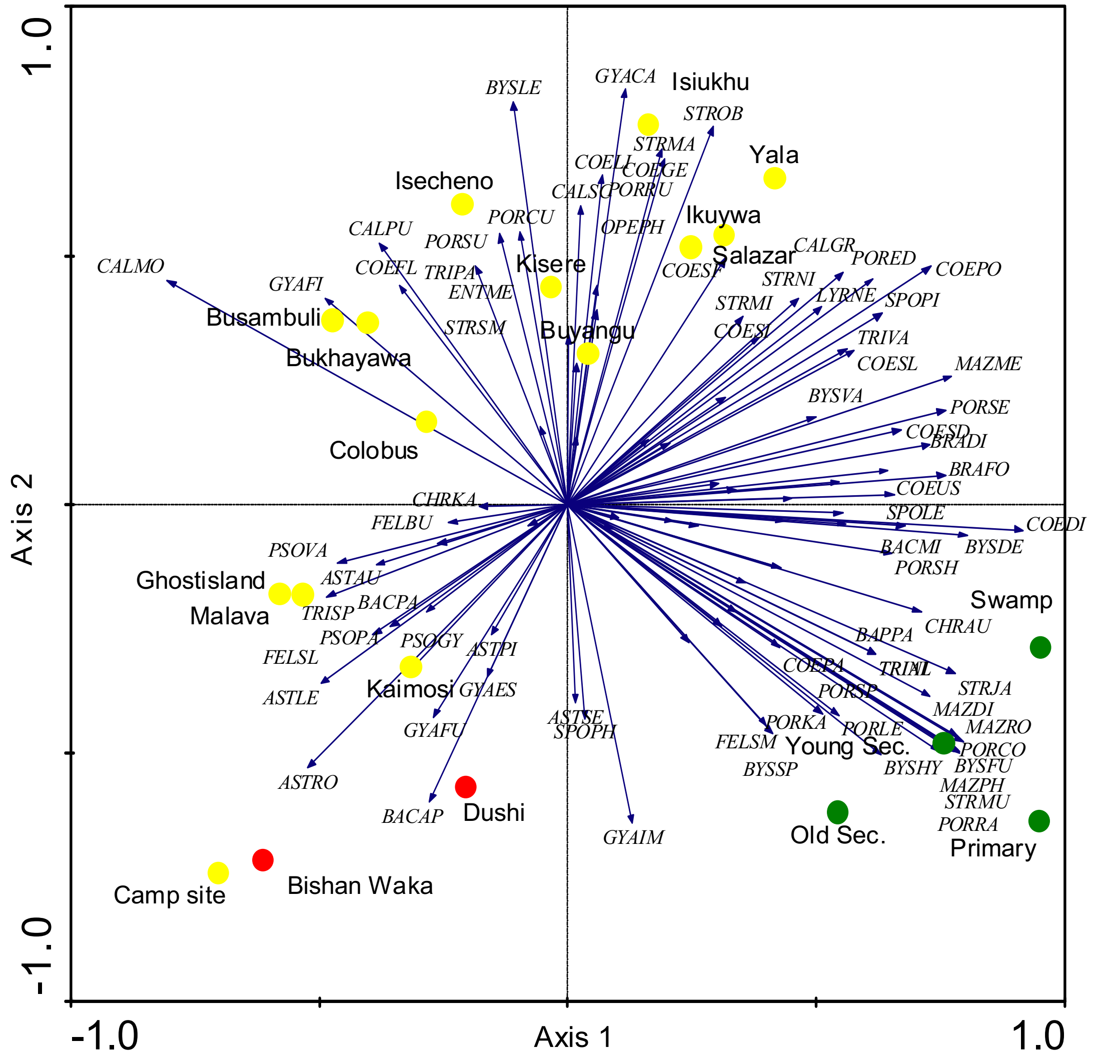


Fig. 6.4 PCA biplot of species and forest sites.. For species acronym see Appendix 4. For the purpose of clarity some of the species are omitted.

6.4.5 Foliicolous lichens as indicator of disturbance

Indicator species of forest types (disturbance regime) are determined from the distribution of species along the first axis of PCA biplot (Fig. 6.4). Species with a strong positive correlation with the first PCA axis are characteristic of undisturbed closed forest. Species with a strong negative correlation with the first axis are characteristic of a heavily disturbed forest site. The frequency of a species in the various forest types is also consulted in order to select indicator species. Only species restricted to a particular forest type with high frequency are considered as indicator of that forest type. Based on the distribution of the species and forest sites on the PCA biplot, the following species are selected as indicator of three forest types with different disturbance regime.

1. **Undisturbed/slightly disturbed closed forest**. Forests of this type have closed canopy with infrequent canopy openings. The primary, swamp, old secondary and young

secondary forests of Budongo belong to this group. The predominant microsite in such forest types is shady understorey and species of such microsite are more abundant than the other species (Table 6.6). Light gap species constitute a very small proportion and canopy species are either absent or very rare. Indicator species for this group are *Porina sphaerocephala, Porina conica, Porina radiata*, and *Mazosia rotula*. These species are mostly confined to the primary or old growth forests and have not been recorded from the middle-aged and young secondary forests.

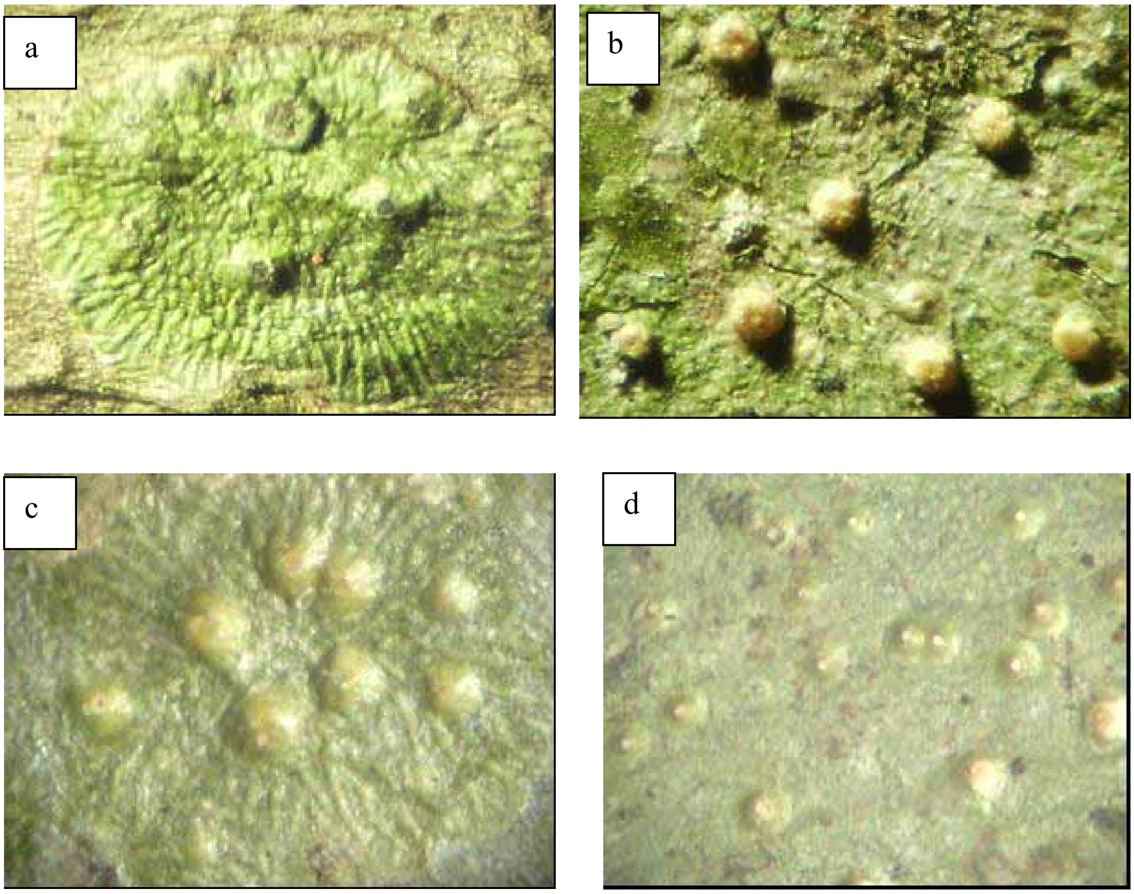


Fig. 6.5 Indicator species for undisturbed closed forest, (a) *Mazosia rotula*, (b) *Porina sphaerocephala,* (c) *Porina radiata,* (d) *Porina conica*

Foliicolous lichens associated with this forest type include *Mazosia phyllospora, M. dispersa, Strigula janeriensis, S. multipunctata, Bysoloma fumosonigricans, B. hymenocarpa, Chroodiscus australiensis, Porina leptosperma, P. kameruensis, P. sphaerocephaloides, Fellhanera submicrommata, Byssoloma subpolychromum,* and *Bapalmuia palmularis.*

2. **Closed forest with moderate disturbance.** This is the largest forest type where most of the forest sites of the study area belong. The forest canopy in this group is largely closed, however irregular openings could be seen here and there. Yala, Ikuywa, Salazar, Buyangu,

Isiukhu, Isecheno, Colobus and Kisere forest sites belong to this category. Forests under this group have most of the species distributed both in the shady understorey and light gap microsites and very few species in the canopy microsite (Table 6.5). Indicator species for this group are *Coenogonium geralense, Coenogonium siquirrense, Coenogonium pocsii,* and *Byssoloma leucoblepharum.*

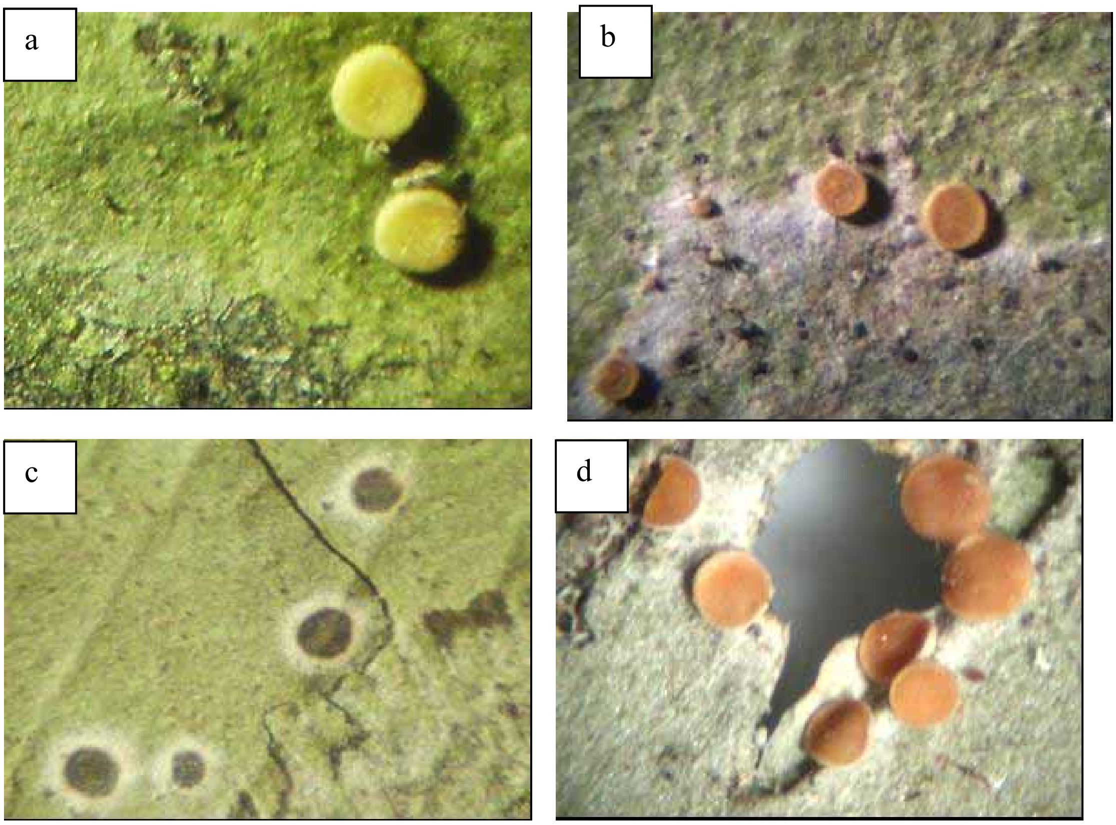


Fig. 6.6 Indicator species for closed forest with moderate disturbance, (a) *Coenogonium geralense*, (b) *C. pocsii*, (c) *Byssoloma leucoblepharum,* (d) *C. siquirrense.*

Foliicolous lichens associated with this forest type include *Coenogonium subfallaciosum, C. subluteum, C. usambarense, C. pocsii, Brasilicia foliicola, B. dimerelloides, Tricharia vainioi, Mazosia melanopthalna, Porina semicarpi, Porina epiphylloides, Byssolecania variabilis* and *Sporopodium pilocarpoides*.

3. **Disturbed semi-open forest**. The forests grouped under this type have semi-open canopy which allows light to reach the inside of the forest. Bukhaywa, Busambuli, Ghostisland, Malava, Kaimosi, Dushi, Bishan Waka and Camp site forests belong to this category. The foliicolous species composition is largely made up of more of light gap species than shady understorey species. In the Camp site forest which is more open than the other forest sites in this group, the proportion of light gap species is very high (70%) and more canopy specialists are recorded in the understorey (Table 6.6). Indicator species for the semi-open canopy forest group are *Asterothyrium rotuliforme, Psorotheciopsis gyalideoides*, *P. varieseptata, Calenia aspidota* and *Gyalectidium imperfectum*. Species

associated with this forest type include *Fellhanera bouteillei, Asterothyrium aulaxinoides, Fellhanera sublecanorina,* and *Calenia monospora.*

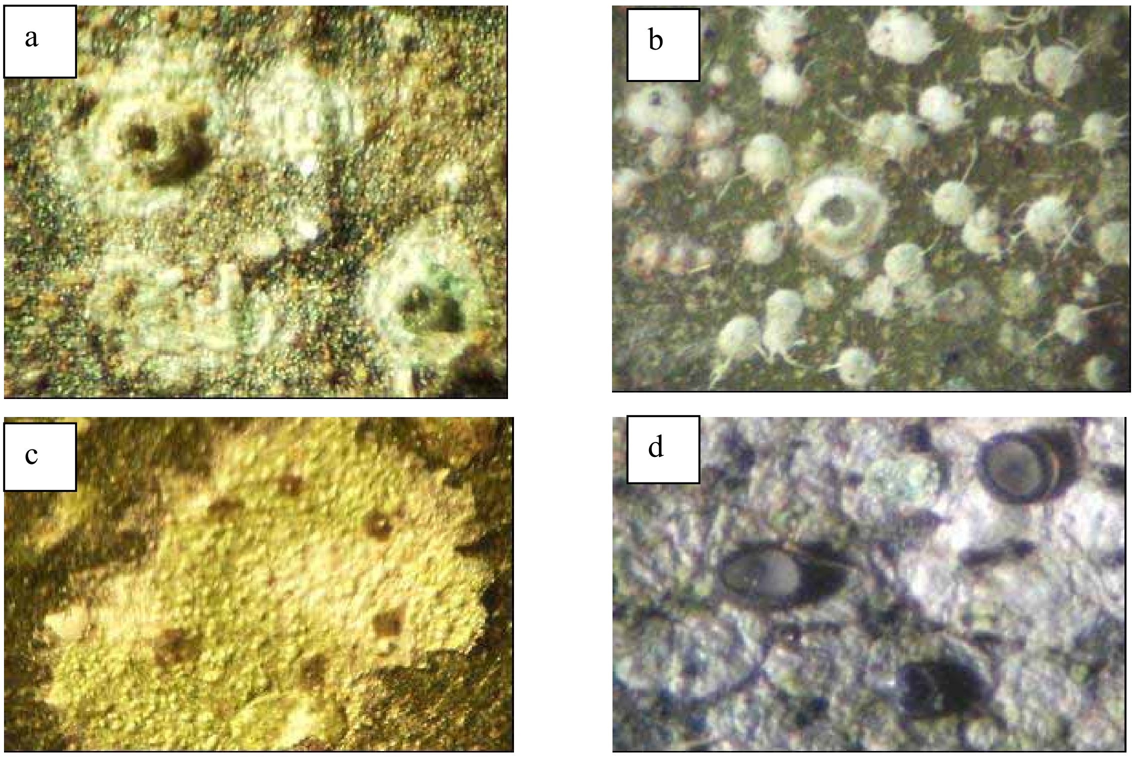


Fig. 6.7 Indicators species for open forest, (a) *Asterothyrium rotuliforme*, (b) *Calenia aspidota*, (c) *Gyalectidium imperfectum*, (d) *Psorotheciopsis gyalideoides*

Table 6.6.Proportion (%) of foliicolous lichen species of the forest sites of Godere, Budongo and Kakamega in the forest microsites

	Shady understorey	Transition to light gap	Light gap	Transition to canopy	Outer canopy
Old secondary	38.6	26.3	29.8	5.3	-
Isecheno	37	26.1	21.7	13	2.2
Primary	34.2	31.6	26.3	6.6	1.3
Kisere	32.3	24.6	27.7	10.8	3.1
Swamp	31.3	31.5	26.1	8.7	2.2
Ikuywa	31.1	23	32.8	9.8	3.3
Colobus	31.1	24.4	33.3	6.7	4.4
Yala	30.8	26.2	29	10.8	3.1
Young secondary	28	30.1	30.1	11.8	-
Dushi	26.7	21.7	35	13.3	3.3
Buyangu	24.7	31.5	27.4	13.7	2.7
Kaimosi	24.4	22	36.6	12.2	4.9
Isikuhu	24.3	27	31.1	16.2	1.4

Table 6.6 contd.

	Shady understorey	Transition to light gap	Light gap	Transition to canopy	Outer canopy
Salazar	23.8	33.3	31.7	9.5	1.6
Ghostislanid	22.6	19.4	38.7	9.7	9.7
Bukhaywa	22.2	24.4	35.6	13.3	4.4
Bishan Waka	19.4	13.9	44.4	13.9	8.3
Busambuli	18.9	18.9	30.2	22.6	7.5
Malava	17.1	19.5	41.5	14.6	7.3
Camp site	7.4	3.7	37	25.9	25.9

6.4.6 Biogeographic affinity of the foliicolous lichens of the study area

Lücking (2003) distinguished 6 lichenogeographical regions for foliicolous lichens. These are (1) Neotropics, (2) African Paleotropics, (3) Eastern Paleotropics, (4) Valdivian region, (5) Tethyan region, and (6) Neozealandic-Tasmanian region. About 57% of the foliicolous lichen species of Ethiopia, Uganda and Kenya were pantropical being distributed in the three tropical regions (Latin America, Africa and Southeast Asia) (Fig. 6.8). The African paleotropical species constituted 18.6% of the total species. Seventeen per cent of the species had their distribution in the African Paleotropics and the Neotropics, and are thus called Western Gondwana. Paleotropical species have their distribution range in the African Paleotropics and the Eastern Paleotropics and they constituted 7.2% of the whole species. About 1% of the species were cosmopolitan with distribution in the tropical regions as well as in the extra tropical regions and 1 species had distribution range in the African Paleotropics and Tethyan region.

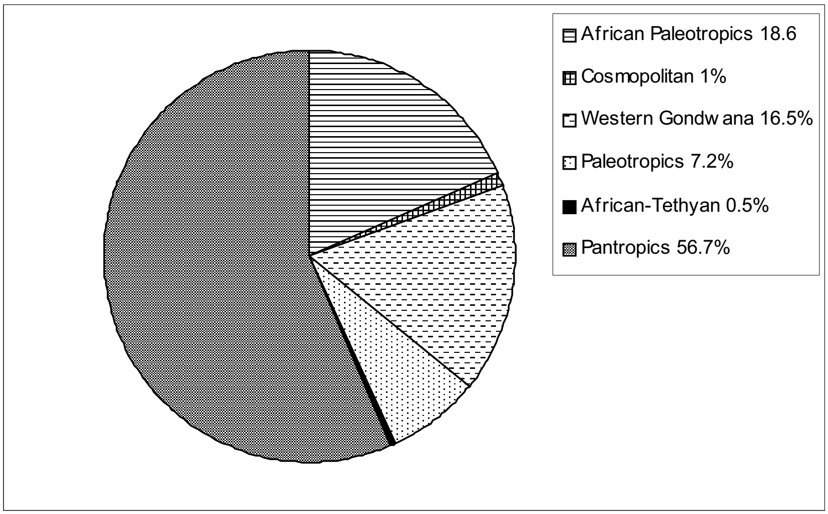


Fig. 6.8 Proportion of world distribution types of currently known foliicolous lichens of Ethiopia, Uganda and Kenya

Thirteen species which had a recorded distribution outside Africa have been recorded from Godere, Budongo and Kakamega forests for the first time and are thus new records for Africa. These are *Aspidothelium geminiparum, Asterothyrium aulaxinoides, Calenia triseptata, Coenogonium barbatum, Coenogonium pannosum, Coenogonium siquirrense, Eugeniella wettsteinii, Fellhanera aurantiaca, Porina rubescens, Strigula microspora,* and *Trichothelium africanum.* All of these species were previously recorded from the Neotropics only. *Aspidothelium scutelicarpum* was previously recorded from the Amphipacific region (Neotropics and Eastern Paleotropics) and *Coenogonium flavum* which was recorded from the Neotropics and Neozealandic-Tasmanian region are new records for Africa.

In order to see if there is similarity in the foliicolous lichens of the study area with other rainforests in Africa, the lowland tropical rainforest of Taï National Park in Ivory Coast was considered (Lücking *et al*. 1998). Taï National Park, located in southwestern Ivory Coast (Cote d'Ivoire) at altitudes 80-396 m, is the largest undisturbed tropical rainforest in West Africa. Comparison of the 97 foliicolous lichen species reported from this forest (Lücking *et al.* 1998) with our study area provided 50 shared species and a Sørensen similarity index of 0.39. This low level of similarity can be partly ascribed to the difference in disturbance conditions. While the forests of our study area are found under different anthropogenic disturbance conditions, the forest in Taï National Park is largely an undisturbed primary rainforest (Santesson & Lücking 1999). The list of foliicolous lichen species of Taï National Park did not contain species typical of open habitats.

6.5 Discussion

6.5.1 Foliicolous lichens diversity in Ethiopia, Uganda and Kenya

Lichens in general and foliicolous lichens in particular were overlooked both in Ethiopia, Uganda and Kenya. The 70 species of foliicolous lichens and lichenicolous fungi new to Ethiopia, 108 species new to Uganda and 77 species new to Kenya recorded in this study from a single forest in each country is a clear indication that high diversity of lichens could be expected in these countries. The number of new species recorded from the three forests is considerably high. It is worthmentioning that most of the new species were recorded from forest sites affected by disturbance. The major reason for the under collection of lichens in Africa is lack of expertise. Many African botanists prefer working on vascular plants to cryptogams. Lack of reference material is also a bottleneck for research in lichens. There is only one book (Swinscow and Krog 1988) available as a reference material for the macrolichens of East African (Ethiopia, Uganda, Kenya and Tanzania). For foliicolous lichens, however, no compiled reference material has ever been prepared for Africa. Santesson (1952) and the various publications after him are the only sources of information. There is therefore much work and challenge ahead before the lichen flora of tropical Africa is fully revealed.

Comparison of the foliicolous lichens recorded in the present study with earlier reports from the Neotropics, Southeast Asia and East and West Africa is made. Diversity of foliicolous lichens is high in the neotropical rainforests. The Central American rainforest, for example, harbours 390 species of foliicolous lichens (Cáceres *et al*. 2000). At site level, high foliicolous lichen diversity is found at ‘’La Selva’’, a lowland rainforest in Costa Rica, with 280 species of foliicolous lichens and 18 species of lichenicolous fungi (Lücking 1999g), at ‘’Jatun Satcha, a lowland rainforest in Ecuador, with 232 species of foliicolous lichens (Lücking 1999d) and at the Botarrama trail, a premontane rainforest in Costa Rica, with 217 species of typically foliicolous lichens (Lücking 1999f). From Guyana, Lücking (1998b) reported 233 species of foliicolous lichens and 18 species of lichenicolous fungi. From the Atlantic rainforest of Brazil, Cáceres *et al*. (2000) reported 191 species of foliicolous lichens and 19 lichenocolous fungi on foliicolous lichens.

For Southeast Asia Papong *et al*. (2006) reported 8 species of foliicolous lichens from Nepal, 53 species from Sri Lanka , 60 species from China, 70 species from Vietnam, 83 species from Japan, 90 species from India, 106 species from Thailand, 120 species from Indonesia, 120 species from Malaysia, 191 species from Papua New Guinea, and 224 species from Philippines. In the continental Australia, 202 species of foliicolous lichens have been reported (Lücking *et al*. 2001). The numbers of foliicolous lichens recorded from Kakamega and Budongo forests are higher than the number of species reported from most of these tropical countries. The number of foliicolous lichens recorded from Godere is higher than the number reported at a country level for Nepal, Sri Lanka, China and Vietnam.

Comparison with reported species number from forest sites in Africa shows higher species diversity in Budongo and Kakamega and comparable or low diversity in Godere. Pócs (1978) reported 75 species from lowland and submontane rainforests in Tanzania and Lücking *et al*. (1998) reported 98 species from a lowland rainforest of Taï National Park in Ivory Coast.

Several studies have documented high foliicolous lichen diversity in undisturbed primary forests compared to disturbed secondary forests (Lücking 1998b, Sipman 1991). Our results show high foliicolous lichen diversity in primary forest and in secondary forests with relatively little disturbance. Although the large part of Kakamega is secondary forest and is more disturbed than Budongo, at forest level high foliicolous lichen species were recorded from the former than the latter. In Budongo Forest, 100 species were recorded from the two primary forest sites and 118 species from the secondary forest sites. In Kakamega Forest comparable numbers of foliicolous lichens were recorded from the secondary forest sites of Yala (67 species), Buyangu (74 species) and Isiukhu (77 species) and the near-primary forest site of Kisere (66 species). In the more disturbed secondary forest sites of Kakamega (e.g. Malava, Kaimosi, Camp site) and in Godere Forest, foliicolous lichen diversity is substantially reduced.

Since high diversity is recorded in forests with relatively low level of disturbance, our observation is in line with the Intermediate Disturbance Hypothesis (Connell 1978). The diversity of an area is influenced by the type, frequency and intensity of disturbance (Petraitis *et al*. 1989). Since the diversity and composition of foliicolous lichens is dependent on the available microsite habitats in a forest, any human impact that results in loss of habitat and significant change in the microclimatic environment will inevitably affect the diversity of foliicolous lichens. Clear-cutting and forest conversion to agricultural land use system, for example, result in total or partial removal of the understorey and light gap microsites resulting in a significant reduction of diversity. The effect on foliicolous lichen diversity of local forest exploitation for example by pit-sawing or fuelwood collection might be minimal. The impoverishment of foliicolous lichens in Godere Forest is primarily due to the conversion of a natural forest to a semi-forest coffee land use system. When understorey shrubs and lianas are removed under such system, foliicolous lichens are also removed along with. Besides, the number of available phorophyte individuals and species are limited, further diminishing the diversity of foliicolous lichens. For maintaining foliicolous lichens diversity, semi-coffee forest land use system is, however, much better than shifting cultivation and conversion to permanent agriculture. Selective logging or pitsawing, on the other hand, could enhance high foliicolous lichen diversity if the intensity and frequency is very limited. These types of human activity have taken place in the secondary forests of Budongo and the middle-age and old secondary forests of Kakamega; nevertheless, foliicolous lichens diversity in these forest types is still high. In contrast where the impact of disturbance was higher (e.g. Malava, Camp site, Kaimosi forests of Kakamega and Godere Forest), the diversity of foliicolous lichens is considerable reduced.

Tropical lowland and lower montane rainforests are most suitable habitats for foliicolous lichens (Lücking 2001). Under natural conditions, high foliicolous lichens diversity is expected from Godere, Budongo and Kakamega forests. The results from our studies confirmed high diversity in Budongo and Kakamega forests which is even higher than the diversity recorded for some countries in Southeast Asia.

6.5.2 Indicator species

Lichens have been found to be sensitive to anthropogenic disturbance and are useful indicators of ecological change (Nimis *et al*. 2002). The use of lichens as bioindicator lies in their poiklohydrous physiological conditions and symbiotic nature. Metabolic processes such as photosynthesis, nitrogen fixation, mineral accumulation, and growth rate in lichens vary in response to seasonal and environmental changes (Galloway 1992, Renhorn *et al*. 1997). Any environmental change that damages either the fungal or the algal partner results in a breakdown of the symbiosis and ultimately to the death of the lichen (Nimis & Purvis 2002)

Several studies (Wolseley and Aguirre-Hudson 1991, Wolseley and Aguirre-Hudson 1997, Mistry 1998, Wolseley 2002, Holz 2003, Nöske 2004, Saipunkaew *et al.* 2005, Plata *et al.* 2007) have demonstrated the potential of lichens as indicators of environmental changes in tropical areas. Furthermore, foliicolous lichens have been shown to have a high potential as bioindicators of altitudinal zonation (Pocs 1977, Lücking 1995b, Herrera-Campos *et al.* 2004, Alejandrina *et al*. 2007), microclimate (Lücking 1994), seasonality (Sérusiaux & De Sloover 1986, Lücking 1995b), anthropogenic disturbances (Lücking 1995a, Lücking 1997d), biodiversity (Lücking 1995b) and biogeographic affinity (Lücking & Kalb 2001). Lücking (2000) discussed the characters that make foliicolous lichens useful as bioindicator. Their relationship to the living leaf is reduced, their dependence on atmospheric factors are high, they have an accelerated life cycle and respond rapidly to environmental changes, there are taxonomically better known and they are particularly useful for ex-situ evaluation, since they are easily collected in large quantities and quickly processed for investigation and documentation.

The distribution of foliicolous lichens within a given forest is largely dependent on microsites (Lücking 1997d). The structure of a forest affects the distribution of foliicolous lichens through its influence on the moisture and light regime in the microsite. In a tropical lowland forest three microsites and two transitions are recognized (Lücking 1997d). These are shady understorey, transition to light gap, light gap, transition to outer canopy and outer canopy. Corresponding to these microsite habitats, foliicolous lichens form three well-defined associations.

In the forest sites of our study area foliicolous lichens belonging to the genera *Arthonia* (Arthoniaceae)*, Bapalmuia, Brasilicia, Byssolecania, Fellhanera* (Pilocarpaceae), *Coenogonium* (Coenogoniaceae), *Enterographa, Mazosia* (Roccellaceae)*, Porina, Trichothelium* (Porinaceae) and *Strigula phyllogena,* and *S. obducta* (Strigulaceae) belong to the shady understorey microsites. Except the family Pilocarpaceae which has Chlorococcaceae photobiont, all the other families have Trentepohliaceae photobiont.

Foliicolous lichen species belonging to the genera *Calenia, Gyalectidium, Echinoplaca* (Gomphillaceae), *Strigula smaragdula, S. nemathora, S. antillarum* (Strigulaceae), *Calopadia, Tapellaria, Loflammia,* and *Lasioloma* (Pilocarpaceae) dominate the light gap microsite. These genera, except *Strigula*, have Chlorococcaceae photobiont. The outer canopy microsite is dominated by the genera *Asterothyrium* and *Psorotheciopsis* (Asterothyriaceae) with Chlorococcaceae photobiont. Our results are in consistence with the observation of Lücking (1995c, 1999e) who recorded foliicolous lichen species of the family Arthoniaceae, Opegraphaceae (=Roccellaceae), Trichotheliaceae (=Porinaceae) and Pilocarpaceae (pycnidia bearing members) in the shady understorey, and Gomphillaceae and Ectolechiaceae (=campylidia bearing members of Pilocarpaceae) in the light gap.

The difference in foliicolous lichens composition in the various microsites is due to light regime (Lücking 1999e). Foliicolous lichens exhibit ecomorphological adaptations to the light regime. Foliicolous lichens in the shady understorey have thin thalli with smooth surface (e.g. species of *Arthonia, Bapalmuia, Brasilicia, Trichothelium, Mazosia phyllosema, Porina epiphylla, P. rufula, P. rubescens*) or are provided with small verrucae (e.g. *Porina sphaerocephala, P. sphaerocephaloides, P. mazosoides, P. radiata, Mazosia rotula*).

Foliicolous lichens in the light gap and outer canopy microsites have dispersed and white thalli (e.g. species of *Calopadia*, *Lasioloma arachnoideum*, *Loflammia epiphylla*) black apothecia (e.g. species of *Tapellaria*) and the phtobiont is *Trebouxia* (Chlorococcaceae). The white thallus reflects light reaching the surface of the thallus thereby reducing excessive loss of evaporation. In addition the thalli of foliicolous lichens in the outer canopy have cortex made from dead cells e.g. species of *Asterothyrium* and *Psorotheciopsis*).

The use of foliicolous lichens as indicator of forest disturbance lies in their compositional differentiation in the different forest microsites. In undisturbed forest, the canopy is closed and the amount of light intensity reaching the understorey vegetation is very small and the moisture content is high. Under such condition, foliicolous lichens adapted to the low light intensity become abundant, the proportion of light gap species is very small and the proportion of canopy species is negligible. In the Primary and Swamp forest of Budongo, for example, more than 60% of the species belong to the shady understorey and the transition to light gap microsites. The most frequent species in the shady understorey of the undisturbed and moderately disturbed group of forest are *Arthonia lividula, Brasilicia dimerelloides, B. foliicola, Coenogonium pocsii, C. siquirrense, C. subfallaciosum, Mazosia melanopthalma* and *Opegrapha velata* (lichenicolous).

When a disturbance occurs in a forest, for example by selective logging, canopy opening allows high light intensity to reach the understorey and this results in reduced moisture content in the understorey. While shady understorey species find these conditions unfavorable for their development, the conditions become favorable for the growth of light gap species. Under extreme condition of disturbance, where the canopy is widely opened, foliicolous lichens adapted to the outer canopy could grow in the understorey. About 22% of the foliicolous lichen species recorded from the understorey of Camp site forest of Kakamega are canopy specialists. All the foliicolous lichen species recorded from the canopy tree of *Ficus lutea* in Susungiru in Uganda have been recorded in the understorey of Camp site forest.

The degree of forest disturbance can be inferred from the proportional abundance of species in the different light regime of a forest. Occurrence of species of the outer canopy (e.g. *Asterothyrium leucophthalmum, A. monsporum, Calenia monosora, C. aspidota, Psorotheciopsis gyalideoides, Psorotheciopsis patellarioides, Psorotheciopsis varieseptata*) in the understorey is a clear indication of wider canopy opening and thus severe forest disturbance. High proportional abundance of species like *Calopadia puiggarii, Fellhanera bouteillei, Gyalectidium caucasicum, G. microcarpum, Lasioloma arachnoideum,* and *Strigula antillarum* in the understorey is an indication of moderate forest disturbance, for example by selective logging or pitsawing resulting in partial or irregular canopy openings.

6.5.3 Biogeography

Among the three tropical lichenogeographical regions, Africa is poor in foliicolous lichens. Lücking (2003) reported 539 species from the Neotropics, 403 from Eastern Paleotropics and 309 from the African Paleotropics. Meggers *et al.* (1973) compared the epiphytic diversity of tropical Africa and South America and indicated that the low epiphytic diversity in Africa is due to paleoclimatic dry periods. It is not known whether the low number of foliicolous lichen species in Africa is due to paleoclimatic conditions or due to insufficient collection. Since many areas of Africa have not been investigated for their foliicolous lichen flora, appropriate explanation for their diversity should be preceded by a thorough collection of different forest types. The 7 new species recorded from the three forests as well as those collections which are expected to belong to new species and the 13 new records for Africa are clear indicators that the foliicolous lichen flora of tropical Africa is under collected.

Santesson & Lücking (1999) analysed the world distribution pattern of the foliicolous lichen flora of Ivory Coast. They found out that 56.5% of the species had pantropical distribution, 22.4% Western Gondwana, 8.7% African Paleotropical, and 6.8% Paleotropical. Foliicolous lichens are known for their wide distribution and high proportion of pantropical species were recorded from collections made in different areas (Santesson & Lücking 1999, Cáceres *et al.* 2000, Herrere-Campos *et al.* 2004). The proportion of pantropical and paleotropical species in Ivory Coast and in Ethiopia, Uganda and Kenya are similar. However, higher proportion of Western Gondwana species and lower proportion of African Paleotropical species were recorded from Ivory Coast than from the three countries investigated in this study. The new species of foliicolous lichens described from the present study have contributed for the increased proportion of the African paleotropical species of the three countries. The low proportion of Western Gondwana species in our study area as compared to those from Ivory Coast indicates that the foliicolous lichen flora of the Ivory Coast is more similar to the flora of Neotropical rainforests than to the flora of the East African rainforests.

The proportion of species common to the African Paleotropics and the Neotropics is more than twice as much as those shared between the African and Eastern Paleotropics. From the foliicolous lichens collected from Ivory Coast, Santesson & Lücking (1999) reported that the Western Gondwana species were three times more than the paleotropical species, indicating higher affinity of the African foliicolous lichens to the Neotropical counterparts. Lücking *et al.* (1998) proposed further study to determine whether this observed similarity is due to paleogeographical relationships between the tropical Africa and tropical South America or due to long distance dispersal.

6.6 Conclusion

The foliicolous lichen flora of Godere, Budongo and Kakamega forests has been found to be considerably high. The number of species recorded especially from Budogo and Kakamega are substantially higher than the species recorded at a country level for many of the tropical countries in Southeast Asia. The numbers of new species science and new records for Africa discovered in this study are indicative that the foliicolous lichens flora of tropical Africa is insufficiently known. The result of the present study predicts high foliicolous lichen diversity in the tropical forests of Africa should such forests are investigated in detail. Therefore it is recommended that more floristic and ecological study should be done especially in the lowland and submontane rainforests of Africa.

At forest level, high foliicolous lichen diversity has been recorded from Kakamega Forest than from Budongo and Godere. It is assumed that the diversity of forest type with different seral stages and disturbance levels has contributed for the diversity of foliicolous lichens in Kakamega Forest. At site level, the forest sites of Budongo have high foliicolous lichen diversity than the forest sites of Kakamega and Godere. Secondary forests with low level of disturbance have been shown to support similar foliicolous lichen diversity like primary forests. Therefore, for the maintenance of high foliicolous lichen diversity in tropical Africa both primary and old growth secondary forests should be conserved.

Due to differences in light intensity and moisture level the composition of foliicolous lichens in the various microsites has been shown to be different. Forest disturbance affects the structure of a forest which in turn affects the environmental conditions in the microsites. Therefore, by observing the composition of foliicolous lichen flora of a given forest site, it is possible to predict the degree of human disturbance in the forest. In addition, some foliicolous lichens have been found to be restricted to a particular microsite making them useful as bioindicator of anthropogenic forest disturbance. Therefore, the identification of indicator foliicolous lichens could provide a basis for management recommendation in areas of disturbed and fragmented forests in tropical Africa.

Most of the foliicolous lichen flora of the study has pantropical distribution and more similar to the Neotropical flora than the Eastern Paleotropical flora. As a result of the new species discovered in this study, the proportion of the African Paleotropical species has ncreased.

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APPENDICIES

Appendix 1. Foliicolous lichens and lichenicolous fungi from Godere Forest

Species acronym	Species	Family	Growth habit
ARTAT	*Arthonia atropunctata* Vain.	Arthoniaceae	Lichenicolous fungi
ARTLI	*Arthonia lividula* Vain.	Arthoniaceae	Typical foliicolous
ASPFU	*Aspidothelium fugiens* (Müll. Arg.) R. Sant.	Aspidotheliaceae	Typical foliicolous
ASPHI	*Aspidothelium hirustum* sp. nov.	Aspidotheliaceae	Typical foliicolous
ASTLE	*Asterothyrium leucophthalmum* (Müll. Arg.) R. Sant.	Asterothyriaceae	Typical foliicolous
ASTMI	*Asterothyrium microsporum* R. Sant.	Asterothyriaceae	Typical foliicolous
ASTOC	*Asterothyrium octomerum* R. Sant.	Asterothyriaceae	Typical foliicolous
ASTRO	*Asterothyrium rotuliforme* (Müll. Arg.) Sérus.	Asterothyriaceae	Typical foliicolous
BACAP	*Bacidina apiahica* (Müll. Arg.) Vezda	Ramalinaceae	Typical foliicolous
BACMI	*Bacidina mirabilis* (Vezda) Vezda	Ramalinaceae	Typical foliicolous
BACPA	*Bacidina pallidocarnea* (Müll. Arg.) Vezda	Ramalinaceae	Typical foliicolous
BRAFO	*Brasilicia foliicola* (Vezda) Lücking, Kalb & Sérus.	Pilocarpaceae	Typical foliicolous
BYSHY	*Byssolecania hymenocarpa* (Vain.) Kalb, Vezda & Lücking	Pilocarpaceae	Typical foliicolous
BYSCH	*Byssoloma chlorinum* (Vain.) Zahlbr.	Pilocarpaceae	Typical foliicolous
BYSLE	*Byssoloma leucoblepharum* (Nyl.) Vain.	Pilocarpaceae	Typical foliicolous
BYSSU	*Byssoloma subpolychromum* Vezda	Pilocarpaceae	Typical foliicolous
CALMO	*Calenia monospora* Vezda	Gomphillaceae	Typical foliicolous
CALSP	*Calenia* sp.	Gomphillaceae	Typical foliicolous
CALTR	*Calenia triseptata* Zahlbr.	Gomphillaceae	Typical foliicolous
CALFU	*Calopadia fusca* (Müll. Arg.) Vezda	Pilocarpaceae	Typical foliicolous
CALPH	*Calopadia phyllogena* (Müll. Arg.) Vezda	Pilocarpaceae	Typical foliicolous
CALPU	*Calopadia puiggarii* (Müll. Arg.) Vezda	Pilocarpaceae	Typical foliicolous

Species acronym	Species	Family	Growth habit
CAPSP	*Caprettia goderei* sp. nov.	Monoblastiaceae	Typical foliicolous
CHRSP	*Chroodiscus kakamegensis* sp. nov.	Thelotremataceae	Typical foliicolous
CHRVE	*Chroodiscus verrucosus* R. Sant., Lücking & Vezda	Thelotremataceae	Typical foliicolous
COCST	*Coccocarpia stellata* Tuck.	Coccocarpiaceae	Facultative foliicolous
COEDI	*Coenogonium dilucidum* (Kremp.) Kalb & Lücking	Coenogoniaceae	Typical foliicolous
COESU	*Coenogonium subluteum* (Rehm) Kalb & Lücking	Coenogoniaceae	Typical foliicolous
COEUS	*Coenogonium usambarense* (Vezda & Farkas) Lücking & Kalb	Coenogoniaceae	Typical foliicolous
ECHPE	*Echinoplaca pellicula* (Müll. Arg.) R. Sant.	Gomphillaceae	Typical foliicolous
FELAU	*Fellhanera* cf. *aurantiaca* (Vezda) Vezda	Pilocarpaceae	Typical foliicolous
FELBO	*Fellhanera bouteillei* (Desm.) Vezda	Pilocarpaceae	Ubiquotus
FELCF	*Fellhanera* aff. *bouteillei* (Desm.) Vezda	Pilocarpaceae	
FELPA	*Fellhanera paradoxa* (Vezda) Vezda	Pilocarpaceae	Typical foliicolous
FELSF	*Fellhanera subfuscatula* Lücking	Pilocarpaceae	Typical foliicolous
FELSL	*Fellhanera sublecanorina* (Nyl.) Vezda	Pilocarpaceae	Typical foliicolous
FELSM	*Fellhanera submicrommata* (Vezda) Lücking & Kalb	Pilocarpaceae	Typical foliicolous
GYAFI	*Gyalectidium filicinum* Müll. Arg.	Gomphillaceae	Typical foliicolous
GYAFU	*Gyalectidium fuscum* Lücking & Sérus.	Gomphillaceae	Typical foliicolous
GYAIM	*Gyalectidium imperfectum* Vezda	Gomphillaceae	Typical foliicolous
GYAEP	*Gyalidea epiphylla* Vezda	Asterothyriaceae	Typical foliicolous
LYRNE	*Lyromma nectandrae* Bat. & H. Maia	Lyrommataceae	Typical foliicolous
OPESP	*Opegrapha* sp.	Roccellaceae	Lichenicolous fungi
OPEVE	*Opegrapha velata* (Müll. Arg.) Vain.	Roccellaceae	Lichenicolous fungi
PHYPO	*Phylloblastia pocsii* (Farkas & Vezda) Lücking	Verrucariaceae	Typical foliicolous
PORCF	*Porina* cf. *triseptata* (Vezda) Lücking	Porinaceae	Typical foliicolous
PORCU	*Porina cupreola* (Müll. Arg.) F. Schill. var. *cupreola*	Porinaceae	Typical foliicolous
POREP	*Porina epiphylla* (Fée) Fée	Porinaceae	Typical foliicolous
PORLE	*Porina leptosperma* Müll. Arg.	Porinaceae	Typical foliicolous

Species acronym	Species	Family	Growth habit
PORNI	*Porina nitidula* Müll. Arg.	Porinaceae	Typical foliicolous
PORRU	*Porina rubentior* (Stirt.) Müll. Arg.	Porinaceae	Typical foliicolous
PORRB	*Porina rubescens* (Lücking) Hafellner & Kalb	Porinaceae	Typical foliicolous
PORRF	*Porina rufula* (Kremp.) Vain.	Porinaceae	Typical foliicolous
PORSU	*Porina subpallescens* Vezda	Porinaceae	Typical foliicolous
PORTE	*Porina tetramera* (Malme) R. Sant.	Porinaceae	Typical foliicolous
PORTI	*Porina trichothelioides* R. Sant.	Porinaceae	Typical foliicolous
PSOPA	*Psorotheciopsis patellarioides* (Rehm) R. Sant.	Asterothyriaceae	Typical foliicolous
PSOVA	*Psorotheciopsis varieseptata* (Vezda) Henssen & Lücking	Asterothyriaceae	Typical foliicolous
SPOAN	*Sporopodium antonianum* Elix, Lumbsch & Lücking	Pilocarpaceae	Typical foliicolous
SPOLE	*Sporopodium leprieurii* Mont.	Pilocarpaceae	Typical foliicolous
SPOPH	*Sporopodium phyllocharis* (Mont.) Massal.	Pilocarpaceae	Typical foliicolous
SPOSP	*Sporopodium* sp.	Pilocarpaceae	
STRMA	*Strigula macrocarpa* Vain.	Strigulaceae	Typical foliicolous
STRMI	*Strigula microspora* Lücking	Strigulaceae	Typical foliicolous
STRHY	*Strigula nemathora* var. *hypothelia* (Nyl.) R. Sant.	Strigulaceae	Typical foliicolous
STRNE	*Strigula nemathora* Mont.	Strigulaceae	Typical foliicolous
STRNI	*Strigula nitidula* Mont.	Strigulaceae	Typical foliicolous
STRPH	*Strigula phyllogena* (Müll. Arg.) R. C. Harris	Strigulaceae	Typical foliicolous
STRSC	*Strigula schizospora* R. Sant.	Strigulaceae	Typical foliicolous
STRSM	*Strigula smaragdula* Fr.	Strigulaceae	Typical foliicolous
TAPBI	*Tapellaria bilimbioides* R. Sant.	Pilocarpaceae	Typical foliicolous
TRIAF	*Trichothelium africanum* Lücking	Porinaceae	Typical foliicolous
TRIEP	*Trichothelium epiphyllum* Müll. Arg.	Porinaceae	Typical foliicolous
TRISP	*Trichothelium minutum* (Lücking) Lücking	Porinaceae	Typical foliicolous
TRIPA	*Trichothelium pauciseptatum* Vezda	Porinaceae	Typical foliicolous

Appendix 2. Foliicolous lichens and lichenicolous fungi from Budongo Forest

Species acronym	Species	Family	Growth habit
ARTLI	*Arthonia lividula* Vain.	Arthoniaceae	Typical foliicolous
ARTOR	*Arthonia orbygniae* (H. B. P. Upadhyay) Matzer	Arthoniaceae	Typical foliicolous
ASPFU	*Aspidothelium fugiens* (Müll. Arg.) R. Sant.	Aspidotheliaceae	Typical foliicolous
ASPGE	*Aspidothelium geminiparum* (Malme) R. Sant.	Aspidotheliaceae	Typical foliicolous
ASTMI	*Asterothyrium microsporum* R. Sant.	Asterothyriaceae	Typical foliicolous
ASTMO	*Asterothyrium monosporum* Müll. Arg.	Asterothyriaceae	Typical foliicolous
ASTPI	*Asterothyrium pittieri* Müll. Arg.	Asterothyriaceae	Typical foliicolous
ASTRO	*Asterothyrium rotuliforme* (Müll. Arg.) Sérus.	Asterothyriaceae	Typical foliicolous
ASTSE	*Asterothyrium septemseptatum* ssp. africanum Lücking & Kalb	Asterothyriaceae	Typical foliicolous
AULMI	*Aulaxina microphana* (Vain.) R. Sant.	Gomphillaceae	Typical foliicolous
BACAP	*Bacidina apiahica* (Müll. Arg.) Vezda	Ramalinaceae	Typical foliicolous
BACMI	*Bacidina mirabilis* (Vezda) Vezda	Ramalinaceae	Typical foliicolous
BACPA	*Bacidina pallidocarnea* (Müll. Arg.) Vezda	Ramalinaceae	Typical foliicolous
BACSI	*Bacidina simplex* Farkas & Vezda	Ramalinaceae	Typical foliicolous
MAPIV	*Bapalmuia ivoriensis* R. Sant. & Lücking	Pilocarpaceae	Typical foliicolous
MAPPA	*Bapalmuia palmularis* (Müll. Arg.) Sérus.	Pilocarpaceae	Typical foliicolous
BIASP	*Biatora* sp.	Bacidiaceae	Facultative foliicolous
BRADI	*Brasilicia dimerelloides* (Vezda) Lücking, Kalb & Sérus.	Pilocarpaceae	Typical foliicolous
BRAFO	*Brasilicia foliicola* (Vezda) Lücking, Kalb & Sérus.	Pilocarpaceae	Typical foliicolous
BYSDE	*Byssolecania deplanata* (Müll. Arg.) R. Sant.	Pilocarpaceae	Typical foliicolous
BYSFU	*Byssolecania fumosonigricans* (Müll. Arg.) R. Sant.	Pilocarpaceae	Typical foliicolous
BYSHY	*Byssolecania hymenocarpa* (Vain.) Kalb, Vezda & Lücking	Pilocarpaceae	Typical foliicolous
BYSVA	*Byssolecania variabilis* (Vain.) Kalb, Vezda & Lücking	Pilocarpaceae	Typical foliicolous

Species acronym	Species	Family	Growth habit
BYSCH	*Byssoloma chlorinum* (Vain.) Zahlbr.	Pilocarpaceae	Typical foliicolous
BYSLE	*Byssoloma leucoblepharum* (Nyl.) Vain.	Pilocarpaceae	Typical foliicolous
BYSSD	*Byssoloma subdiscordans* (Nyl.) P. James	Pilocarpaceae	Typical foliicolous
BYSSP	*Byssoloma subpolychromum* Vezda	Pilocarpaceae	Typical foliicolous
CALAS	*Calenia aspidota* (Vain.) Vezda	Gomphillaceae	Typical foliicolous
CALBU	*Calenia bullatinoides* Lücking	Gomphillaceae	Typical foliicolous
CALDE	*Calenia depressa* Müll. Arg.	Gomphillaceae	Typical foliicolous
CALGR	*Calenia graphidea* Vain.	Gomphillaceae	Typical foliicolous
CALSP	*Calenia* sp.	Gomphillaceae	Typical foliicolous
CALFU	*Calopadia fusca* (Müll. Arg.) Vezda	Pilocarpaceae	Typical foliicolous
CALPU	*Calopadia puiggarii* (Müll. Arg.) Vezda	Pilocarpaceae	Typical foliicolous
CHRAU	*Chroodiscus australiensis* Vezda & Lumbsch	Thelotremataceae	Typical foliicolous
CHRKA	*Chroodiscus kakamegensis* sp. nov.	Thelotremataceae	Typical foliicolous
CHRVE	*Chroodiscus verrucosus* R. Sant., Lücking & Vezda	Thelotremataceae	Typical foliicolous
COCST	*Coccocarpia stellata* Tuck.	Coccocarpiaceae	Facultative foliicolous
COEBA	*Coenogonium barbatum* Lücking, Aptroot & Umaña	Coenogoniaceae	Typical foliicolous
COEDI	*Coenogonium dilucidum* (Kremp.) Kalb & Lücking	Coenogoniaceae	Typical foliicolous
COEFA	*Coenogonium fallaciosum* (Müll. Arg.) Kalb & Lücking	Coenogoniaceae	Typical foliicolous
COEGE	*Coenogonium geralense* (P.Henn) Lücking	Coenogoniaceae	Typical foliicolous
COELI	*Coenogonium lisowskii* (Vezda) Lücking	Coenogoniaceae	Typical foliicolous
COEPA	*Coenogonium pannosum* Mull.Arg.	Coenogoniaceae	Typical foliicolous
COEPO	*Coenogonium pocsii* (Vezda & Farkas) Lücking	Coenogoniaceae	Typical foliicolous
COESI	*Coenogonium siquirrense* (Lücking) Lücking	Coenogoniaceae	Typical foliicolous
COESP	*Coenogonium* sp.	Coenogoniaceae	Typical foliicolous
COESD	*Coenogonium subdilucidum* (Vezda) Lücking	Coenogoniaceae	Typical foliicolous

Species acronym	Species	Family	Growth habit
COESF	*Coenogonium subfallaciosum* (Vezda & Farkas) Lücking	Coenogoniaceae	Typical foliicolous
COESL	*Coenogonium subluteum* (Rehm) Kalb & Lücking	Coenogoniaceae	Typical foliicolous
COEUS	*Coenogonium usambarense* (Vezda & Farkas) Lücking & Kalb	Coenogoniaceae	Typical foliicolous
COEZO	*Coenogonium zonatum* (Müll. Arg.) Kalb & Lücking	Coenogoniaceae	Typical foliicolous
ECHDI	*Echinoplaca diffluens* (Müll. Arg.) R. Sant.	Gomphillaceae	Typical foliicolous
ECHPE	*Echinoplaca pellicula* (Müll. Arg.) R. Sant.	Gomphillaceae	Typical foliicolous
EUGWE	*Eugeniella wettsteinii (Müll.Arg.)* Lücking, Sérus. & Kalb	Pilocarpaceae	Typical foliicolous
FELAF	*Fellhanera africana* (Vezda) Lücking	Pilocarpaceae	Typical foliicolous
FELBO	*Fellhanera bouteillei* (Desm.) Vezda	Pilocarpaceae	Ubiquotus
FELPA	*Fellhanera paradoxa* (Vezda) Vezda	Pilocarpaceae	Typical foliicolous
FELRH	*Fellhanera rhaphidophylli* (Rehm) Vezda	Pilocarpaceae	Typical foliicolous
FELSF	*Fellhanera subfuscatula* Lücking	Pilocarpaceae	Typical foliicolous
FELSM	*Fellhanera submicrommata* (Vezda) Lücking & Kalb	Pilocarpaceae	Typical foliicolous
GYACA	*Gyalectidium caucasicum* (Elenk. & Woron.) Vezda	Gomphillaceae	Typical foliicolous
GYAES	*Gyalectidium eskuchei* Sérus.	Gomphillaceae	Typical foliicolous
GYAFI	*Gyalectidium filicinum* Müll. Arg.	Gomphillaceae	Typical foliicolous
GYAFU	*Gyalectidium fuscum* Lücking & Sérus.	Gomphillaceae	Typical foliicolous
GYAIM	*Gyalectidium imperfectum* Vezda	Gomphillaceae	Typical foliicolous
GYAMI	*Gyalectidium microcarpum* (Vezda) Lücking, Sérus. & Vezda	Gomphillaceae	Typical foliicolous
GYAEP	*Gyalidea epiphylla* Vezda	Asterothyriaceae	Typical foliicolous
LICEP	*Lichenopeltella epiphylla* R. Sant.	Microthyriaceae	Lichenicolous fungi
LOFEP	*Loflammia epiphylla* (Fée) Lücking & Vezda	Pilocarpaceae	Typical foliicolous
LYRNE	*Lyromma nectandrae* Bat. & H. Maia	Lyrommataceae	Typical foliicolous
MAZDI	*Mazosia dispersa* (Hedr.) R. Sant.	Roccellaceae	Typical foliicolous
MAZME	*Mazosia melanopthalma* (Müll. Arg.) R. Sant.	Roccellaceae	Typical foliicolous

Species acronym	Species	Family	Growth habit
MAZPA	*Mazosia paupercula* (Müll. Arg.) R. Sant.	Roccellaceae	Typical foliicolous
MAZPH	*Mazosia phyllosema* (Nyl.) Zahlbr.	Roccellaceae	Typical foliicolous
MAZRO	*Mazosia rotula* (Mont.) Massal.	Roccellaceae	Typical foliicolous
OPEEP	*Opegrapha epiporina* Matzer	Roccellaceae	Lichenicolous fungi
OPEMA	*Opegrapha mazosiae* Matzer	Roccellaceae	Lichenicolous fungi
OPEPH	*Opegrapha phylloporinae* Müll. Arg.	Roccellaceae	Lichenicolous fungi
OPESP	*Opegrapha* sp.	Roccellaceae	Lichenicolous fungi
PHYPO	*Phylloblastia pocsii* (Farkas & Vezda) Lücking	Verrucariaceae	Typical foliicolous
PORAL	*Porina alba* (R.Sant.) Lücking	Porinaceae	Typical foliicolous
PORCF	*Porina* cf. *triseptata* (Vezda) Lücking	Porinaceae	Typical foliicolous
PORCO	*Porina conica* R. Sant.	Porinaceae	Typical foliicolous
PORCU	*Porina cupreola* (Müll. Arg.) F. Schill. var. *cupreola*	Porinaceae	Typical foliicolous
POREP	*Porina epiphylla* (Fée) Fée	Porinaceae	Typical foliicolous
POREI	*Porina epiphylloides* Vezda	Porinaceae	Typical foliicolous
PORKA	*Porina kamerunensis* F. Schill.	Porinaceae	Typical foliicolous
PORLE	*Porina leptosperma* Müll. Arg.	Porinaceae	Typical foliicolous
PORLI	*Porina limbulata* (Kremp.) Vain.	Porinaceae	Typical foliicolous
PORMA	*Porina mazosoides* Lücking & *Vezda*	Porinaceae	Typical foliicolous
PORNI	*Porina nitidula* Müll. Arg.	Porinaceae	Typical foliicolous
PORRA	*Porina radiata* Kalb, Lücking & Vezda	Porinaceae	Typical foliicolous
PORRU	*Porina rubentior* (Stirt.) Müll. Arg.	Porinaceae	Typical foliicolous
PORRB	*Porina rubescens* (Lücking) Hafellner & Kalb	Porinaceae	Typical foliicolous
PORRF	*Porina rufula* (Kremp.) Vain.	Porinaceae	Typical foliicolous
PORSE	*Porina semicarpi* Vain.	Porinaceae	Typical foliicolous
PORSR	*Porina sphaerocephala* Vain.	Porinaceae	Typical foliicolous

Species acronym	Species	Family	Growth habit
PORSH	*Porina sphaerocephaloides* Farkas	Porinaceae	Typical foliicolous
PORSP	*Porina subpallescens*Vezda	Porinaceae	Typical foliicolous
PORTE	*Porina tetramera* (Malme) R. Sant.	Porinaceae	Typical foliicolous
PORTR	*Porina trichothelioides* R. Sant.	Porinaceae	Typical foliicolous
PSOPA	*Psorotheciopsis gyalideoides* (Vezda) Henssen & Lücking	Asterothyriaceae	Typical foliicolous
SPOAN	*Sporopodium antonianum* Elix, Lumbsch & Lücking	Pilocarpaceae	Typical foliicolous
SPOLE	*Sporopodium leprieurii* Mont.	Pilocarpaceae	Typical foliicolous
SPOPH	*Sporopodium phyllocharis* (Mont.) Massal.	Pilocarpaceae	Typical foliicolous
SPOPI	*Sporopodium pilocarpoides* (Zahlbr.) Lücking & Kalb	Pilocarpaceae	Typical foliicolous
STRAN	*Strigula antillarum* (Fée) Müll. Arg.	Strigulaceae	Typical foliicolous
STRJA	*Strigula janeriensis* (Müll. Arg.) Lücking	Strigulaceae	Typical foliicolous
STRMA	*Strigula macrocarpa* Vain.	Strigulaceae	Typical foliicolous
STRMC	*Strigula maculata* (Cooke & Massee) R. Sant.	Strigulaceae	Typical foliicolous
STRMI	*Strigula microspora* Lücking	Strigulaceae	Typical foliicolous
STRMU	*Strigula multipunctata* (G. Merr. ex R. Sant.) R. C. Harris	Strigulaceae	Typical foliicolous
STRHY	*Strigula nemathora* var. *hypothelia* (Nyl.) R. Sant.	Strigulaceae	Typical foliicolous
STRNE	*Strigula nemathora* Mont.	Strigulaceae	Typical foliicolous
STRNI	*Strigula nitidula* Mont.	Strigulaceae	Typical foliicolous
STROB	*Strigula obducta* (Müll. Arg.) R. C. Harris	Strigulaceae	Typical foliicolous
STRPH	*Strigula phyllogena* (Müll. Arg.) R. C. Harris	Strigulaceae	Typical foliicolous
STRSC	*Strigula schizospora* R. Sant.	Strigulaceae	Typical foliicolous
STRSM	*Strigula smaragdula* Fr.	Strigulaceae	Typical foliicolous
STRST	*Strigula subtilissima* (Fée) Müll. Arg.	Strigulaceae	Typical foliicolous
TAPMO	*Tapellaria molleri* (Lücking) Lücking	Pilocarpaceae	Typical foliicolous
TAPNI	*Tapellaria nigrata* (Müll. Arg.) R. Sant.	Pilocarpaceae	Typical foliicolous

Species acronym	Species	Family	Growth habit
TRINI	*Tricharia nigriuncinata* sp.nov.	Gomphillaceae	Typical foliicolous
TRIVA	*Tricharia vainioi* R. Sant.	Gomphillaceae	Typical foliicolous
TRIAF	*Trichothelium africanum* Lücking	Porinaceae	Typical foliicolous
TRIAL	*Trichothelium alboatrum* Vain.	Porinaceae	Typical foliicolous
TRIEP	*Trichothelium epiphyllum* Müll. Arg.	Porinaceae	Typical foliicolous
TRISP	*Trichothelium minutum* (Lücking) Lücking	Porinaceae	Typical foliicolous
TRIPA	*Trichothelium pauciseptatum* Vezda	Porinaceae	Typical foliicolous

Appendix 3 Foliicolous lichens and lichenicolous fungi from Kakamega Forest

Species acronym	Species	Family	Growth habit
ADEDI	*Aderkomyces dilatatus* (Vezda) Lücking, Serusiaux & Vezda	Gomphillaceae	Typical foliicolous
ARTAT	*Arthonia atropunctata* Vain.	Arthoniaceae	Lichenicolous fungi
ARTFL	*Arthonia flavoverrucosa* U. Becker & Lücking	Arthoniaceae	Typical foliicolous
ARTFU	*Arthonia fuscocyanea* U. Becker & Lücking	Arthoniaceae	Typical foliicolous
ARTLI	*Arthonia lividula* Vain.	Arthoniaceae	Typical foliicolous
ARTOR	*Arthonia orbygniae* (H. B. P. Upadhyay) Matzer	Arthoniaceae	Typical foliicolous
ASPFU	*Aspidothelium fugiens* (Müll. Arg.) R. Sant.	Aspidotheliaceae	Typical foliicolous
ASPGE	*Aspidothelium geminiparum* (Malme) R. Sant.	Aspidotheliaceae	Typical foliicolous
ASPHI	*Aspidothelium hirustum* sp. nov.	Aspidotheliaceae	Typical foliicolous
ASPSC	*Aspidothelium scutelicarpum* Lücking	Aspidotheliaceae	Typical foliicolous
ASTAU	*Asterothyrium aulaxinoides* Lücking	Asterothyriaceae	Typical foliicolous
ASTLE	*Asterothyrium leucophthalmum* (Müll. Arg.) R. Sant.	Asterothyriaceae	Typical foliicolous
ASTMI	*Asterothyrium microsporum* R. Sant.	Asterothyriaceae	Typical foliicolous
ASTPI	*Asterothyrium pittieri* Müll. Arg.	Asterothyriaceae	Typical foliicolous
ASTRO	*Asterothyrium rotuliforme* (Müll. Arg.) Sérus.	Asterothyriaceae	Typical foliicolous
ASTSE	*Asterothyrium septemseptatum* ssp. africanum Lücking & Kalb	Asterothyriaceae	Typical foliicolous
ASTSP	*Asterothyrium* sp.	Asterothyriaceae	Typical foliicolous
AULEP	*Aulaxina epiphylla* (Zahlbr.) R. Sant.	Gomphillaceae	Typical foliicolous
AULMI	*Aulaxina opegraphina* Fée	Gomphillaceae	Typical foliicolous
AULOP	*Bacidia medialis* (Tuck. ex Nyl.) de Lesd.	Ramalinaceae	Facultative foliicolous
BACAP	*Bacidina apiahica* (Müll. Arg.) Vezda	Ramalinaceae	Typical foliicolous
BACMI	*Bacidina mirabilis* (Vezda) Vezda	Ramalinaceae	Typical foliicolous
BACPA	*Bacidina pallidocarnea* (Müll. Arg.) Vezda	Ramalinaceae	Typical foliicolous
BACSI	*Bacidina simplex* Farkas & Vezda	Ramalinaceae	Typical foliicolous
BADDI	*Badimia dimidiata* (C. Bab. ex Leight.) Vezda	Pilocarpaceae	Typical foliicolous

Species acronym	Species	Family	Growth habit
BAPIV	*Bapalmuia ivoriensis* R. Sant. & Lücking	Pilocarpaceae	Typical foliicolous
BIASP	*Biatora* sp.	Bacidiaceae	Facultative foliicolous
BRADI	*Brasilicia dimerelloides* (Vezda) Lücking, Kalb & Sérus.	Pilocarpaceae	Typical foliicolous
BRAFO	*Brasilicia foliicola* (Vezda) Lücking, Kalb & Sérus.	Pilocarpaceae	Typical foliicolous
BYSDE	*Byssolecania deplanata* (Müll. Arg.) R. Sant.	Pilocarpaceae	Typical foliicolous
BYSHY	*Byssolecania hymenocarpa* (Vain.) Kalb, Vezda & Lücking	Pilocarpaceae	Typical foliicolous
BYSVA	*Byssolecania variabilis* (Vain.) Kalb, Vezda & Lücking	Pilocarpaceae	Typical foliicolous
BYSCH	*Byssoloma chlorinum* (Vain.) Zahlbr.	Pilocarpaceae	Typical foliicolous
BYSLE	*Byssoloma leucoblepharum* (Nyl.) Vain.	Pilocarpaceae	Typical foliicolous
BYSSU	*Byssoloma subdiscordans* (Nyl.) P. James	Pilocarpaceae	Typical foliicolous
CALAS	*Calenia aspidota* (Vain.) Vezda	Gomphillaceae	Typical foliicolous
CALBU	*Calenia bullatinoides* Lücking	Gomphillaceae	Typical foliicolous
CALDE	*Calenia depressa* Müll. Arg.	Gomphillaceae	Typical foliicolous
CALGR	*Calenia graphidea* Vain.	Gomphillaceae	Typical foliicolous
CALMO	*Calenia monospora* Vezda	Gomphillaceae	Typical foliicolous
CALSP	*Calenia* sp.	Gomphillaceae	
CALTH	*Calenia thelotremela* Vain.	Gomphillaceae	Typical foliicolous
CALFU	*Calopadia fusca* (Müll. Arg.) Vezda	Pilocarpaceae	Typical foliicolous
CALPU	*Calopadia puiggarii* (Müll. Arg.) Vezda	Pilocarpaceae	Typical foliicolous
CALSC	*Calopadia subcoerulescens* (Zahlbr.) Vezda	Pilocarpaceae	Typical foliicolous
CHRAU	*Chroodiscus australiensis* Vezda & Lumbsch	Thelotremataceae	Typical foliicolous
CHRKA	*Chroodiscus kakamegensis* sp. nov.	Thelotremataceae	Typical foliicolous
CHRVE	*Chroodiscus verrucosus* R. Sant., Lücking & Vezda	Thelotremataceae	Typical foliicolous
COCST	*Coccocarpia stellata* Tuck.	Coccocarpiaceae	Facultative foliicolous
COEDI	*Coenogonium dilucidum* (Kremp.) Kalb & Lücking	Coenogoniaceae	Typical foliicolous
COEFA	*Coenogonium fallaciosum* (Müll. Arg.) Kalb & Lücking	Coenogoniaceae	Typical foliicolous
COEFL	*Coenogonium flavum* (Malcom & Vezda) Lücking	Coenogoniaceae	Typical foliicolous
COEGE	*Coenogonium geralense* (P.Henn) Lücking	Coenogoniaceae	Typical foliicolous

Species acronym	Species	Family	Growth habit
COELI	*Coenogonium lisowskii* (Vezda) Lücking	Coenogoniaceae	Typical foliicolous
COEPO	*Coenogonium pocsii* (Vezda & Farkas) Lücking	Coenogoniaceae	Typical foliicolous
COESI	*Coenogonium siquirrense* (Lücking) Lücking	Coenogoniaceae	Typical foliicolous
COESP	*Coenogonium* sp.	Coenogoniaceae	Typical foliicolous
COESD	*Coenogonium subdilucidum* (Vezda) Lücking	Coenogoniaceae	Typical foliicolous
COESF	*Coenogonium subfallaciosum* (Vezda & Farkas) Lücking	Coenogoniaceae	Typical foliicolous
COESL	*Coenogonium subluteum* (Rehm) Kalb & Lücking	Coenogoniaceae	Typical foliicolous
COEUS	*Coenogonium usambarense* (Vezda & Farkas) Lücking & Kalb	Coenogoniaceae	Typical foliicolous
COEZO	*Coenogonium zonatum* (Müll. Arg.) Kalb & Lücking	Coenogoniaceae	Typical foliicolous
ECHDI	*Echinoplaca diffluens* (Müll. Arg.) R. Sant.	Gomphillaceae	Typical foliicolous
ECHPE	*Echinoplaca pellicula* (Müll. Arg.) R. Sant.	Gomphillaceae	Typical foliicolous
ENTFE	*Enterographa fellhaneroides* sp.nov.	Roccellaceae	Typical foliicolous
ENTME	*Enterographa meklitiae* sp.nov.	Roccellaceae	Typical foliicolous
ERECA	*Eremothecella calamicola* Syd.	Arthoniaceae	Typical foliicolous
FELBU	*Fellhanera bouteillei* (Desm.) Vezda	Pilocarpaceae	Ubiquotus
FELBU	*Fellhanera* aff. *bouteillei*	Pilocarpaceae	
FELEN	*Fellhanera encephalarti* (Vezda) Vezda	Pilocarpaceae	Typical foliicolous
FELPA	*Fellhanera paradoxa* (Vezda) Vezda	Pilocarpaceae	Typical foliicolous
FELPR	*Fellhanera parvula* (Vezda) Vezda	Pilocarpaceae	Typical foliicolous
FELRH	*Fellhanera rhaphidophylli* (Rehm) Vezda	Pilocarpaceae	Typical foliicolous
FELSF	*Fellhanera subfuscatula* Lücking	Pilocarpaceae	Typical foliicolous
FELSL	*Fellhanera sublecanorina* (Nyl.) Vezda	Pilocarpaceae	Typical foliicolous
FELSM	*Fellhanera submicrommata* (Vezda) Lücking & Kalb	Pilocarpaceae	Typical foliicolous
GYACA	*Gyalectidium caucasicum* (Elenk. & Woron.) Vezda	Gomphillaceae	Typical foliicolous
GYAES	*Gyalectidium eskuchei* Sérus.	Gomphillaceae	Typical foliicolous
GYAFI	*Gyalectidium filicinum* Müll. Arg.	Gomphillaceae	Typical foliicolous
GYAFU	*Gyalectidium fuscum* Lücking & Sérus.	Gomphillaceae	Typical foliicolous

Species acronym	Species	Family	Growth habit
GYAIM	*Gyalectidium imperfectum* Vezda	Gomphillaceae	Typical foliicolous
GYAEP	*Gyalidea epiphylla* Vezda	Asterothyriaceae	Typical foliicolous
GYAPS	*Gyalidea psorotheciopides* sp. nov.	Asterothyriaceae	Typical foliicolous
GYACO	*Gyalideopsis cochlearifer* Lücking & Sérus.	Gomphillaceae	Lichenicolous fungi
LASAR	*Lasioloma arachnoideum* (Kremp.) R. Sant.	Pilocarpaceae	Typical foliicolous
LICEP	*Lichenopeltella epiphylla* R. Sant.	Microthyriaceae	Lichenicolous fungi
LOFEP	*Loflammia epiphylla* (Fée) Lücking & Vezda	Pilocarpaceae	Typical foliicolous
LYRNE	*Lyromma nectandrae* Bat. & H. Maia	Lyrommataceae	Typical foliicolous
MAZME	*Mazosia melanopthalma* (Müll. Arg.) R. Sant.	Roccellaceae	Typical foliicolous
MUSKA	*Musaespora kalbii* Lücking & Sérus.	Monoblastiaceae	Typical foliicolous
OPEEP	*Opegrapha epiporina* Matzer	Roccellaceae	Lichenicolous fungi
OPEPH	*Opegrapha phylloporinae* Müll. Arg.	Roccellaceae	Lichenicolous fungi
OPESP	*Opegrapha* sp.	Roccellaceae	Lichenicolous fungi
OPEVE	*Opegrapha velata* (Müll. Arg.) Vain.	Roccellaceae	Lichenicolous fungi
PHYPO	*Phylloblastia pocsii* (Farkas & Vezda) Lücking	Verrucariaceae	Typical foliicolous
PHYSP	*Phyllospora* sp.	Bacidiaceae	Facultative foliicolous
PORAT	*Porina atrocoerulea* Müll. Arg.	Porinaceae	Typical foliicolous
PORCF	*Porina* cf. *triseptata* (Vezda) Lücking	Porinaceae	Typical foliicolous
PORCU	*Porina cupreola* (Müll. Arg.) F. Schill. var. *cupreola*	Porinaceae	Typical foliicolous
PORDI	*Porina distans* Vezda & Vivant	Porinaceae	Typical foliicolous
POREP	*Porina epiphylla* (Fée) Fée	Porinaceae	Typical foliicolous
PORED	*Porina epiphylloides* Vezda	Porinaceae	Typical foliicolous
PORKA	*Porina kamerunensis* F. Schill.	Porinaceae	Typical foliicolous
PORLE	*Porina leptosperma* Müll. Arg.	Porinaceae	Typical foliicolous
PORLI	*Porina limbulata* (Kremp.) Vain.	Porinaceae	Typical foliicolous
PORLU	*Porina lucida* R. Sant. var. *lucida*	Porinaceae	Typical foliicolous
PORMA	*Porina mazosoides* Lücking & *Vezda*	Porinaceae	Typical foliicolous
PORNI	*Porina nitidula* Müll. Arg.	Porinaceae	Typical foliicolous

Species acronym	**Species**	**Family**	**Growth habit**
PORPA	*Porina pallescens* R. Sant.	Porinaceae	Typical foliicolous
PORRB	*Porina rubentior* (Stirt.) Müll. Arg.	Porinaceae	Typical foliicolous
PORRF	*Porina rubescens* (Lücking) Hafellner & Kalb	Porinaceae	Typical foliicolous
PORRU	*Porina rufula* (Kremp.) Vain.	Porinaceae	Typical foliicolous
PORSE	*Porina semicarpi* Vain.	Porinaceae	Typical foliicolous
PORSH	*Porina sphaerocephaloides* Farkas	Porinaceae	Typical foliicolous
PORSP	*Porina subpallescens*Vezda	Porinaceae	Typical foliicolous
PORTE	*Porina tetramera* (Malme) R. Sant.	Porinaceae	Typical foliicolous
PORTR	*Porina trichothelioides* R. Sant.	Porinaceae	Typical foliicolous
PSOGY	*Psorotheciopsis gyalideoides* (Vezda) Henssen & Lücking	Asterothyriaceae	Typical foliicolous
PSOPA	*Psorotheciopsis patellarioides* (Rehm) R. Sant.	Asterothyriaceae	Typical foliicolous
PSOVA	*Psorotheciopsis varieseptata* (Vezda) Henssen & Lücking	Asterothyriaceae	Typical foliicolous
SPOAN	*Sporopodium antonianum* Elix, Lumbsch & Lücking	Pilocarpaceae	Typical foliicolous
SPOLE	*Sporopodium leprieurii* Mont.	Pilocarpaceae	Typical foliicolous
SPOPI	*Sporopodium pilocarpoides* (Zahlbr.) Lücking & Kalb	Pilocarpaceae	Typical foliicolous
SPOSP	*Sporopodium* sp.	Pilocarpaceae	
STRAN	*Strigula antillarum* (Fée) Müll. Arg.	Strigulaceae	Typical foliicolous
STRCO	*Strigula concreta* (Fée) R. Sant.	Strigulaceae	Typical foliicolous
STRJA	*Strigula janeriensis* (Müll. Arg.) Lücking	Strigulaceae	Typical foliicolous
STRMA	*Strigula macrocarpa* Vain.	Strigulaceae	Typical foliicolous
STRMC	*Strigula maculata* (Cooke & Massee) R. Sant.	Strigulaceae	Typical foliicolous
STRME	*Strigula melanobapha* (Kremp.) R. Sant.	Strigulaceae	Typical foliicolous
STRMI	*Strigula microspora* Lücking	Strigulaceae	Typical foliicolous
STRMU	*Strigula nemathora* var. *hypothelia* (Nyl.) R. Sant.	Strigulaceae	Typical foliicolous
STRNE	*Strigula nemathora* Mont.	Strigulaceae	Typical foliicolous
STRNI	*Strigula nitidula* Mont.	Strigulaceae	Typical foliicolous
STROB	*Strigula obducta* (Müll. Arg.) R. C. Harris	Strigulaceae	Typical foliicolous
STRPH	*Strigula phyllogena* (Müll. Arg.) R. C. Harris	Strigulaceae	Typical foliicolous

Acronym	**Species**	**Family**	**Growth habit**
STRSC	*Strigula schizospora* R. Sant.	Strigulaceae	Typical foliicolous
STRSM	*Strigula smaragdula* Fr.	Strigulaceae	Typical foliicolous
STRST	*Strigula subtilissima* (Fée) Müll. Arg.	Strigulaceae	Typical foliicolous
TAPEP	*Tapellaria epiphylla* (Müll. Arg.) R. Sant.	Pilocarpaceae	Typical foliicolous
TAPNI	*Tapellaria nigrata* (Müll. Arg.) R. Sant.	Pilocarpaceae	Typical foliicolous
TRIVA	*Tricharia vainioi* R. Sant.	Gomphillaceae	Typical foliicolous
TRIAF	*Trichothelium africanum* Lücking	Porinaceae	Typical foliicolous
TRIEP	*Trichothelium epiphyllum* Müll. Arg.	Porinaceae	Typical foliicolous
TRIMI	*Trichothelium minutum* (Lücking) Lücking	Porinaceae	Typical foliicolous
TRIPA	*Trichothelium pauciseptatum* Vezda	Porinaceae	Typical foliicolous

Appendix 4. Distribution of foliicolous lichens in the forest sites of Godere, Budongo and Kakamega.

1 = presence, 0 = absence. * = new to Africa, ** new to science

Species acronym	**Species**	**Bishan Waka**	**Bukhaywa**	**Buyangu**	**Busambuli**	**Camp site**	**Colobus**	**Dushi**	**Ghostislanid**	**Ikuywa**	**Isecheno**	**Isikuhu**	**Kaimosi**	**Kisere**	**Malava**	**Salazar**	**Yala**	**Old secondary**	**Primary**	**Swamp**	**Young secondary**
ADEDI	*Aderkomyces dilatatus*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
ARTAT	*Arthonia atropunctata*	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
ARTFL	*Arthonia flavoverrucosa*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARTFU	*Arthonia fuscocyanea*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARTLI	*Arthonia lividula*	0	0	0	1	0	0	1	0	1	1	1	0	0	1	0	1	1	1	0	1
ARTOR	*Arthonia orbygniae*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0
ASPFU	*Aspidothelium fugiens*	1	0	1	0	0	0	1	0	1	0	1	0	0	0	1	1	0	1	0	1
ASPGE	**Aspidothelium geminiparum*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
ASPHI	**Aspidothelium scutelicarpum*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
ASPSC	***Aspidothelium hirsutum* sp. nov.	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
ASTAU	*Asterothyrium aulaxinoides*	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASTLE	*Asterothyrium leucophthalmum*	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASTMI	*Asterothyrium microsporum*	0	0	0	1	0	0	1	0	0	0	1	0	1	1	1	0	1	1	1	1
ASTMO	*Asterothyrium monosporum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
ASTOC	*Asterothyrium octomerum*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
ASTPI	*Asterothyrium pittieri*	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
ASTRO	*Asterothyrium rotuliforme*	1	0	1	0	1	0	1	1	0	0	0	1	1	1	0	0	0	0	0	1
ASTSE	*Asterothyrium septemseptatum*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
ASTSP	*Asterothyrium* sp.	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AULEP	*Aulaxina epiphylla*	0	0	1	0	1	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0
AULMI	*Aulaxina microphana*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
AULOP	*Aulaxina opegraphina*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
BACAP	*Bacidia medialis*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
BACME	*Bacidina apiahica*	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	1	1
BACMI	*Bacidina mirabilis*	0	0	1	0	0	0	1	0	1	0	0	0	1	0	1	0	1	1	1	0

Species acronym	Species	Bishan Waka	Bukhaywa	Buyangu	Busambuli	Camp site	Colobus	Dushi	Ghostislanid	Ikuywa	Isecheno	Isikuhu	Kaimosi	Kisere	Malava	Salazar	Yala	Old secondary	Primary	Swamp	Young secondary
BACPA	*Bacidina pallidocarnea*	1	1	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0
BACSI	*Bacidina simplex*	0	1	1	0	0	1	0	0	1	1	1	0	1	1	1	0	1	1	0	1
BADDI	*Badimia dimidiata*	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
BAPIV	*Bapalmuia ivoriensis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0
BAPPA	*Bapalmuia palmularis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
BRADI	*Brasilicia dimerelloides*	0	1	1	0	0	0	0	0	1	0	0	0	0	0	1	1	1	1	1	1
BRAFO	*Brasilicia foliicola*	0	0	0	0	0	0	1	0	1	1	1	1	1	0	1	1	1	1	1	1
BYSCH	*Byssolecania deplanata*	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	1	1	1	1
BYSDE	*Byssolecania fumosonigricans*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
BYSFU	*Byssolecania hymenocarpa*	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	1	1	1
BYSHY	*Byssolecania variabilis*	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	1	0	1
BYSLE	*Byssoloma chlorinum*	0	1	0	1	0	1	1	0	1	0	1	0	1	1	0	1	1	1	1	1
BYSSD	*Byssoloma leucoblepharum*	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1
BYSSP	*Byssoloma subdiscordans*	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
BYSVA	*Byssoloma subpolychromum*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1
CALAS	*Calenia aspidota*	0	0	1	1	1	0	0	1	1	1	1	1	0	0	1	1	0	0	1	1
CALBU	*Calenia bullatinoides*	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1
CALDE	*Calenia depressa*	0	1	1	1	1	0	0	0	1	0	1	0	0	0	1	1	0	1	1	1
CALGR	*Calenia graphidea*	0	0	1	1	0	0	0	0	1	0	1	0	1	0	1	1	0	1	1	1
CALMO	*Calenia monospora*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
CALTH	*Calenia thelotremela*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
CALTR	**Calenia triseptata*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
CALFU	*Calopadia fusca*	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
CALPH	*Calopadia phyllogena*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
CALPU	*Calopadia puiggarii*	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
CALSC	*Calopadia subcoerulescens*	0	0	0	1	0	0	0	0	1	1	1	1	0	0	1	1	0	0	0	0
CAPGO	***Caprettia goderei* sp. nov.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
CHEVE	*Chroodiscus australiensis*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1
CHRAU	***Chroodiscus kakamegensis* sp. nov.	0	0	1	0	0	0	1	1	0	1	0	1	1	1	1	0	0	1	0	0
CHRKA	*Chroodiscus verrucosus*	1	0	1	1	1	0	1	1	1	1	1	0	1	1	1	1	0	1	1	1

Species acronym	Species	Bishan Waka	Bukhaywa	Buyangu	Busambuli	Camp site	Colobus	Dushi	Ghostislanid	Ikuywa	Isecheno	Isikuhu	Kaimosi	Kisere	Malava	Salazar	Yala	Old secondary	Primary	Swamp	Young secondary
COCST	*Coccocarpia stellata*	1	0	0	1	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	1
COEBA	**Coenogonium barbatum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
COEDI	*Coenogonium dilucidum*	0	0	1	0	0	0	1	0	1	0	1	0	1	0	1	1	1	1	1	1
COEFA	*Coenogonium fallaciosum*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0
COEFL	**Coenogonium flavum*	0	1	0	1	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0
COEGE	*Coenogonium geralense*	0	1	1	1	0	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1
COELI	*Coenogonium lisowskii*	0	1	0	1	0	1	0	0	1	1	1	0	1	1	1	1	0	0	1	1
COEPA	**Coenogonium pannosum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
COEPO	*Coenogonium pocsii*	0	0	1	0	0	1	0	0	1	1	1	0	1	0	1	1	1	1	1	1
COESI	**Coenogonium siquirrense*	0	0	0	0	0	1	0	0	1	1	0	1	1	0	1	1	1	0	1	1
COESD	*Coenogonium subdilucidum*	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	1	0	1	1	1
COESF	*Coenogonium subfallaciosum*	0	0	1	0	0	0	0	1	0	1	1	0	1	0	1	1	0	0	1	1
COESL	*Coenogonium subluteum*	0	0	1	1	0	1	1	0	1	0	1	1	1	0	1	1	1	1	1	1
COEUS	*Coenogonium usambarense*	0	0	1	0	0	0	1	0	1	0	0	1	1	0	1	1	1	1	1	1
COEZO	*Coenogonium zonatum*	0	0	1	0	0	1	0	1	0	0	0	1	1	0	1	1	1	0	1	1
ECHDI	*Echinoplaca diffluens*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1
ECHPE	*Echinoplaca pellicula*	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	1	1	1
ENTFE	***Enterographa fellhaneroides* sp.nov.	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
ENTME	***Enterographa meklitiae* sp.nov.	0	0	0	1	0	1	0	0	1	1	0	0	1	0	0	0	0	0	0	0
ERECA	*Eremothecella calamicola*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
EUGWE	*Eugeniella wettsteinii*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
FELAF	*Fellhanera africana*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
FELAU	*Fellhanera aurantiaca*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
FELBU	*Fellhanera bouteillei*	1	1	1	1	1	0	1	0	1	0	1	1	1	1	0	1	0	1	0	1
FELEN	*Fellhanera encephalarti*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
FELPA	*Fellhanera paradoxa*	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	1
FELPR	*Fellhanera parvula*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FELRH	*Fellhanera rhaphidophylli*	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0
FELSF	*Fellhanera subfuscatula*	0	0	1	1	0	0	1	0	0	0	1	0	1	0	1	1	0	0	1	1
FELSL	*Fellhanera sublecanorina*	1	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0

Species acronym	**Species**	**Bishan Waka**	**Bukhaywa**	**Buyangu**	**Busambuli**	**Camp site**	**Colobus**	**Dushi**	**Ghostislanid**	**Ikuywa**	**Isecheno**	**Isikuhu**	**Kaimosi**	**Kisere**	**Malava**	**Salazar**	**Yala**	**Old secondary**	**Primary**	**Swamp**	**Young secondary**
FELSM	*Fellhanera submicrommata*	0	0	0	1	0	0	1	0	0	0	0	1	1	0	0	0	1	1	1	1
GYACA	*Gyalectidium caucasicum*	0	1	1	1	0	0	0	0	1	1	1	0	1	0	1	1	0	0	1	0
GYAES	*Gyalectidium eskuchei*	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
GYAFI	*Gyalectidium filicinum*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
GYAFU	*Gyalectidium fuscum*	1	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
GYAIM	*Gyalectidium imperfectum*	1	0	0	0	1	0	1	0	1	0	1	1	0	1	0	0	1	1	1	1
GYAMI	*Gyalectidium microcarpum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
GYAEP	*Gyalidea epiphylla*	1	1	0	0	0	1	1	0	0	1	1	0	1	0	0	1	0	1	1	1
GYAPS	***Gyalidea psorothecioides* sp. nov.	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
GYACO	*Gyalideopsis cochlearifer*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
LASAR	*Lasioloma arachnoideum*	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
LICEP	*Lichenopeltella epiphylla*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0
LOFEP	*Loflammia epiphylla*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
LYRNE	*Lyromma nectandrae*	0	1	1	0	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
MAZDI	*Mazosia dispersa*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
MAZME	*Mazosia melanopthalma*	0	1	1	0	0	1	0	0	1	0	1	0	1	0	1	1	1	1	1	1
MAZPA	*Mazosia paupercula*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
MAZPH	*Mazosia phyllosema*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
MAZRO	*Mazosia rotula*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
MUSKA	*Musaespora kalbii*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OPEEP	*Opegrapha epiporina*	0	1	1	0	0	0	0	0	0	0	1	1	0	0	1	0	1	0	1	1
OPEMA	*Opegrapha mazosiae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
OPEPH	*Opegrapha phylloporinae*	0	1	1	1	0	1	0	0	1	1	1	1	1	1	0	1	1	0	1	1
OPESP	*Opegrapha* sp.	0	1	0	1	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	1
OPEVE	*Opegrapha velata*	0	1	0	1	0	1	1	0	0	0	1	1	1	0	0	0	0	0	0	0
PHYPO	*Phylloblastia pocsii*	1	1	0	0	0	1	0	0	0	1	0	0	1	0	1	0	0	0	0	0
PORAL	*Porina alba*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
PORAT	*Porina atrocoerulea*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
PORCF	*Porina* cf. *triseptata*	1	1	0	0	0	0	1	0	0	0	0	0	1	1	1	1	0	1	0	1
PORCO	*Porina conica*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1

Species acronym	**Species**	**Bishan Waka**	**Bukhaywa**	**Buyangu**	**Busambuli**	**Camp site**	**Colobus**	**Dushi**	**Ghostislanid**	**Ikuywa**	**Isecheno**	**Isikuhu**	**Kaimosi**	**Kisere**	**Malava**	**Salazar**	**Yala**	**Old secondary**	**Primary**	**Swamp**	**Young secondary**
PORCU	*Porina cupreola* var. *cupreola*	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
PORDI	*Porina distans*	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
PORED	*Porina epiphylla*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
POREP	*Porina epiphylloides*	0	0	1	1	0	0	0	0	0	1	1	0	1	0	1	1	0	1	1	1
PORKA	*Porina kamerunensis*	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	1
PORLE	*Porina leptosperma*	1	0	1	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1	1	1
PORLI	*Porina limbulata*	0	0	1	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	1
PORLU	*Porina lucida* var. *lucida*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PORMA	*Porina mazosoides*	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0
PORNI	*Porina nitidula*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PORPA	*Porina pallescens*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
PORRA	*Porina radiata*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
PORRB	*Porina rubentior*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PORRF	*Porina rubescens*	0	0	0	0	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
PORRU	*Porina rufula*	0	0	1	0	0	0	1	0	0	1	0	1	0	1	1	0	1	1	1	0
PORSE	*Porina semicarpi*	0	0	1	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	1	1
PORSH	*Porina sphaerocephala*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
PORSP	*Porina sphaerocephaloides*	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1
PORSU	*Porina subpallescens*	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PORTE	*Porina tetramera*	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	1
PORTR	*Porina trichothelioides*	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	1
PSOGY	*Psorotheciopsis gyalideoides*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PSOPA	*Psorotheciopsis patellarioides*	1	1	0	0	1	1	0	1	1	0	0	0	1	1	0	0	0	0	1	1
PSOVA	*Psorotheciopsis varieseptata*	0	0	1	1	1	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0
SPOAN	*Sporopodium antonianum*	0	0	1	0	0	0	1	0	1	0	0	1	0	0	1	1	0	1	1	1
SPOLE	*Sporopodium leprieurii*	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	1	0	1	1	1
SPOPH	*Sporopodium phyllocharis*	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
SPOPI	*Sporopodium pilocarpoides*	0	0	1	0	0	0	0	0	1	0	1	0	0	0	1	1	0	1	1	0
STRAN	*Strigula antillarum*	0	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1
STRCO	*Strigula concreta*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0

Species acronym	Species	Bishan Waka	Bukhaywa	Buyangu	Busambuli	Camp site	Colobus	Dushi	Ghostislanid	Ikuywa	Isecheno	Isikuhu	Kaimosi	Kisere	Malava	Salazar	Yala	Old secondary	Primary	Swamp	Young secondary
STRHY	*Strigula janeriensis*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1
STRJA	*Strigula macrocarpa*	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
STRMA	*Strigula maculata*	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
STRMC	*Strigula melanobapha*	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
STRME	**Strigula microspora*	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
STRMI	*Strigula multipunctata*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
STRMU	*Strigula nemathora* var. *hypothelia*	1	1	1	1	0	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1
STRNE	*Strigula nemathora* var. *nemathora*	1	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	1	1
STRNI	*Strigula nitidula*	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
STROB	*Strigula obducta*	0	1	1	1	0	1	0	0	1	1	1	0	1	1	1	1	1	1	1	0
STRPH	*Strigula phyllogena*	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
STRSC	*Strigula schizospora*	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
STRSM	*Strigula smaragdula*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
STRST	*Strigula subtilissima*	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1	1	1	1	1
TAPBI	*Tapellaria bilimbioides*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
TAPEP	*Tapellaria epiphylla*	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
TAPMO	*Tapellaria molleri*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
TAPNI	*Tapellaria nigrata*	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
TRINI	***Tricharia nigriuncinata* sp.nov.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
TRIVA	*Tricharia vainioi*	0	0	1	1	0	0	0	0	1	0	1	1	0	0	1	1	0	1	1	1
TRIAF	**Trichothelium africanum*	1	0	1	1	0	1	1	1	1	0	1	1	0	0	0	0	1	1	1	1
TRIAL	*Trichothelium alboatrum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
TRIEP	*Trichothelium epiphyllum*	1	1	1	0	0	1	1	0	0	0	1	0	0	0	0	0	1	1	1	1
TRISP	**Trichothelium minutum*	1	1	1	1	1	0	1	1	1	0	0	0	0	1	0	0	0	0	0	1
TRIPA	*Trichothelium pauciseptatum*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

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EFFECTS OF ANTHROPOGENIC DISTURBANCE ON THE DIVERSITY OF FOLIICOLOUS LICHENS IN TROPICAL RAINFORESTS OF EAST AFRICA: GODERE (ETHIOPIA), BUDONGO (UGANDA) AND KAKAMEGA (KENYA)

Dissertation

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In Memory of

my late mother Bekelech Cheru

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ABSTRACT

Foliicolous lichens are one of the most abundant epiphytes in tropical rainforests and one of the few groups of organisms that characterize these forests. Tropical rainforests are increasingly affected by anthropogenic disturbance resulting in forest destruction and degradation. However, not much is known on the effects of anthropogenic disturbance on the diversity of foliicolous lichens. Understanding such effects is crucial for the development of appropriate measures for the conservation of such organisms.

In this study, foliicolous lichens diversity was investigated in three tropical rainforests in East Africa. Godere Forest in Southwest Ethiopia is a transitional rainforest with a mixture of Afromontane and Guineo-Congolian species. The forest is secondary and has been affected by shifting cultivation, semi-forest coffee management and commercial coffee plantation. Budongo Forest in West Uganda is a Guineo-Congolian rainforest consisting of primary and secondary forests. Kakamega Forest in western Kenya is a transitional rainforest with a mixture of Guineo-Congolian and Afromontane species. The forest is a mosaic of near-primary forest, secondary forests of different seral stages, grasslands, plantations, and natural glades.

Leaves carrying foliicolous lichens were collected from the forest understorey in the shady understorey and light gap microsite regimes. Morphological and anatomical characters were used for the identification of foliicolous lichens. Different indices were used for the computation of α- and β-diversity. The biogeographical distribution patterns of the foliicolous lichens of the study area and the possible use of foliicolous lichens as indicator of forest disturbance were analysed.

A total of 70 species of foliicolous lichens and lichenicolous fungi belonging to 27 genera and 15 families were recorded from Godere Forest. From Budongo Forest 125 species of foliicolous lichens & lichenicolous lichens belonging to 32 genera and 16 families were recorded. From Kakamega Forest 137 species belonging to 41 genera and 17 families were recorded. In addition, 7 foliicolous lichens new to science have been recorded in this study. The most species-rich families in both forests were Pilocarpaceae, Porinaceae, Gomphillaceae, and Strigulaceae.

In Godere higher foliicolous lichen diversity was recorded in Dushi than in Bishan Waka forest site. In Budongo high foliicolous lichen diversity was recorded in the young secondary and the primary swamp forests. In Kakamega Forest high foliicolous lichen diversity was recorded in the sites of Yala, Buyangu, Isiukhu, and Kisere. Low diversity was recorded in Malava, Kaimosi and Camp site. Among the 3 forests investigated, α-diversity was significantly higher in Kakamega and Budongo than in Godere forest. β-diversity was high in Kakamega and Budongo and low in Godere. Several studies have shown higher foliicolous lichen diversity in undisturbed primary forests than in disturbed secondary forests. Our study showed high foliicolous lichen diversity in both primary forest and secondary forests with little disturbance. Therefore, for the maintenance of high foliicolous lichen diversity in tropical Africa both primary and old growth forests should be conserved.

This study has shown that foliicolous lichens are good indicators of forest disturbance. The composition of foliicolous differed from primary to secondary and disturbed forests. In addition, some foliicolous lichens were found to be restricted to a particular forest type. The distribution of forest sites along PCA ordination axis has been found to depend on the level of disturbance. Based on the distribution of species and forest sites on the PCA ordination biplot, indicator species for three forest types with different disturbance regimes were selected. *Porina sphaerocephala, P. conica, P. radiate* and *Mazosia rotula* were found to have high fidelity to undisturbed or slightly disturbed closed forets. *Coenogonium geralense, C. siquirrense, C. pocsii* and *Byssoloma leucoblepharum* were identified as indicators of closed forest with moderate disturbance. *Asterothyrium rotuliforme, Psorotheciopsis gyalideoides, P. varieseptata, Calenia aspidota* and *Gyalectidium imperfectum* were found to be indicators of disturbed semi-open forests.

Biogeographic affinity of the foliicolous lichens of the study area shows that 57% of the species have pantropical distribution, 18.6% of the species are restricted to the African paleotropics, 17% of the species are distributed both in the African paleotropics and the Neotropics, and 7.2% of the species are distributed both in the African and Eastern paleotropics. In addition 13 species which have not been recorded from Africa have for the first time been recorded in this study.

Chapter 1. GENERAL INTRODUCTION

1.1 Tropical Rainforests

1.1.1 Extents and uses

Tropical rainforests are Earth’s most complex ecosystem in terms of both structure and species diversity. They are composed of evergreen broadleaved trees which flourish in the high temperature and humidity of the low altitudes between 10^0 north and 10^0 south of the equator (Park 1992). Although tropical rainforests cover only 6% of Earth's land surface, they harbour roughly half of all the world's plant and animal species (National Research Council 1992).

Tropical rainforests are found in Central and South America, Southeast Asia and Central and Western Africa. The tropical rainforests of Latin America harbours 56 percent of the world total, Southeast Asia harbours 25 percent and Central and West Africa harbour 18 percent (Park 1992, Whitmore 1998).

According to the review made by Richards (1996), the large mass of rainforest in Africa is found in the Congo basin from where it continues westwards into Gabon and Cameroon. From there a narrow belt follows the coast of the Gulf of Guinea through Nigeria to Ghana and beyond, finally ending in Guinea at about 10^0N. This western extension of the rainforest is interrupted from western Nigeria to a little west of the Volta River in Ghana by Dahomey Gap, where savannas reach the sea and divide the forest into an eastern and a western block. South of the Democratic Republic of Congo, the African rainforest extends into Angola to about 9^0S. In East Africa the area of continuous forest reaches its eastern limit at Bwamba in western Uganda. East of the Western Rift Valley, forest similar to tropical rainforest is absent except for outliers of various sizes, e.g. Budongo Forest and fragments near Lake Victoria in Uganda, a relic near Kakamega in western Kenya and some small areas in northwestern Tanzania.

The tropical rainforests of Africa are the most species-riche ecosystem in the region housing more than half of Africa’s biota (Sayer *et al*. 1992). They are estimated to contain over 8000 plant species, some 80 % of which are endemic (White, 1983). The total forest cover in Africa is estimated at 635,412,000 ha, accounting for 21 % of the land area and 16 % of global forest cover (FAO, 2006).

Tropical forests provide environmental, economical and aesthetic services and values. They provide row materials for plant improvement programs and modern pharmaceutical industries. They regulate local and global climate and play important role in watershed management, soil erosion control and the carbon dioxide budget of global atmosphere. Millions of people living in or around tropical forests depend on the forests for many forest products and environmental services. Tropical forests are the main source of energy in the form of fuelwood; they provide timber and non-timber forest products; they are sources of food, particularly in times of drought and famine; and they are sources of traditional medicines.

1.1.2 Deforestation and fragmentation in tropical forests

Human activity has had devastating impacts on tropical forests. Human impact could be in the form of conversion of natural forest into other land uses (deforestation), fragmentation into smaller patches with deforested areas in between, and various degrees of disturbance, such as silvicultural activities.

Deforestation is the permanent loss of forest to other land uses such as agriculture, grazing, new settlements, and infrastructure. Deforestation in the tropics is widely recognized as one of the main environmental problems facing the world today. Tropical forests are being destroyed and fragmented at an ever-increasing rate with series environmental and biological consequences including loss of biodiversity (Whitmore & Sayer 1994, Turner 1996) and climate change at local, regional and global levels (Myers 1988). The Food and Agriculture Organization of the United Nations (FAO 2006) estimated that in the 1990s tropical countries have lost 111,350 km^2 of forests annually and 114,270 km^2 of tropical forests were lost between 2000 and 2005.

The forests of Africa have long been affected by humans. Outside the Congo core the African rainforests have been extensively destroyed (Whitmore 1998). The estimate for the annual rates of deforestation in Africa is 43,750 km^2 for the period 1990-2000 and 40,400 km^2 for 2000-2005 (FAO 2006). In East Africa the forest resources are steadily disappearing and those that are left are being degraded. Between 1990 and 2000 the forest covers of Ethiopia, Uganda and Kenya were respectively reduced from 49,960 km^2 to 45,930 km^2, from 51,030 km^2 to 41,900 km^2 and from 180,270 km^2 to 170,960 km^2 (FAO 2001). Most of the remaining forests in these countries today exist as disturbed and secondary forests of different seral stages.

One major consequence of deforestation is the fragmentation of habitats in natural forests. Habitat fragmentation is the subdivision of continuous habitat blocks into clusters of small remnant patches isolated by matrix of other land use types (Andrén 1994, Fahrig 2003). Fragmentation could occur by natural disturbance (e.g. fire, windthrow) or due to anthropogenic disturbance which include clearing of forest for agriculture, road and dam construction and logging (Attiwill 1994, Wade *et al.* 2006).

Habitat fragmentation causes changes in the physical environment and biogeographic entities (Saunders *et al.* 1990). Loss and fragmentation of natural habitat are considered major threats to global biodiversity (Lovett & Wasser 1993, Laurance & Bierregaard 1997). The effect is more severe in tropical forests where diversity is high and forests are being removed and fragmented at an increasing rate (Pineda & Halffter 2004).

General Introduction

Forest fragmentation has impact on biodiversity (Turner 1996), increasing isolation of habitats, endangering species of plants, mammals and birds (Skole & Tucker 1993, Scariot 1999, Laurance *et al.* 2000) and on a variety of population and community dynamic processes (Saunders *et al*. 1991, Valladares *et al.* 2006). However, the effects of habitat fragmentation on species diversity vary among different habitats and taxa. These effects could be both positive and negative (Fahrig 2003). Positive effects include the creation of edge habitat increasing the abundances of edge or gap species (Yahner 1988, Malcom 1994) and negative impacts include increasing the local rate of extinction by reducing population sizes (Leach & Givnish 1996), creating forest edges and altering microclimate at forest edges (Matlack 1993), changing forest dynamics (Wade *et al*. 2006), and increasing predation at forest edges (Chalfoun *et al*. 2002). These impacts may be due to one or a combination of four separate effects: forest fragmentation *per se*, the loss of habitat during fragmentation, habitat degradation following the isolation of fragments, and the effect of isolation *per se* (Harrison & Bruna 1999). Some ecologists (Fahrig 1997, Caley *et al*. 2001, Fahrig 2003) advocate the separation of habitat loss and habitat fragmentation *per se* and claim that species loss and decline in species abundance following fragmentation is associated with habitat loss than with fragmentation *per se* (Caley *et al*. 2001).

Although there are various studies on the impact of habitat fragmentation on bryophytes (Zartman 2003), lichens (Esseen & Renhorn 1998), palms (Fleury 2006), beetles (Davies & Margules 1998), butterflies (Daily & Ehrlich 1995), corals (Caley et al. 2001), amphibians (Pineda 2003), birds (Hagen *et al*. 1996, Carlson 2001, Githiru & Lens 2007, Giraudo *et al*. 2008) and mammals (Laurance 1994, Malcolm 1997), the long-term effect of habitat fragmentation on species diversity is far from being known.

The major causes of forest destruction and degradation in the tropical Africa are conversion to subsistence and commercial agricultural land use, fuelwood collection, human settlement, commercial logging, and overgrazing by domestic animals. These causes are driven and aggravated by poverty and population growth. Most of the people in tropical Africa live in rural area and the rate of population growth in these areas is high (e.g. > 2.5% in East Africa, Masci 2006). The increasing population growth demands additional land for agriculture which in most cases can only be met by forest conversion. Migration and settlement of landless people from densely populated and draught affected parts to areas covered by forest in search of agricultural land and to engage in charcoal production and pit sawing to sell for the rapidly growing urban centers has also accelerated the rate of deforestation. Development policies outside the forestry sector have contributed for the destruction of forests in many African countries. The conversion of natural forests into commercial plantations such as coffee and tea plantations in Ethiopia (Yeshitela 2001), sugarcane plantation in Uganda and sugarcane and tea plantations in Kenya are some of the examples.

1.2 Foliicolous lichens

Santesson (1952) defined foliicolous lichens as those growing on living leaves of vascular plants. Ecologically, foliicolous lichens could be grouped into three groups. Typical foliicolous lichens grow and reproduce entirely on leaves. Facultative foliicolous lichens grow on barks, petioles and twigs but exceptionally grow on leaves. Ubiquitous species equally grow and reproduce on living leaves and twigs. In addition, foliicolous lichens have been observed growing on artificial substrates such as plastics materials (Sipman 1994, Lücking 1998c, Sanders 2002, Sanders & Lücking 2002, Sanders 2005).

Foliicolous lichens are found in tropical forests of central and south America, Africa and Southeast Asia. They are one of the most abundant epiphytes in tropical rainforests (Richards 1996, Lücking 2001, Anthony *et al.* 2002) and one of the few groups of organisms that characterize these forests (Lücking 2001). Outside the tropical areas, foliicolous lichens are found in subtropical areas (Vězda 1983, Sérusiaux 1993, 1996, Puntillo & Ottonello 1997, Puntillo *et al*. 2000, Thor *et al*. 2000, Llop & Gómez-Bolea 2006) and temperate rainforests (Malcolm & Galloway 1997, Lücking *et al*. 2003), but then occurrence is very limited and restricted to very humid areas.

After the monographic work of Santesson (1952) on obligately foliicolous lichens, there has been a considerable study on the taxonomy, distribution and even phylogeny of foliicolous lichens and several publications, including revisions and monographs, have been produced. Several new taxa have been described and the taxonomy of already described taxa has been amended. Compared to corticolous microlichens of tropical forests, the taxonomy, diversity and distribution of foliicolous lichens is well understood.

The checklist of foliicolous lichens and lichenicolous lichens (Lücking *et al*. 2000a) listed 716 species and 72 genera of foliicolous lichens. Since then many foliicolous lichens have been described, among others, by Ferraro *et al*. (2001), Lücking & Kalb (2001), Lücking & Lumbsch (2001), Lücking & Santesson (2001), Lücking *et al*. (2001), Sérusiaux & Lücking (2001), Herrera-Campos & Lücking (2002, 2003), Lücking & Kalb (2002), Lücking & Santesson (2002), Ferraro & Lücking (2003), Lücking *et al*. (2003), Sérusiaux & Lücking (2003), Herrera-Campos *et al*. (2004a), Vezda (2004), Lücking *et al*. (2006), Lücking (2006), Rivas-Plata *et al*. (2006), Lücking *et al*. (2007), Papong *et al*. (2007), Sérusiaux (2007), Sérusiaux & Lücking (2007) and Lücking (2008)

Foliicolous lichens exhibit structural diversity of growth form, thallus, ascomata and conidiomata. All foliicolous lichens are crustose except members of the genera *Coccocarpia, Leptogium, Parmeliella* and *Psoroma* which assume foliose/squamulose growth habit. Growth could be supracuticular (most follicolous lichens) or subcuticular (e.g. *Strigula antillarum*, *S. nemathora*, *S. smaragdula*), epiphyllous (most foliicolous lichens) or hypophyllous (*Coenogonium hypophyllous, Strigula janeirensis, Bacidina hypophylla*).

Thallus could be smooth (e.g. *Coengonium pocsii, Porina rubentior*) or verrucose (e.g. *Mazosia melanopthalma, Porina mazosioides, Sporopodium leprieurii*) or farinose-granulose (*Bacidina* sp.), corticate (e.g. species of *Asterothyrium*, and *Psorotheciopsis* and *Calenia bullatinoides*) or ecorticate (most follicolous lichens); with hairs (e.g. species of *Aderkomyces, Tricharia,* and *Rubrotricha*) or with out hairs (most foliicolous lichens); dispersed (e.g. species of *Loflammia*, and *Tapellaria major*) or continuous (e.g. *Strigula macrocarpa*).

Mycobiont could be ascomycetes (most foliicolous lichens), or basidiomycetes (*Dictyonema* sp.). Phycobiont could be *Trentepohlia* sp. (e.g. *Coenogonium* sp.), *Phycopeltis* (e.g. *Porina epiphylla*), *Cephaleuros* (e.g. species of *Strigula*) or *Trebouxia* sp. (e.g. *Sporopodium leprieurii*).

Ascomata could be apothecia (e.g. species of *Fellhanera*, *Chroodiscus*), or perithecia (e.g. species of *Porina* and *Strigula*). Ascomata could occur singly (most foliicolous lichens) or within stromata (e.g. *Flavobathelim epiphyllum*). Conidiomata could be pycnidia (e.g. *Coenogonium subluteum, Fellhanera africana, Caprettia setifera*), campylidia (e.g. *Musaespora kalbii,* species of *Sporopodium, Calopadia, Tapllaria*, and *Badimia*) or hyphophores (species of Gomphillaceae).

Vegetative propagation could be with isidia (e.g. *Chroodiscus mirificus, Coccocarpia domingensis, Phylloblastia borhidii, Porina distans, Bacidina scutellifera, Coenogonium isidiiferum*), or soredia (e.g. *Fellhanera ivoriensis, Bapalmuia napoensis*).

The diversity and distribution of foliicolous lichens is influenced by geographical distribution and environmental factors. Generally foliicolous lichens diversity is high in tropical regions, usually close to the equator (Herrera-Campos *et al*. 2004b) and species richness decreases with increasing latitudes. Altitudinal zonation of vegetation, degree of seasonality and microclimatic condition of light intensity are the most important factors (Lücking 1992b, Lücking 1995, Lücking 1997d). Species richness is highest at low altitude forests and decreases at high altitude forests (Herrera-Campos *et al*. 2004b). Diversity decreases with increasing seasonality where synchronized leaf shading becomes a hindrance for foliicolous lichens establishment, growth and reproduction (Lücking 1997d). Therefore, diversity is high in the wet, humid or moist forests in which a dry season is absent or is slight and decreases as the length of dry season increases. Within a tropical rainforest, diversity is high in the shady understorey and decreases in the light gap and the upper canopy. Not only is there a change in diversity along microclimatic gradient, but also differences in species composition. In tropical rain forest, for example, species of the family Arthoniaceae, Porinaceae and supra-cuticular Strigulaceae dominate in the shady understorey, in the light gap species of Gomphillaceae, sub-cuticular Strigulaceae and campylidia bearing members of the Pilocarpaceae dominate and members of the Asterothyriaceae and Gomphillaceae dominate in the canopy (Cáceres *et al*. 2000, Lücking 2001).

In tropical rainforests, foliicolous lichens exhibit broad phorophyte ranges and low specificity (Aptroot 1997, Lücking 1998b). They exhibit phorophyte preference only in species poor sites of subtropical forests (Conran 1997). The principal features of the phorophytes that govern species richness of foliicolous lichens are leaf surface structure, leaf longevity and presence or absence of hairs (Lücking 1998e). Species richness is high on phorophytes having long-lived leaves with grooved or ornamented fine surface and high surface continuity. Hairs or glands on the upper leaf surface influence the growth of foliicolous lichens by influencing air and water currents on leaf surface (Lücking 1998e), thus rendering the successful establishment of diaspores more difficult.

Lichens are poikilohydric organisms lacking mechanisms for regulating uptake and loss of water. They take water and nutrients across the surface of their body. As a result, their growth and distribution are influenced by microenvironmental features of light intensity, humidity and temperature (Connelissen & Ter Steege 1989, Renhorn *et al.* 1997). Therefore, activities and events that result changes in microhabitat could affect their diversity. Conversion of tropical rainforest into agricultural land (Pócs 1996) and forest fragmentation (Brown & Jarman 1994) are the biggest threat to lichens and other epiphyllous flora. Foliicolous lichens are more vulnerable than corticolus ones as the later could survive in small niches after destruction of the forest (Pócs 1996). Shade loving lichens with higher air moisture requirements are affected by canopy openings and the formation of edges during forest degradation.

As compared to tropical America and South East Asia, the foliicolous lichen flora of tropical Africa is insufficiently known. Among the East African countries Tanzania and Kenya are comparatively better known for their foliicolous lichens with 144 species in Tanzania (Feuerer 2007) and 97 species including 5 lichenicolous fungi in Kenya (Lücking & Kalb 2002). Feuerer (2007) listed only 29 foliicolous lichen species for Uganda while no foliicolous lichen species is included among the 279 lichen species list of Ethiopia. Therefore, much task is ahead before the foliicolous lichens of tropical Africa are adequately known. However, the ongoing high rate of deforestation is frustrating that many lichens may disappear before we discover and name them. It is therefore high time that the foliicolous lichen diversity of primary as well as anthropogenic forests is documented and utilized for the development of a sustainable forest management program.

1.3 Objectives

With the current state of increasing dependence of people on forest resources, degradation and conversion of forests in tropical Africa is not going to stop soon. It is thus necessary to design mechanisms by which biodiversity can be conserved and the conservation value of forests already degraded improved under conditions of high human pressure. However, our knowledge on the biodiversity of tropical forests is fragmentary and many groups of organisms, including cryptogams, are unknown or inadequately known. It is therefore necessary to study diversity in primary forests as well as the impact of human exploitation on biodiversity.

1. The phanerogamic flora of Godere, Budongo and Kakamega forests are comparatively well known. However, there is no information on the cryptogamic flora the area. Therefore, the first objective of the present study is to describe the foliicolous lichen flora of these forests.

2. Anthropogenic disturbances affect the biodiversity of an area and the response of organisms to such disturbances is variable. Therefore, in this study
    - the effects of forest disturbance on the diversity of foliicolous lichens is evaluated
    - the change in the diversity of foliicolous lichens along forest disturbance gradient is analyzed
3. For a sustainable forest management, emphasis should be given to the conservation of forest biodiversity. For this to happen, the current status of biodiversity should be known and assessed. In this regard, the importance of foliicolous lichens as bioindicators of particular forest types and disturbance levels is evaluated.
4. Foliicolous lichens have different geographic distribution patterns. In this regard, the lichenogeographical distribution of the foliicolous lichens of the study area is evaluated.

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Chapter 2. GENERAL METHODOLOGY

2.1 Foliicolous lichens sampling

Sampling for foliicolous lichens was performed following the sampling methods outlined by Lücking & Lücking (1996). Transects were laid in a homogenous stand of forest and phorophytes reaching a height of up to 3 m were considered for sampling both in the shady understorey and in the light gap microsites of the understorey vegetation. From each phorophyte individuals, a single branch with comparatively much foliicolous lichen was selected as a sample and the leaves that carried foliicolous lichens were collected. From *Dracaena fragrans,* the shoot was considered as a sample and up to 10 leaves were collected. Leaves were also collected from a recently fallen canopy trees. On average 633 leaves were collected from Godere Forest, 2040 leaves from Budongo Forest and 3040 leaves from Kakamega Forest.

Identification of specimen of foliicolous lichens was based on examination of morphological and anatomical features. Morphological characters of thallus, ascomata and conidiomata were examined under stereomicroscope. Hand cut sections and squash preparations were made for studies of the anatomy of thalli and reproductive structures, including perithecia, apothecia, campylidia, pycnidia, and hyphophores and examined under Olympus light microscope. Luglo's solution was used for the color reactions of ascus walls. Photographs were taken under the light microscope. Voucher specimens of all collections are deposited in the herbarium of the department of Biology of the University of Koblenz-Landau (KOBL) in Germany.

2.2 Foliicolous lichen identification

For a general identification of foliicolous lichen genera, Santesson (1952), Lücking (1992a) and the internet key developed by Lücking (2000a) were utilized. In addition, the following literatures were consulted for generic identification. For genera in the Arthoniaceae Lücking (1995a) and Ferraro & Lücking (1997), for Asterothyriaceae Lücking (1999b) and Henssen & Lücking (2002), for Coccocarpiaceae Swinscow & Krog (1988), for Gomphillaceae Lücking *et al*. (2005), for lichenicolous fungi Matzer (1996), for Pilocarpaceae Vězda (1986), for Porinaceae Hafellner & Kalb (1995), for Rocellaceae Grübe (1998) and Sparrius (2004), and for Thelotremataceae Frisch (2006).

For species and infra-specific taxa identification, the following sources of information were used. For *Aderkomyces* Vězda (1975a) and Lücking *et al.* (2005); for *Arthonia* Santesson (1952), Lücking (1992a), Lücking (1995a), and Ferraro & Lücking (1997); for *Aspidothelium* Sérusiaux & Lücking (2001); for *Asterothyrium* Santesson (1952), Vězda (1979), Lücking (1999b), Henssen & Lücking (2002), and Lücking & Kalb, K. (2002); for *Aulaxina* Vězda (1979), Lücking (1997a), and Lücking *et al.* (2005); for *Bacidia* Ekman (1996); for *Bacidina* Vězda (1980), Vězda (1990a), and Farkas & Vězda (1993); for

Badimia Vězda (1980); for *Bapalmuia* Santesson & Lücking (1999), and Kalb *et al.* (2000); for *Brasilicia* Vězda (1974) and Santesson & Lücking (1999); for *Byssolecania* Santesson (1952) and Lücking & Kalb (2000); for *Byssoloma* Santesson 1952, Vezda (1975b), Vězda (1987), Kalb & Vězda (1990), and Lücking (1997c); for *Calenia* Vězda (1979), Lücking (1997a), Lücking *et al.* (2001b), and Lücking *et al.* (2005); for *Calopadia* Santesson (1952), Vězda (1986), Lücking (1997c), and Lücking (1999c); for *Caprettia* Vězda (1975), Malcolm & Vězda (1995b), Sérusiaux & Lücking (2003), and Vězda (2004); for *Chroodiscus* Lücking (1999b), Santesson & Lücking (1999), and Lücking & Grube (2002); for *Coccocarpia* Santesson (1952), Arvidsson (1991) and Lücking *et al.* (2007); for *Coenogonium* Vězda & Farkas (1988), Vězda (1990b), Malcolm & Vězda (1995b), Lücking (1999a), Lücking & Kalb (2000), and Rivas-Plata *et al.* (2006); for *Echinoplaca* Vězda (1979), Lücking (1997a), Lücking *et al.* (2005); for *Enterographa* Herrera-Campos & Lücking (2002), Lücking & Matzer (1996), Sparrius (2004), and Ertz *et al.* (2005); for *Eremothecella* Sérusiaux (1992), and Lücking (1995a); for *Eugeniella* Sérusiaux & Lücking (unpublished); for *Fellhanera* Vězda (1974), Vězda (1975), Vězda (1980), Vězda (1986), Sérusiaux (1996), Lücking (1997b), Lücking & Santesson (2001), and Lücking *et al.* (2001a); for *Gyalectidium* Vězda (1979), Sérusiaux & De Sloover (1986), Lücking (1997a), Ferraro *et al.* (2001), and Lücking *et al.* (2005); for *Gyalidea* Vězda (1966), Vězda (1973), Vězda (1979), Vězda & Poelt (1991), and Henssen & Lücking (2002); for *Gyalideopsis* Lücking & Sérusiaux (1998), and Lücking *et al.* (2006); for *Lasioloma* Vězda (1986), and Lücking & Sérusiaux (2001); for *Loflammia* Santesson (1952), Vězda (1986), and Lücking (1999c); for *Lyromma* Lücking (1992), and Lücking & Kalb (2000); for *Mazosia* Vězda (1973), Farkas (1987), and Kalb & Vězda (1988a); for *Musaespora* Lücking & Sérusiaux (1997); for *Phylloblastia* Vězda (1982), Farkas & Vězda (1993), and Lücking (2008); for *Porina* Santesson (1952), Vězda (1975a), Farkas (1987), Lücking (1991), Vězda (1994), Hafellner & Kalb (1995), Lücking (1996), Lücking & Vězda (1998), Lücking *et al.* (1998), and Lücking (2004); for *Psorotheciopsis* Santesson (1952), Vězda (1973), Vězda (1974), and Henssen & Lücking (2002); for *Sporopodium* Santesson (1952), Vězda (1986), Elix *et al.* (1995), Lücking (1999c), and Lücking & Kalb (2002); for *Strigula* Santesson (1952), Farkas (1987), Lücking (1991), and Lücking (1992a); for *Tapellaria* Santesson (1952), Sérusiaux (1984), and Vězda (1986); for *Tricharia* Vězda (1979), Lücking (1997a), Lücking *et al.* (2005), and Kalb & Vězda (1988b); and for *Trichothelium* Lücking (1991), Malcolm & Vězda (1995a), Lücking (1998a) and Vězda (1994).

Nomenclature follows Lücking *et al.* (2000) for species described until 2000 and for species described after 2000 the most recent literature for the taxon are followed. For species in the genus *Coenogonium* nomenclature follows Rivas-Plata *et al.* (2006).

2.3 Data Analysis

2.3.1 Floristic composition and species frequency

The foliicolous lichen species compositions of Godere, Budongo and Kakamega forests as well as their respective forest types are described. Frequency which is the number of samples in which a species occurs is computed for each forest as a whole and the various forest types separately. The following frequency classes were used to designate the frequency status of a species:

≤10% occurrence = Rare
11-20% occurrence =Occasional
21-30% occurrence =Less frequent
31-40% occurrence =Frequent
41-50% occurrence = Very frequent
>50% occurrence = Dominant

2.3.2 Alpha-diversity

Alpha-diversity is the diversity within a particular sample or community. It is also called the within-habitat diversity. Direct species count to give species richness is the simplest measure of diversity. Many diversity indices, however, take into account two aspects of species diversity: species richness and species evenness (equitability). Species richness describes how large the number of species in a community is, while species evenness describes the relative abundance with which each species is represented in an area. There are various measures of species richness, evenness and diversity to compare communities.

2.3.2.1 Sample based rarefaction and species accumulation curves

Comparison of community samples based on different sample sizes is problematic in the determination of species richness as the number of species observed is dependent on the sample size (Peet 1974, Magurran 1988). To overcome this problem, all samples from different communities should be standardized to a common sample size of the same number of individuals (Krebs 1994). A rarefaction method (Sanders 1968) provides a procedure to scale down all collections to the same sample size number for comparison when the samples are taxonomically similar and the sampling methods the same. A species accumulation curve is the graph of the cumulative number of observed species as a function of some measure of sampling effort (Colwell & Coddington 1994). Sample based accumulation curves result when sampling is based on some sampling units (e.g. quadrats) and the total number of species is accumulated as a result of successively sampling additional sampling units (Gotelli & Colwell 2001). Rarefaction and species accumulation curves are closely related (Magurran 2004). Rarefaction estimates the number of species expected to be seen in a smaller sample. The species accumulation curves are used to estimate the total number of species.

In this study sample based rarefaction curves (Gotelli & Colwell 2001) are computed in order to compare the species richness of different forest types in Godere, Budongo and Kakamega forests. Species accumulation curves were computed for the various forest types to estimate the number of species, to examine the degree of foliicolous lichen collection, and to evaluate the effectiveness of the species richness estimators.

2.3.2.2 Species richness estimation

The observed number of species in a given habitat is usually less than the number of actually occurring species. There are different estimation methods that allow estimation of the expected number of species from sample data (Colwell & Coddington 1994, Magurran 2004). In this study non-parametric species estimators which are appropriate for incidence-based (presence/absence) data were followed. The estimators are Chao 2, First Order Jackknife (Jack 1), Second Order Jackknife (Jack 2), Bootstrap, and Incidence Based Coverage Estimator (ICE), and Michaelis-Menten Means (MMMeans). These non-parametric estimators estimate species that are absent in the sample data, but likely to exist in a larger homogenous sample, from the proportional abundances of species within the total sample (Soberón & Llorente 1993, Chao *et al*. 2005)

EstimateS version 8 (Colwell 2006) which is a public domain software was used to compute the expected species accumulation curves and estimates of the expected species richness. The sample order was randomized 100 times to compute the mean estimator and expected species richness for each sample accumulation level.

The equations EstimateS uses in estimating species richness are as follows (Colwell 2006).

1. The Chao 2 incidence-based estimator is based on the number of uniques (species found in only one sample), and the number of duplicates (species found in exactly two samples). The classic formula is

$$S_{Chao2} = S_{obs} + \frac{Q_1^{\ 2}}{2Q_2},$$

and the bias-corrected formula is

$$S_{Chao2} = S_{obs} + \left(\frac{m-1}{m}\right)\left(\frac{Q_1(Q_1-1)}{2(Q_2+1)}\right)$$

where S_{chao2} = the expected species number based on Caho 2 estimator

S_{obs} = the number of species observed

Q_1 = the number of uniques

Q_2 = the number of duplicates

m = total number of species

2. The first order Jackknife estimator is based on the number of species occurring in only one sample.

$$S_{jack1} = S_{obs} + Q_1\left(\frac{m-1}{m}\right)$$

where S_{jack1} = the expected species number based on Jack 1 estimator
S_{obs} = the number of species observed
Q_1 = the number of uniques
m = total number of species

3. The second order Jackknife estimator is based on the number of species occurring in only 1 sample and the number of species occurring in exactly 2 samples.

$$S_{jack2} = S_{obs} + \left[\frac{Q_1(2m-3)^2}{m} - \frac{Q_2(m-2)^2}{m(m-1)}\right]$$

where S_{jack2} = the expected species number based on Jack 2 estimator
S_{obs} = the number of species observed
Q_1 = the number of uniques
Q_2 = the number of duplicates
m = total number of species

4. The Bootstrap estimator is based on the proportion of samples containing each species.

$$S_{boot} = S_{obs} + \sum_{k=1}^{S_{obs}} (1-p_k)^m$$

where S_{boot} = the expected species number based on Bootstrap estimator
S_{obs} = the number of species observed
p_k = proportion of samples that contain species k
m = total number of species

5. Incidence-based Coverage Estimator is based on species found in 10 or fewer samples.

$$S_{ice} = S_{freq} + \frac{S_{\inf r}}{C_{ice}} + \frac{Q_1}{C_{ice}}\gamma^2{}_{ice}$$

$$C_{ice} = 1 - \frac{Q_1}{N_{\inf r}} \quad , \qquad N_{\inf r} = \sum_{j=1}^{10} jQ_j \ ,$$

$$\gamma^2{}_{ice} = \max\left[\frac{S_{\inf r}}{C_{ice}} \frac{m_{\inf r}}{(m_{\inf r}-1)} \frac{\sum_{j=1}^{10} j(j-1)Q_j}{(N_{\inf r})^2} - 1, 0\right]$$

where S_{ice} = expected species number based on incidence-based coverage estimator

S_{freq} = number of frequent species (each found in more than 10 samples)
S_{infr} = number of infrequent species (each found in 10 or fewer samples)
C_{ice} = sample incidence coverage estimator
N_{infr} = total number of incidences (occurrences) of infrequent species
m_{infr} = number of samples that have at least one infrequent species
γ^2_{ice} = estimated coefficient of variation of the Q_1 for infrequent species

6. Michaelis-Menten Mean richness estimator (MMMean) is an asymptotic extrapolation of the species accumulation curve. It computes the estimates once for each sample pooling level based on the species accumulation curve as computed by MaoTau in EstimateS.

2.3.2.3 Shannon-Wiener measure of diversity

The Shannon-Wiener index (Shannon & Weaver 1949) of diversity is the most commonly used to characterize diversity in a community. The index is based on the rationale that the diversity or information in a natural system can be measured in a similar way to the information contained in a code or a message (Magurran 2004). It assumes that individuals are randomly sampled from an infinitely large community, and that all species are represented in the sample (which is always difficult to attain in plant communities). The index has the following formula:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

$$p_i = \frac{n_i}{N}$$

where H'= Shannon-Wiener index of species diversity (calculated with base e logs)
pi = proportion of total sample belonging to ith species
N = total number of species
ni = individual number of species i

The Shannon Diversity Index typically falls between 1.5 and 4.0, with lower values indicating lower diversity, and higher values indicating higher diversity. The Shannon index tends to be weighted slightly towards rare species.

2.3.2.4 Shannon's Index of evenness

The evenness component of diversity expresses how individuals are distributed among the species. A community with all individuals equally distributed among the species is more diverse than a community with high dominance of one or few species. Among the various indicies of evenness, the Shannon's evenness was computed as the ratio of observed diversity to maximum diversity (Magurran 1988).

$$J' = \frac{H'}{H'_{\max}} = \frac{\sum_{i=1}^{s} p_i \ln p_i}{\ln s}$$

where J' = Equitability (evenness)
s = the number of species
p_i = the proportion of individuals of the ith species
ln = log base_e

2.3.3 Beta-diversity

Beta diversity or between-habitat diversity is the measure of the change in species diversity between habitats or communities. It is usually expressed in terms of a similarity index between communities or as a species turnover rate. In this study the former is computed with Sørensen index of similarity for qualitative data (Sørensen 1948) and the latter with Whittaker's index for β-diversity (Whittaker 1960).

$$\beta_w = \frac{S}{\alpha}$$

where β_w = Whittaker's index of diversity
S = the total number of species in a forest type
α = the mean sample species number

$$S_s = \frac{2c}{a+b}$$

where S_s= Sørensen similarity index,
a = the number of species in one forest type
b= the number of species in the other forest types
c= the number of species common to both forest types

2.3.4 Statistical analysis

Statistical analysis were performed to determine whether the data are normally distributed, to check the equality of variances of means and for the comparison of the mean species number of samples. Levene Equal-Variance test was performed to test the equality of variances.

Shapiro-Wilk test (Shapiro & Wilk 1965) was run in order to test for normal distribution of the species distribution of samples. When distributions were found to be non normal, the Kruskal-Wallis Analysis of Variance test (Kruskal & Wallis 1952) was employed for the comparison of samples. This test is a non-parametric method for testing equality of population medians among groups. It is most commonly used when the measurement variable does not meet the normality assumption of an analysis of variance (ANOVA). The basic assumptions of the Kruskal-Wallis test are independent samples, continuous variables, a measurement scale of at least ordinal scale and the distributions for the groups are identical (Hintze 2007). When Kruskal–Wallis test provided significant difference, it was followed by comparisons of mean ranks using Kruskal-Wallis multiple comparison procedures.

The values of Shannon diversity indices of the various study sites in Godere, Budongo and Kakamega forests were compared for significant differences using t-test and ANOVA. Magurran (2004) pointed out that estimate of diversity produced by the Shannon index is approximately normally distributed making comparisons with parametric tests feasible. When ANOVA resulted in significant difference, it was followed by Fischer's least significant post hoc treatment to see which study sites are significantly different.

For calculating the variance of the Shannon index of diversity, the following formula given by Magurran (1988) was used.

$$VarH' = \frac{\sum p_i (\ln pi)^2 - \sum (pi \ln pi)^2}{N} - \frac{S-1}{2N^2}$$

The t statistic for the t test associated with the Shannon index is

$$t = \frac{H'_1 - H'_2}{\sqrt{VarH_1' + VarH'_2}}$$

where VarH' = variance of the Shannon index

N= sample size

S= No. of species

A significance probability less than $p < 0.05$ was considered as significant differences between means and medians. All statistical analyses were performed with the software NCSS (Hintze 2007) and Statigraphics version 5 software (Statistical Graphics Corporation).

2.3.5 Multivariate analysis

Data from community ecology usually consist of the abundance or importance of taxa (usually species) indexed by sampling units (Palmer 1993). Such data are multidimensional and multivariate analysis is required for easy summarization of the data. In this study an indirect gradient analysis (indirect ordination) is followed to summarize the floristic data of the study sites. Indirect ordination is based on analysis of floristic data with the assumption that examination of variability in floristics reflects variation in environment (Kent & Coker 1992).

Detrended Correspondence Analysis (DCA; Hill and Gauch 1980) is an indirect gradient analysis for ordination of samples and species. DCA is a method based on the assumption of unimodal response of species abundance to environmental gradient and uses weighted averaging for calculation of ordination scores. The axes of DCA are scaled in units of the average standard deviation of species turnover and describe gradients. The eigenvalue associated with each axis can be thought of as the proportion of variation in sample or species dispersion explained by that axis (Gauch 1982). DCA arranges samples according to their species similarity along axes in a multi-dimensional space with the eigenvalue of the first axis greater than that of the second and so on.

Principal Component Analysis (PCA) is a method that reduces data dimensionality by performing a covariance analysis between factors. It involves a mathematical procedure that transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called principal components. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. PCA is a method based on the assumption of linear response of species abundance to environmental gradient and uses eigenvalues to determine axis values.

The species by sample data matrices of Godere and Budongo forests were subject to ordination analysis by DCA as a means of summarizing the information in the data matrices. Before subjecting the data matrices to DCA analysis, samples with 3 and less species were removed to reduce noise resulting from rare species. Presence/absence data were converted to quantitative value ranging between 0 and 1 expressing the probability of a species occurrence in a sample in relation to the other species in the sample. The resulting data matrix contained 75 species and 60 samples for Godere, 129 species and 164 samples for Budongo, and 146 species and 304 samples for Kakamega. However, the variation explained by the first three axes of DCA ordination of the data matrix of Kakamega was very small (14.3% of the total variation). Therefore, for the ordination of Kakamega's data Principal Component Analysis was performed on the species by forest site data matrix. PCA is preferred to DCA because the gradient length was short (less than 3) in the initial correspondence analysis and ter Braak & Šmilauer (2002) recommended PCA for short gradient lengths. In the DCA ordination detrending by segment (26 segments), downweighting of rare species and log transformation of species data were selected. In the PCA ordination centering by species was selected. Both DCA and PCA ordinations were run using the software CANOCO 4.5 (ter Braak & Šmilauer 2002).

Chapter 3 DIVERSITY OF FOLIICOLOUS LICHENS IN GODERE FOREST, ETHIOPIA

3.1 Study area

3.1.1 Location and physiography

Godere Forest is situated in Godere District of the Gambella People's National Regional State (GPNRS) in southwestern Ethiopia between $07^0$08.395'- $7^0$23.437'N Latitude and 34°52.793'-35°25.445'E Longitude (Fig. 3.1). The forest covers an area of 120,000 ha (Bureau of Agriculture, GPNRS, unpublished document) and altitude in the forest varies from 500 m a.s.l. to 2400 m a.s.l. At altitudes between 500 and 1500 m the natural forests belong to the transitional rainforest type of Friis (1992) and the afromontane rainforest type is found at altitudes above 1500 m. About 52 % of the forest is found at elevations between 500 and 1000 m and 38 % of the forest between 1000 and 1500 m altitude (Ersado 2003).

At altitudes above 1250 m, the topography is characterized by undulating and dissected terrain. At altitudes below 1250 m and the terrain becomes rather flat and about 83 % of the forest develops on this flat terrain. Godere, Achani and Gilo are the major rivers in the forest and belong to the Baro-Akobo drainage system which is the tributary of the Nile River.

3.1.2. Geology and Soil

In Ethiopia, the basement complex upon which all the younger formations were deposited contains the intensively folded and faulted Precambrian rocks (Mohr 1962, Kazmin 1972, Westphal 1975). These rocks are overlain by Mesozoic rocks, mainly sandstone and limestone, and by Tertiary volcanic rocks, mainly basalts, rhyolites, trachytes, tuffs, ignimbrites, agglomerates (Friis 1992). The Southwest Ethiopia Volcanites, which include the Omo Basalts (Oligocene to Miocene) and the Jimma Volcanites (Oligocene to Miocene), are found in southwestern Ethiopia (Asres 1996).

There is no published information on the soils of the study area. From the general account of the soils of southwestern Ethiopia by Asres (1996), it can be deduced that the soils of the study area are Nitosols having a depth of more than 1.5 m. An analysis of soil samples take from Godere Forest undertaken by the National Soil Laboratory of the Ethiopian Institute of Agricultural Research on behalf of the Institute of Biodiversity Conservation shows that the soil is slightly acidic (pH 6.5), and is rich in exchangeable bases (Sodium 0.72 meq/100 g, Potassium 2.4 meq/100 gm, Calcium 22.4 meq/100 g, Magnesium 7.7 meq/100 g) and cation exchange capacity (38.6 meq/100 g). The soils were reddish brown, well drained and clay in texture.

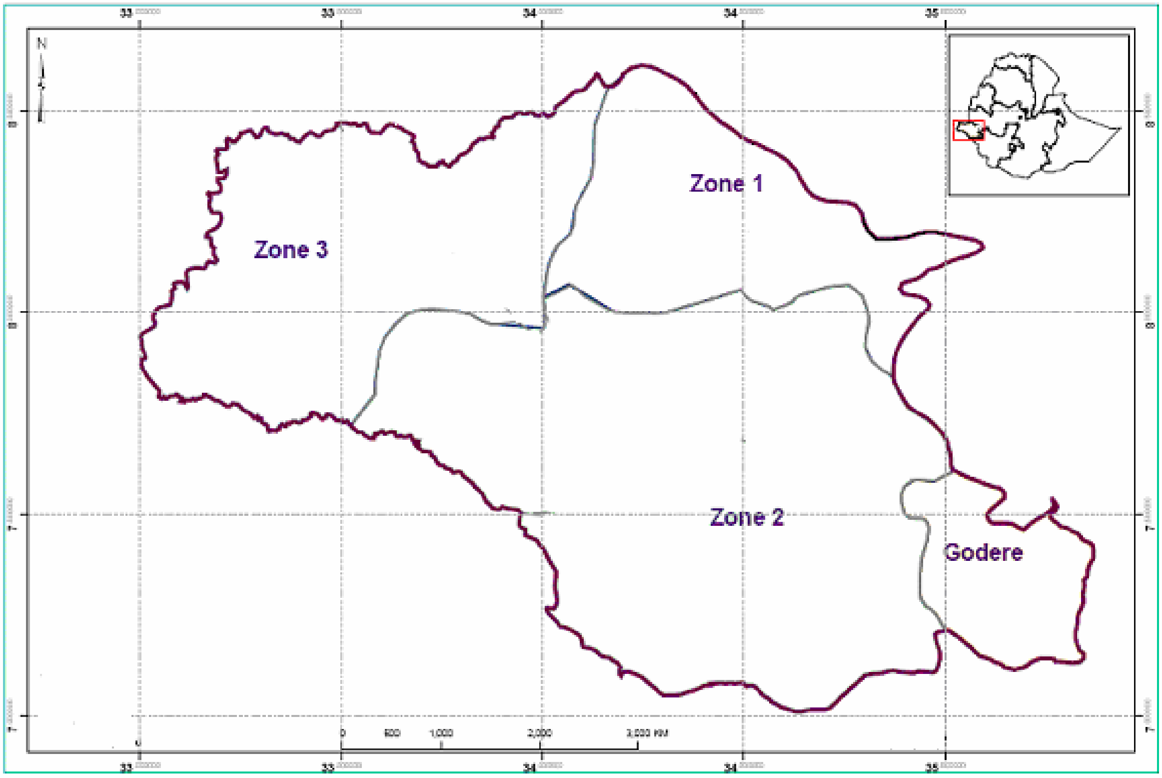


Fig. 3.1 Map of Gambella Regional State in southwestern Ethiopia and the location of Godere District

3.1.3. Climate

The climate in Ethiopia depends on the prevailing winds of the humid Southwest Monsoon and the dry Northeast Trade Winds, which are governed by the movement of the Inter-Tropical Convergence Zone (ITCZ), (Liljequist 1986). In the summer (May to October), the ITCZ is north of the Equator; the prevailing wind over most of Ethiopia is southwesterly. These moisture-laden wind-systems produce rain over large areas of the escarpments and plateaux, the highest rainfall being in the southwestern parts of the country (Friis 1992). In the winter (December to February), the ITCZ is south of the equator, the Northeast Trade Winds influence the climate of southwestern Ethiopia resulting in a dry season.

All the highlands in southwest which are above 1000 m altitude receive an annual rainfall of between 1400 and 2200 mm (Ayele & Al Shadily 2000). At Tepi ($7^0$05’ N, $35^0$15’ E, 1250 m altitude), a town about 40 km from Godere Forest, the mean annual rainfall is 1562 mm with most of the rain occurring from May to September (Asres 1996). Average annual temperature in the forest ranges between 15-25 ^{0}C.

3.1.4 Vegetation and flora

The forest vegetation of Ethiopia has been classified by various authors (Logan 1946, Chaffey 1979, Friis 1986, Friis 1992). Friis (1992) classified the forests of Ethiopia in to seven types: lowland dry peripheral semi-deciduous Guineo-Congolian forest, transitional rainforest, Afromontane rainforest, undifferentiated Afromontane forest, dry single dominant Afromontane forest of the Ethiopian Highlands, dry single-dominant Afromontane forest of the escarpments, and riverine forest.

According to the classification of Friis (1992), a lowland dry peripheral semi-deciduous Guineo-Congolian forest, transitional rainforests, and Afromontane rainforests are found in southwestern Ethiopia. The following description of these forest types is based on Friis (1992).

The dry peripheral semi-deciduous Guineo-Congolian forests are restricted to the Baro lowlands of Gambella in southwestern Ethiopia. The forests occur on well drained sandy soils on flat area at altitudes ranging from 450-600 m a.s.l. The mean annual maximum temperature is 35-38°C and the corresponding minimum temperature is 18-20°C and the mean annual rainfall ranges from 1300 to 1800 mm, the rainy season being from May to September. The forest is semi-deciduous, with a 15-20 m tall, more or less continuous canopy of *Baphia abyssinica* (endemic to the lowlands of southwestern Ethiopia and adjacent parts of Sudan on the Boma Plateau and Mt. Tomadur) mixed with less common species such as *Celtis toka, Diospyros abyssinica, Lecaniodiscus fraxinifolius, Malacantha alnifolia, Trichilia prieureana, Zanha golungensis,* and *Zanthoxylum leprieurii.* The species that emerge high above the main canopy are *Alstonia boonei, Antiaris toxicaria, Melicia excelsa,* and *Celtis gomphophylla.* Small trees such as *Acalypha neputnica, Erythroxylum fischri, Tapura fischeri, Ziziphus pubescens,* and *Xylopia parviflora* form a continuous stratum below the canopy. The shrub layer is sometimes dense and includes *Alchornea laxiflora, Argomuellera marcophylla, Mimulopsis solmsii, Oncoba spinosa, Oxyanthus speciosus, Rinorea ilicifolia* and *Whitfieldia elongata. Hippocratea parvifolia, H. goetzei, Combretum paniculatum,* and *Ampelocissus abyssinica* are the dominating woody climbers.

The transitional rainforests occur on the escarpments of southwestern highlands in Bench-Maji Zone, Illubabor Zone and Godere District. The forest occurs at altitudes between 500 and 1500 m a.s.l., partly in river valleys, partly in areas presumed to have a high water table. The mean annual rainfall is about 2000 mm with rain falling most of the year, the maximum being between May and September. The mean annual temperatures range from 20 to 25°C. The transitional rainforest is similar in physiognomy and composition to the Afromontane rainforest of southwestern Ethiopia, with additional species from the lowland dry peripheral semi-deciduous Guineo-Congolian forest and with few species restricted to the transitional rainforest. The species in the latter forest type include *Pouteria (Aningeria) altissima, Anthocleista schweinfurthii, Campylospermum bukobense, Celtis philippensis, C. zenkeri, Croton sylvaticus, Dracaena fragrans, Elaeodendron buchananii, Eugenia bukobensis, Ficus exasperata, Garcinia huillensis, Manilkara butugi, Morus mesozygia, Strychnos mitis, Trichilia dregeana,* and *Trilepisium madascariense*.

An inventory of Godere Forest made by the Institute of Biodiversity Conservation in 2001 has recorded 97 woody species. Awas *et al*. (2001) recognized *Manilkara butugi-Cordia africana* community type in Godere Forest. The community type is characterized by *Manilikara butugi* and *Cordia africana*. Other trees include *Mimusops kummel, Pouteria (Aningeria) altissima, Alchornea laxiflora,* and *Celtis zenkeri.* The shrubs include *Justicia schimperiana, Dracaena fragrans, Whitfieldia elongate, Argomuellera macrophylla* and *Acalypha acrogyna*. Lianas include *Hippocratea africana* and *H. pallens*.

The afromontane rainforests are found distributed in Illubabor, Sheka, Kefa, Bench-Maji, and Jimma Zones in southwestern Ethiopia. The forest is found at altitudes between 1500 and 2500 m with mean annual temperatures ranging from 18-20^{0}C and annual rainfall between 1500 and more than 2000 mm with rain most of the year, but a maximum between April and October. *Pouteria* (*Aningeria*) *adlofi-frederici* is an emergent tree in the 20-30 m high canopy. The canopy trees include *Olea capensis, Ilex mitis, Schefflera abyssinica, Ekebergia capensis, Macaranga capensis, Euphorbia ampliphylla, Euphorbia ampliphylla, Schefflera abyssinica, Ficus thonningii, Ocotea kenyensis, Croton macrostachyus, Albizia schimperiana, A. gummifera, A. grandibracteata, Ficus sur. F. ovata, F. thonningii, Prunus africana, Sapium ellipticum, Syzygium guineense,* and *Polyscias fulva*. A discontinuous lower canopy of smaller trees includes *Allophylus abyssinicus, Apodytes dimidiata, Bersama abyssinica, Brucea antidysenterica, Calpurnia aurea, Canthium oligocarpum, Chionanthus mildbraedii, Clausena anisata, Coffea arabica, Cyathea manniana, Deinbollia kilimandscharica, Dracaena afromontana, D. fragrans, D. steudneri, Ehretia abyssinica, Erythrina brucei, Galiniera saxifraga, Lepidotrichilia volkensii*, *Milletia ferruginea* (endemic to Ethiopia), *Nuxia congesta, Oncoba routledgei, Oxyanthus speciosus, Phoenix reclinata, Pittosporum viridiflorum, Psychotria orophila, Ritchiea albersii, Rothmannia urcelliformis, Teclia nobilis, Trema orientalis, Turraea holstii,* and *Vepris dainellii.* Ground herbs include *Aframomum corrorima, Desmodium repandum* and many grass species. Lianas include *Hippocratea goetzei, H. africana, Landolphia buchananii*, *Jasminium abyssinicum*, *Urera hypselodendron,* and *Tiliacora troupinii*.

3.1.5 Fauna

The fauna of the forests of southwestern Ethiopia have not been adequately studied. Brown & Urban (1971) studied the mammals and birds of southwestern Ethiopia including the forest in Godere and came up with a list of 48 mammals species. Godere Forest falls under Metu-Gore-Tepi forest Important Bird Areas (EWNHS 1996) and the area supports Afrotropical highlands biome species and small populations of *Rougetius rougetii* (Rouget's Rail) and *Macronyx flavicoliis* (Abyssinian Longclaw), which are classified as Globally threatend. *Poicephalus flavifrons* (Yellow Fronted Parrot) and *Dendropicos abyssinicus* (Abyssinian Woodpecker) are two endemic birds of Ethiopia found in the area. Species otherwise rarely recorded in Ethiopia include *Podica senegalensis*, *Cossypha niveicapilla*, *Nectarinia chloropygia* and *Euplectes gierowii*.

3.1.6 Management status

Natural forests in Ethiopia are administered by the regional governments. The Yeki Forest in Yeki District and Godere Forest in Godere District were designated as Yeki-Godere state forest in 1988. Following the separation of the regional administration of Yeki and Godere districts, Godere Forest became a state forest and its management and administration rested on the Gambella Peoples' National Regional Government.

Godere Forest is one of the 58 National Forest Priority Areas of Ethiopia established in 1989 for conservation and production purpose. However, nothing has been done to fulfill the articulated purposes as there were no legislations issued to enforce management. Godere Forest lacks proper demarcation and a forest management plan has never been prepared. The Institute of Biodiversity Conservation with financial support from the German Technical Cooperation undertook an inventory of woody plant diversity and socio-economic survey in Godere and other forests in southwestern Ethiopia in order to identify priority woody species for *in situ* and *ex situ* conservation (see Dessie 2003 & Ersado 2003). *Baphia abyssinica, Malacantha alnifolia, Morus mesozygia* and *Celtis zenkeri* were the priority species selected from Godere Forest (Bekele *et al.* 2002).

3.1.7 Human Impact

Human impact in Godere Forest is seen in the form of fallow farming, commercial logging, resettlement and coffee plantation. The lowland part of Godere Forest is predominantly inhabited by the Mejenger ethnic group who are dependent on the forest for their survival. The people speak Mejenger which belongs to the Nilotic language family. Population density in Godere District is 22.7 people per square kilo meter (CSA 2007). Traditionally, the Mejenger people were hunter gatherer and shifting cultivator for long until they lost their forest land for the establishment of state coffee plantation and expansion of agriculture by settlers and changed their life style to fallow and sedentary farming and bee keeping (Tadesse 2007).

In shifting cultivation, the farmers set fire in the forest to remove trees, shrubs and lianas and they cultivate the land for food crops for three to five years. When they assume that the fertility of the land is declined, they abandon the land and shift to another forest area in their surrounding to do the same. The farmers dig hole with traditional wooden stick and plant maize, sorghum, pumpkin and beans together. In addition, root crops like Yam (*Dioscorea cayenensis*), Cassava (*Manihot esculenta*), and Taro (*Colocasia esculenta*) are planted by the Mejenger.

The natural forests of southwestern Ethiopia are the source of logs for most of the forest industries in Ethiopia (Abebe 2003). Godere Forest is the supplier of logs for Bebeka sawmill in Meti, a town 10 km far from Godere Forest, and other three sawmills in the southwestern Ethiopia (Abebe & Holm 2003). Timber extraction from Godere Forest started in 1986 (Abebe 2003). The sawmills use selective logging and the main tree species logged were *Cordia africana* and *Pouteria adolfi-friederici*.

Coffee production has contributed for the decline in the natural vegetation cover of Godere Forest. Two types of coffee production system are practiced in Godere forest area. In the semi-forest coffee production system, all small trees, shrubs and climbers are removed while big trees are maintained to provide shade to the coffee plant. This system is practiced by individual farmers. In the state and private large-scale coffee plantation system, the natural forest is removed for coffee plantation leaving only few shade trees.

For more than two decades, Godere Forest has been affected by commercial coffee plantation by the state-owned Tepi Coffee Plantation Enterprise (TCPE) which was established in 1988 and maintains 7082 ha of coffee plantation in the area (Tadesse 2007). In the last decade, private investors were granted forestland for the same purpose. As the forest is converted for coffee plantation, all shrubs, lianas and most of the trees are removed, leaving only those trees which provide shade for the coffee. *Albizia gummifera, Millettia ferruginea* and *Cordia africana* are the most preferred indigenous shade trees while *Gravillea robusta* is an exotic tree planted as shade tree. In addition, the construction of access roads inside the forest, construction of residences for the staff and families of TCPE, establishment of offices and coffee processing facilities, have resulted in the clearing of the natural forest cover.

The employment opportunity provided by TCPE for the collection of coffee beans has attracted many people from different parts of Ethiopia. Some of these people do not go back home after they finish their contract with the enterprise. They rather try to acquire forestland illegally and start cultivation. Once settled, these people go back to their former home area to bring family members and provoke relatives and friends to come to the forest area of Godere for settlement. As a result of such illegal settlement, most areas of Godere Forest has been converted for settlement, coffee plantation and food crop production.

In the mid of 1980s, the Ethiopian government carried out a large scale resettlement program in parts of southwestern Ethiopia for people from draught affected parts of Ethiopia. In addition to arable lands, natural forests were selected for the resettlement program. Godere Forest was one of the forests selected for the program. Most of these settlers came from parts of the country which practice sedentary agriculture and where no natural forests exist. As a result vast area of the forest had been converted to agricultural land, coffee plantation and villages.

Tadesse (2007) investigated the forest cover change in parts of southwestern Ethiopia including Godere using satellite image analysis. The result showed that the high forest cover of the area decreased from 71 % to 48 % between 1973 and 2005. Commercial coffee plantation accounted for 30 % of the loss and 70 % of the loss was due to the local community farming practice.

3.2 Study sites

Two sites were selected in Godere Forest for the present study: a forest around Bishan Waka Lake in Gubeti Peasant Association and a forest in Dushi Peasant Association.

Bishan Waka is a small lake surrounded by a forest. *Manilkara butugei* forms the 20-25 m upper canopy of the forest. The species in the 15-20 m tree layer are *Mimusops kummel, Cordia africana, Celtis africana, Diospyros abyssinica, Morus mesozygia, Croton macrostachyus, Polyscia fulva, Cassipourea malosana, Phoenix reclinata,* and *Olea capensis* ssp. *welwitschii.* Small trees and shrubs include *Chionanthes mildbraedii, Lepidotrichilia volkensii, Rothmannia urcelliformis, Oxyanthus speciosum, Argomuellera macrophylla, Rinorea friisii,* and *Dracaena fragrans.* Altitude in the forest varies from 1430 to 1560 m. The canopy is open and enough light reaches the ground. Human pressure on this forest in the form of logging and conversion to other land use types is relatively minimal.

The forest in Dushi area is a very disturbed secondary forest severely affected by slash-and-burn agriculture and both semi-forest coffee and commercial coffee management. The sampling site for the present study is in the semi-forest coffee managed area at altitude between 1230 and 1270 m. The forest has three layers, two tree layers and a shrub layer. Trees and shrubs in this area include *Antiaris toxicaria, Millettia ferruginea, Baphia abyssinica, Polyscias fulva, Mimusops kummel, Strychnos mitis, Diospyros abyssinica, Trichilia dregeana, Croton macrostachyus, Celtis africana, C. philippensis, Cordia africana, Pouteria (=Aningeria) altissima, Albizia grandibracteata, Ficus sur, F. mucuso, F. lutea, Morus mesozygia, Trichilia dregeana, , Trilepisium madagascariense, Malacantha alnifolia,* and *Vepris dainellii*, The shrubs layer is dominated by *Coffea arabica*. Other less abundant shrubs include *Argomuellera macrophylla*, *Maytenus gracilipes, Alchornea laxiflora,* and *Dracaena fragrans.*

3.3 Results

3.3.1 Floristic composition

Altogether 75 taxa of foliicolous lichens and lichenicolous fungi growing on foliicolous lichens belonging to 27 genera and 15 families were recorded from Godere Forest (Fig. 3.2). Out of these, 70 were identified to a species level, 4 were identified to a genus level and one species was identified to a variety level. Three species were found to be new to science. The full species list is presented in Appendix 1.

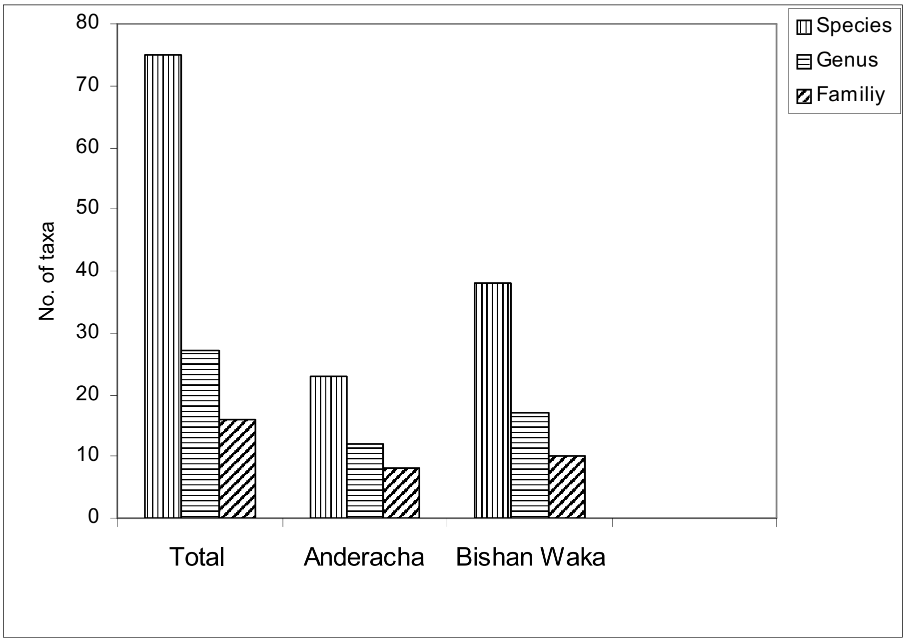


Fig. 3.2 Distribution of foliicolous lichen taxa in Godere Forest and the study sites of Bisha Waka and Dushi

About 93 % of the species in Godere Forest were typically foliicolous, 1.3 % facultatively foliicolous, 1.3 % ubiquitous and 4 % were lichenicolous fungi growing on foliicolous lichens (Fig. 3.3). *Arthonia atropunctata, Opegrapha velata* and an unidentified species of *Opegrapha* are the lichenicolous fungi recorded from the forest. *Coccocarpia stellata* is the facultative foliicolous lichen species and *Fellhanera bouteillei* is the ubiquitous lichen.

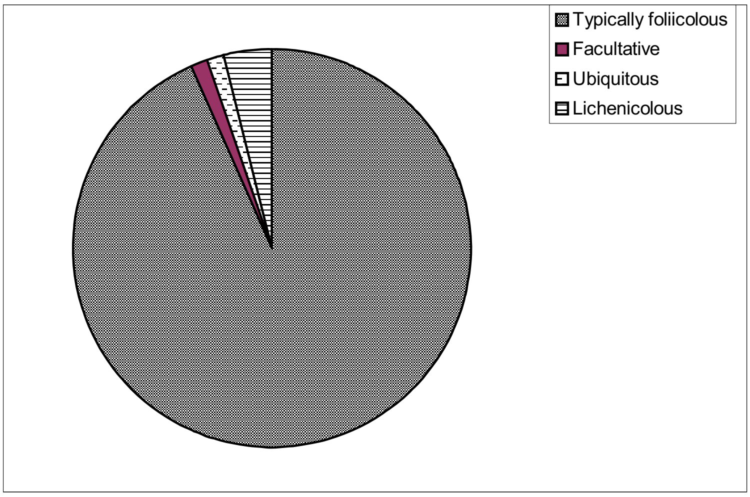


Fig. 3.3 Proportion of typical, facultative, and ubiquitous foliicolous lichens and lichenicolous lichens in Godere Forest

The most dominant lichen family in Godere Forest was Pilocarpaceae with 6 genera and 20 sub generic taxa (Fig. 3.4). Porinaceae was the second largest family with 2 genera, 13 species and 1 subspecies. The family Strigulaceae was represented by one genus, 7 species and 2 subspecies. The families Asterothyriaceae and Gomphillaceae were each represented by 3 genera and 7 species. The families Coenogoniaceae and Ramalinaceae were each represented by one genus and three species. The families Arthoniaceae, Roccellaceae, Aspidotheliaceae, and Thelotremataceae were each represented by one genus and two species. The two taxa of Roccellaceae belonging to the genus *Opegrapha* grew para-symbiotically on foliicolous lichens. The families with one genus and one species were Coccocarpiaceae, Lyromataceae, Monoblastiaceae and Verrucariaceae.

Among the two sampling sites, higher number of families, genera and species were recorded from Dushi with 14 families, 24 genera and 68 species. From Bishan Waka 10 families, 17 genera and 38 species were recorded (Fig. 3.2).

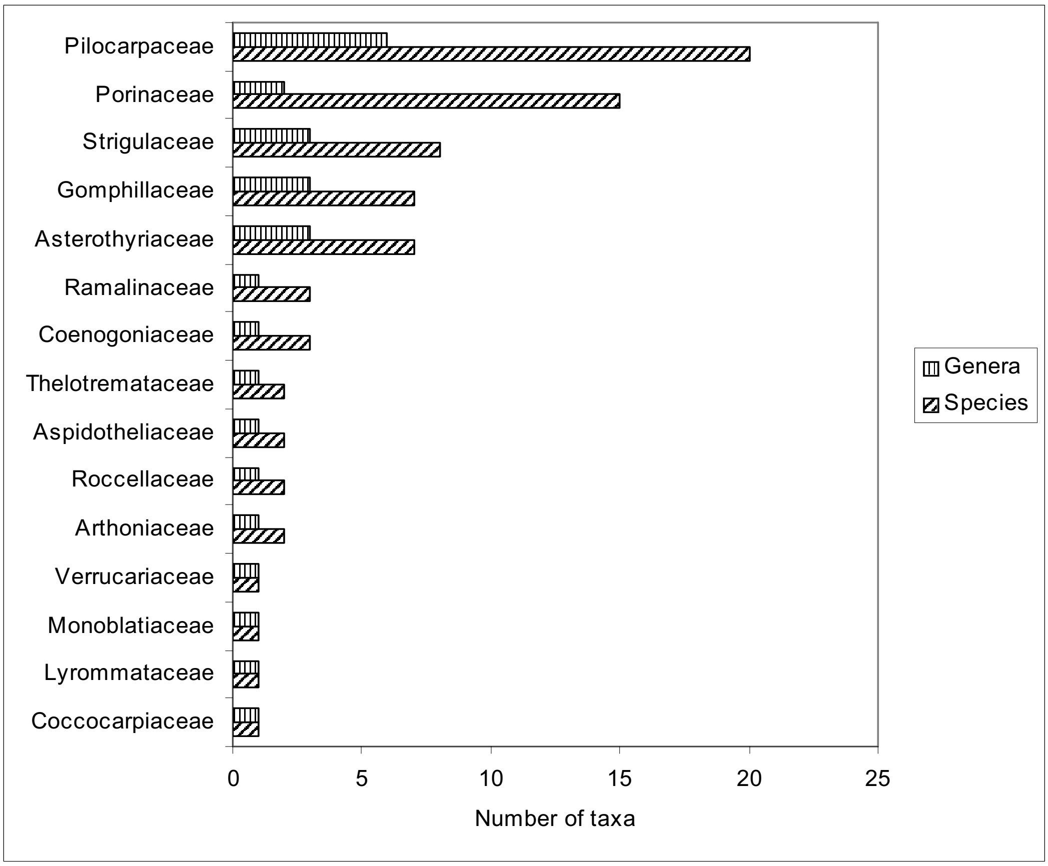


Fig. 3.4 Number of species and genera of foliicolous lichens per family in Godere

The following species were recorded from both Dushi and Bishan Waka study sites: *Aspidothelium fugiens*, *Asterothyrium rotuliforme, Bacidina apiahica, B. pallidocarnea, Calenia monospora, Calopadia fusca, C. puiggarii, Chroodiscus verrucosus, Coccocarpia* *stellata, Fellhanera bouteillei, F. paradoxa, F. sublecanorina, Gyalectidium filicinum, Gyalidea epiphylla, Porina cupreola var. cupreola, P. epiphylla, P. leptosperma, P. nitidula, P. rubescens, P. subpallescens, P.* cf. *triseptata, Sporopodium phyllocharis, Strigula nemathora* var. *hypothelia, S. nitidula, S. phyllogena, S. smaragdula, Trichothelium africanum,T. pauciseptatum,* and *T. epiphyllum.*

The species recorded from Dushi but absent in Bishan Waka were *Arthonia atropunctata, A. lividula, Aspidothelium hirsutum* sp. nov.*, Asterothyrium microsporum, A. octomerum, Bacidina mirabilis, Brasilicia foliicola, Byssolecania hymenocarpa, B. chlorinum, B. leucoblepharum, B. subpolychromum, Calenia triseptata, Calopadia phyllogena, Caprettia goderei* sp. nov.*, Chroodiscus kakamegensis* sp. nov.*, Coenogonium dilucidum, C. subluteum, C. usambarense, Fellhanera* cf. *aurantiaca, F. subfuscatula, F. submicrommata, Lyromma nectandrae, Opegrapha velata, Porina rubescens, P. rufula, P. tetramera, P. trichothelioides, Psorotheciopsis varieseptata, Sporopodium antonianum, S. leprieurii, Strigula schizospora,* and *Tapellaria bilimbioides*

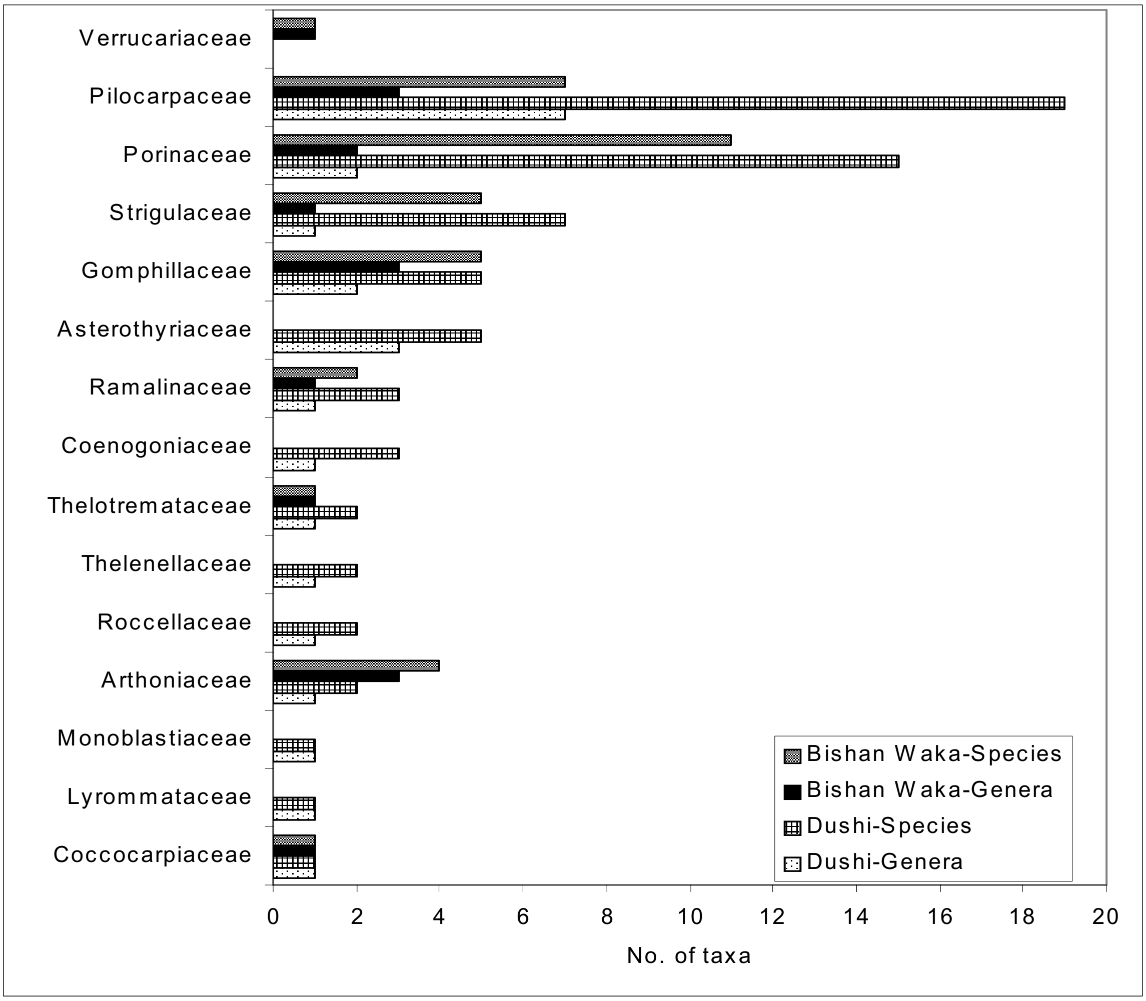


Fig. 3.5 Foliicolous lichen genera and species per family in Dushi & Bishan Waka

The species rich family in Dushi is Pilocarpaceae with 19 species, followed by Porinaceae with 15 species and Strigulaceae with 7 species (Fig. 3.5). In Bishan Waka the family Porinaceae was the richest with 11 species, followed by Pilocarpaceae with 7 species and Gomphillaceae and Strigulaceae had 5 species each.

3.3.2 Species frequency

The frequency of occurrences of species in the sample plots of the study sites of Godere Forest are presented in Fig 3.6. In Dushi most of the species (59%) were rare. Occasional and very frequent species made 18% and 8% of the whole species respectively. The frequent species made 7% and the less frequent species made 6% of the whole species. Only 3% of the species were dominant.

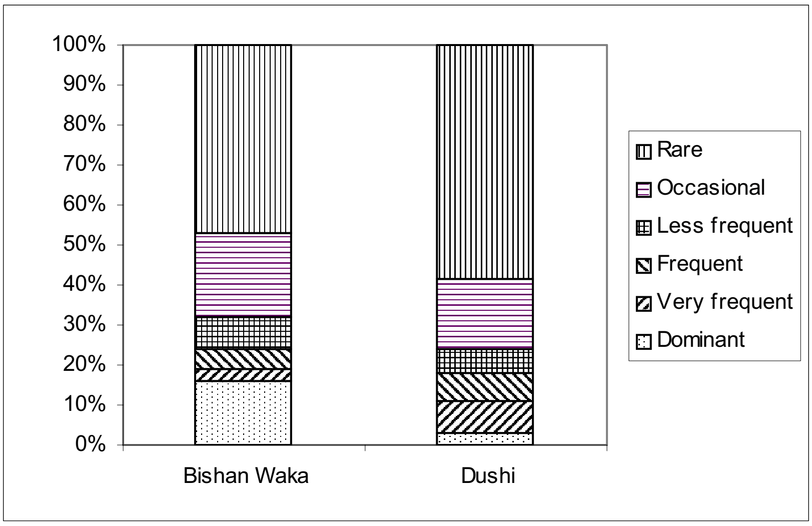


Fig. 3.6 Frequency distribution of species in Dushi and Bishan Waka

The dominant species in Dushi were *Porina nitidula, P. rubentior, P. epiphylla, P. cupreola* var. *cupreola and P. subpallescens. Bacidina apiahica* and *Porina leptosperma* were the very frequent species. The frequent species were *Strigula phyllogena, Strigula smaragdula, Gyalidea epiphylla, Calopadia fusca,* and *Lyromma nectandrae. Calopadia puiggarii, Aspidothelium fugiens, Fellhanera paradoxa, Trichothelium africanum* were the less frequent species. The occasional species were *Brasilicia foliicola, Byssolecania hymenocarpa, Calenia monospora, Gyalectidium filicinum, Strigula nemathora* var. *hypothelia, Trichothelium pauciseptatum. Fellhanera bouteillei, Gyalectidium imperfectum, Strigula nitidula, Fellhanera subfuscatula,* and *F. submicrommata*. The rare species were *Arthonia atropunctata, A. lividula, Aspidothelium hirsutum sp. nov., Asterothyrium microsporum, A. octomerum, Asterothyrium rotuliforme, Bacidina mirabilis, Bacidina pallidocarnea, Byssoloma chlorinum, B. leucoblepharum, B. subpolychromum, Calenia triseptata, Calopadia phyllogena, Caprettia goderei* sp. nov., *Chroodiscus kakamegensis* sp. nov., *C. verrucosus, Coccocarpia stellata, Coenogonium* *dilucidum, C. subluteum, C. usambarense, Fellhanera* cf. *aurantiaca, F. sublecanorina, Opegrapha velata, Porina* cf. *triseptata, P. rubescens, P. rufula, P. tetramera, P. trichothelioides, Psorotheciopsis varieseptata, Sporopodium antonianum, S. leprieurii, S. phyllocharis, Strigula macrocarpa, S. microspora, S. schizospora, Tapellaria bilimbioides* and *Trichothelium epiphyllum.*

In Bishan Waka 47% of the species were rare and 21% occasional. Unlike Dushi, the dominant species in Bishan Waka constituted higher proportion (16%). The less frequent, frequent, and very frequent species constituted 8%, 5% and 3% of the total species respectively

The dominant species in Bishan Waka were *Porina nitidula, P. epiphylla, P. subpallescens, Calopadia puiggarii, Strigula phyllogena* and *Gyalectidium filicinum. Fellhanera paradoxa* was the only species designated as very frequent and *Calopadia fusca* and *Bacidina apiahica* constituted the frequent category. The less frequent species constituted *Fellhanera bouteillei, Calenia monospora* and *Strigula smaragdula. Asterothyrium leucophthalmum, A. rotuliforme, Coccocarpia stellata, Gyalectidium fuscum, Gyalidea epiphylla, Porina leptosperma, P. rubentior* and *Trichothelium africanum* constituted the occasional species. The rare species were *Aspidothelium fugiens, Bacidina pallidocarnea, Chroodiscus verrucosus, Echinoplaca pellicula, Fellhanera sublecanorina, Gyalectidium imperfectum, Phylloblastia pocsii, Porina* cf. *triseptata, P. cupreola* var. *cupreola, Psorotheciopsis patellarioides, Sporopodium phyllocharis, Strigula nemathora* var. *hypothelia, S. nemathora* var. *nemathora, S. nitidula, Trichothelium pauciseptatum,* and *T. epiphyllum*

The frequency occurrences of species in the samples of Godere Forest and in the study sites of Bishan Waka and Dushi are presented in Appendicies 3, 4 and 5 respectively.

3.3.3 New records and new species of foliicolous lichens

The foliicolous lichens and lichenicolous fungi recorded in this study are all new records for Ethiopia. Three species of foliicolous lichens new to science were recorded from Godere Forest. Furthermore, two more records are expected to be new to science; however the specimens were not adequate for description. Some interesting records of foliicolous lichens and lichenicolous fungi are also recorded.

3.3.3.1 *Species new to science*

1. *Caprettia goderei* sp. nov. (Monoblastiaceae) (Fig 3.7 A & B)

A single collection from Godere Forest producing pale brownish to black, wart shaped perithecia and tubular pycnidia looking like those of *Caprettia nyssaegenoides* was found to be new to science. It has been described and sent for publication.

Specimen examined: Godere: Dushi Peasant Association 07^{0}16’13 N and 035^{0}12’17 E, 1230 m, epiphyllous on *Strychnos mitis*, 2005, Kumelachew 301(KOBL)

2. *Chroodiscus kakamegensis* sp. nov. (Thelotremataceae) (Fig. 3.7 C & D)

A single collection from Godere Forest belonging to the genus *Chroodiscus* which was lichenicolous on *Porina epiphylla* and having smooth thallus and 1-3 septate ascospores was found to be new to science. The smooth thallus points to *Chroodiscus africana* described from Ivory Coast (Santesson & Lücking 1999) but this species had consistently 1-septate ascospores. It was described and sent for publication.

Specimen examined: Godere: Godere Forest, Dushi Peasant Association, 1230 m, 07^{0}16’13 N and 035^{0}12’17 E, epiphyllous on *Diospyros abyssinica*, Kumelachew 297(KOBL).

3. *Aspidothelium hirsutum* sp. nov. (Aspidotheliaceae) (Fig. 3.7 E & F)

A single collection having small thallus with hairs produced by the fungus and on which the photobiont growing up from the thallus was collected from Godere Forest. No member of the genus produced hairs on the thallus and therefore this collection represents a species new to science. It has been described and sent for publication.

Specimen examined: Godere Forest, Dushi Peasant Association, 1262 m, 07^{0}16’56 N and 035^{0}12’14 E, epiphyllous on *Strychnos mitis*, 1262 m Kumelachew 277 (KOBL).

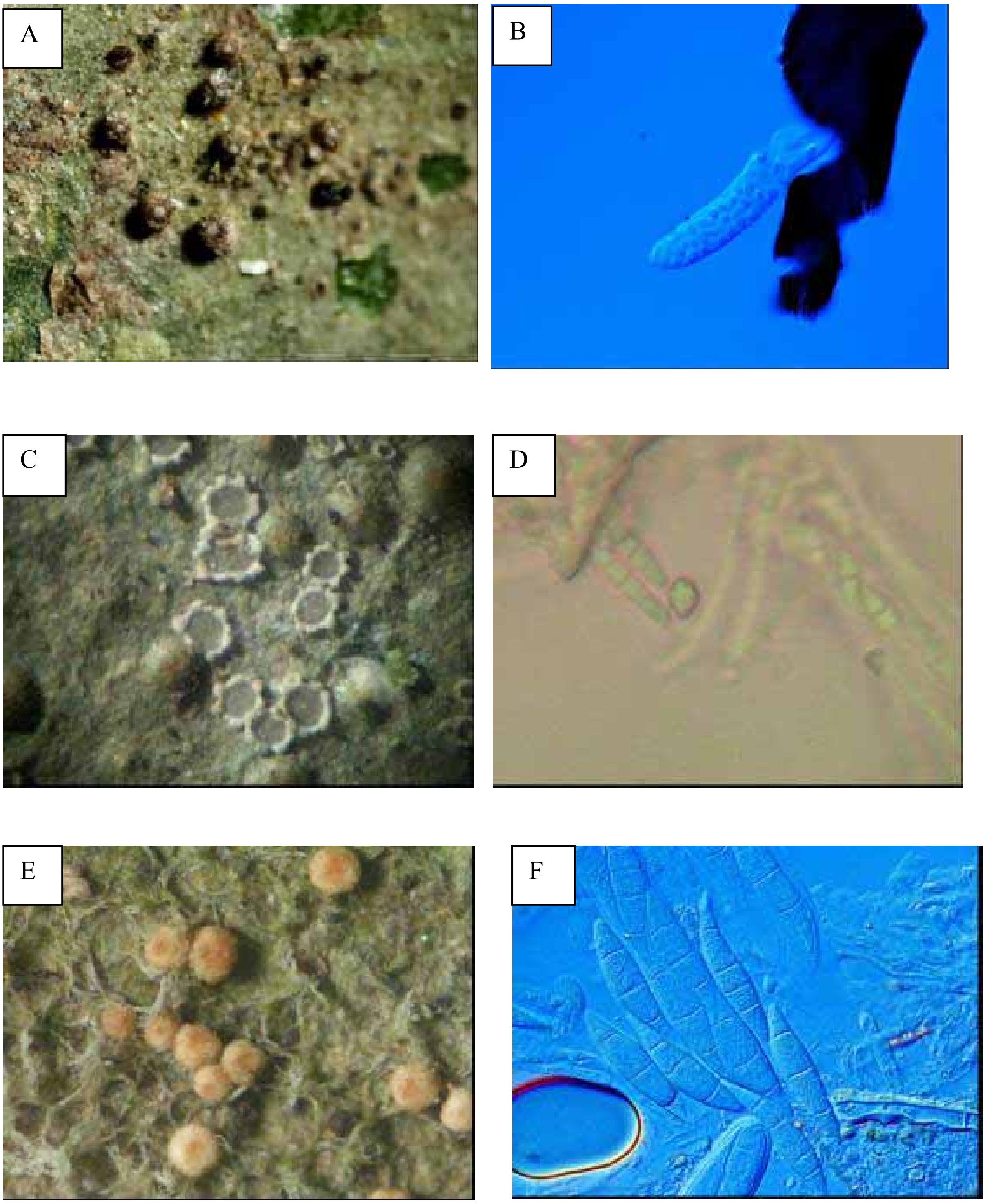


Fig. 3.7 Pictures of new species. (A) *Caprettia goderei* sp. nov., habit, (B) *Caprettia goderei* sp. nov. , conidia in saccus being expelled from pycnidium, (C) *Chroodiscus kakamegensis* sp. nov., habit, (D) *Chroodiscus kakamegensis* sp. Nov., ascospores (note the different septation), (E) *Aspidothelium hirsutum* sp. nov., habit, (F) *Aspidothelium hirsutum* sp. nov., ascospores in ascus

3.3.3.2 *Interesting records of foliicolous lichens*

1. *Fellhanera* cf. *aurantiaca* (Pilocarpaceae) (Fig. 3.8A & B)

Two collections listed below had green thallus; a typical paraplectenchymatous excipulum with large cells (upto 8-10 µm) under the hypothecium; hypothecium K+ red-brown; ascospores 3-septate, 12-18 x 3-4.5 µm. Our specimens match the description of *Fellhanera aurantiaca* from Guinea (Vězda 1974) and also known from the DR Congo except that the excipullar cells under the hypothecium are not said to be large. From the photos of Lücking & Colin (2004), our specimen looked like *F. rubida* (only known from South America) and said to have very large cells in the excipulum under the hypothecium (Lücking 1997b).

Specimen examined: Godere Forest, Dushi Peasant Association, 1230 m, $07^0$16'53 N, $035^0$12'11 E, on living leaves of *Argomuellera macrophylla*, Kumelachew 3/275 & 1250 m; $07^0$16'16 N, $035^0$12'24 E, on living leaves of *Diospyros abyssinica*, Kumelachew 297 (KOBL)

2. *Fellhanera* aff. *bouteillei* (Pilocarpaceae) (Fig. 3.8C)

The collection cited below had green, rather coherent thallus, apothecia medium sized, pale orange to brownish orange, with a thin but distinct margin, ascospores 1-septate, 22-25 x 4-5 µm. The collection belongs to the *Felhanera subternella* aggregate (Lücking 1997b) and is close to *F. bouteillei,* a species known to exhibit variations in thallus and apothecial morphology. It differs from *Fellhanera bouteillei* in thallus morphology and having longer (22-25 µm) ascospores with the proximal and distant cells being more or less equal in size.

Specimen examined: Godere Forest, Bishan Waka, 1370 m, on living leaves of *Phoenix reclinata,* 2005, Kumelachew 318 (KOBL).

3. *Calenia* sp. (Gomphillaceae) (Fig. 3.8D)

Thallus continuous, smooth, pale green, to 2 mm in diameter; apothecia 0.025-0.05 mm in diameter, slightly pruinose, ascospores muriform, one per ascus, 38-45 x 12-18 µm. This specimen seems to represent a new species, but the material is scanty for proper description.

Specimen examined: Godere Forest, 1230 m, $07^0$16'04 N, $035^0$12'11 E, on living leaves of *Dracaena fragrans*, Kumelachew 308, (KOBL).

4. *Opegrapha* sp. (Rocellaceae) (Fig. 3.8E)

Ascomata lichenicolous on *Strigula phyllogena*, asci 8-spored, ascospores 3-septate, 10-13 x 2.5-3.5 µm. The size and shape of the asci and size of ascospores and septation of this collection are similar with those of *Opegrapha phylloporinae.* However, the host of our collection is *Strigula phyllogena* where as O. *phylloporinae* grows on *Porina conica, P. epiphylla, P. similis, P. virescens* (Matzer 1996).

Specimen examined: Godere Forest, Dushi Peasant Association, 1230 m, 07^{0}16’04 N, 035^{0}12’11 E, on living leaves of *Argomuellera macropylla,* 2005, Kumelachew 304 (KOBL).

5. ***Porina*** **cf.** ***triseptata*** **(Porinaceae) (Fig. 3.8F)**

Porina triseptata was described by Vĕzda (1994) as *Trichothelium triseptatum* but it was later transferred to the genus *Porina* by Lücking (1998). The present collections match perfectly with the description of the species except that ascospores are shorter (15-25 µm) and lobules, instead of stiff setae, are present on the perithecia.

Specimen examined: Godere Forest, Dushi Peasant Association, 1232 m, 07^{0}16’53 N and 035^{0}12’11 E, on leaves of *Argomuellera macrophylla,* Kumelachew 1/275 (KOBL).

6. ***Sporopodium*** **sp. (Pilocarpaceae) (Fig. 3.8G)**

Two collections had campylidia producing pearl-shaped conidia and thallus is sorediate. Soredia have so far not been observed in the species of *Sporopodium*. Therefore, these collections could represent new taxon of *Sporopodium*, but proper description was not possible as the specimens were with out apothecia.

Specimen examined: Godere Forest, Dushi Peasant Association, 1232 m, 07^{0}16’53 N and 035^{0}12’11 E, on leaves of *Argomuellera macrophylla,* Kumelachew 3/275; 1250 m, 07^{0}16’19 N and 035^{0}12’21 E, on living leaves of *Argomuellera macrophylla,* Kumelachew 290 (KOBL).

7. ***Trichothelium pauciseptatum*** **(Porinaceae) (Fig. 3.8H)**

Trichothelium pauciseptatum was described by Vĕzda (1994) from a collection of S. Lisowski from the Orientale province (former Haut Zaire) in the DR Congo. The present collection matches well with the description of the species except for the color of the tip of the setae. In the description of *T. pauciseptatum*, setae are black in color. In our collection, the setae are black with pale tip. In addition, the ascospores of Kumelachew 307 were longer (27 x 3 µm), those of Kumelachew 325 were narrower (17.5 x 2.5 µm) and of Kumelachew 293 narrower and shorter (15-17.5 x 2.5 µm) than the holotype (16-20 x 3-3.5 µm).

Specimen examined: Godere Forest, Dushi Peasant Association, 1270 m, 07^{0}16’56 N, 035^{0}12’14 E, on living leaves of *Argomuellera macropylla,* 2005, Kumelachew 284; 1250 m, 07^{0}16’19 N, 035^{0}12’21 E, on living leaves of *Tiliachora funifera,* 2005, Kumelachew 293; 1230 m, 07^{0}16’04 N, 035^{0}12’11 E, Kumelachew 307; (KOBL).

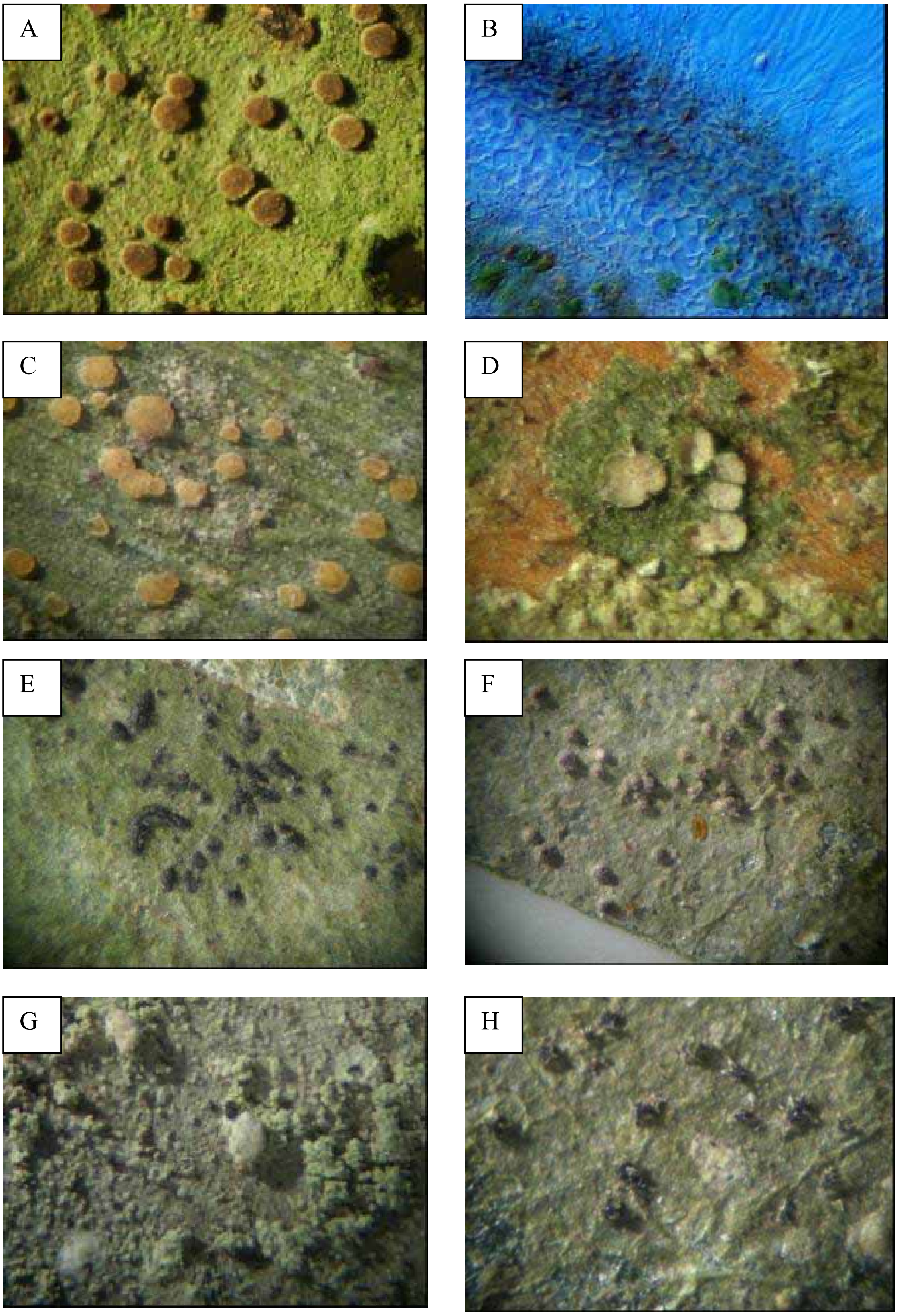


Fig. 3.8 A) *Fellhanera* cf. *aurantiaca*, B) Excipulum of *Fellhanera* cf. *aurantiaca*, C) *Fellhanera* aff. *bouteillei*, D) *Calenia* sp., E) *Opegrapha* sp. growing on *Strigula phyllogena*, F) *Porina* cf. *triseptata*, G) Sorediate specimen of *Sporopodium* sp.
H) *Trichothelium pauciseptatum*

3.3.2 Alpha-diversity

3.3.2.1 Mean species number

There were more species per sample in Dushi than in Bishan waka. In Dushi a mean of 11 species were recorded per sample and in Bishan Waka a mean of 8.04 species were recorded (Fig. 3.9). This difference is statistically significant (t-value 1.98, $p<0.05$).

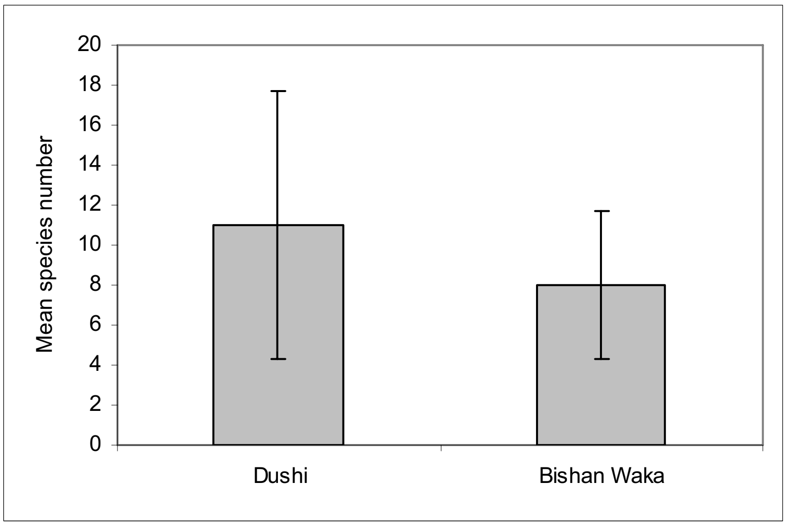
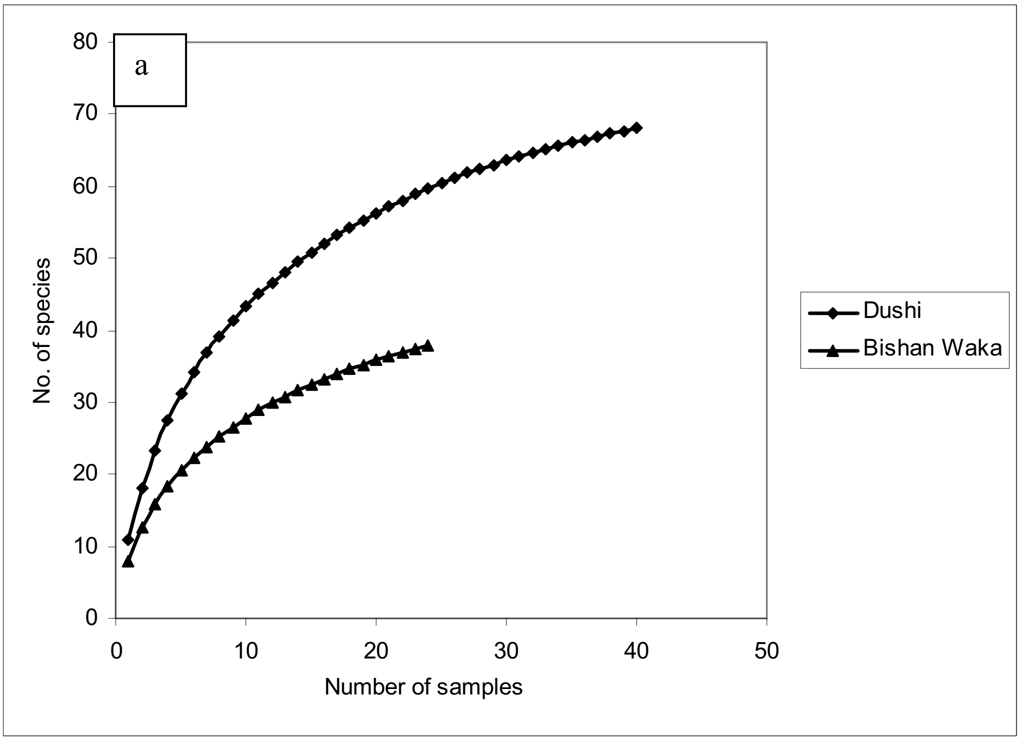


Fig. 3.9 Mean number of species per sample per study site of Godere Forest (values are mean ± SD)

3.3.2.2 Species accumulation curve

Species accumulation (rarefaction) curves were plotted for the foliicolous lichen species recorded from Dushi and Bishan Waka forest parts of Godere (Fig. 3.10). The graphs were plotted for the mean number of species against the number of samples pooled (Fig. 3.10a) and the mean number of species against the number of individuals pooled (Fig. 3.10b). The first graph compares species density and the second graph compares species richness.

Although the rate of species accumulation decreased as increasing number of samples were successively added to the total, neither of the curves reached an asymptote. The number of species for Dushi was higher than for Bishan Waka at all levels of sample accumulation. For 24 samples (sample size of Bishan Waka) pooled, 38 species were observed in Bishan Waka and 59.7 species in Dushi. To see if there is significant difference in species richness, Magurran (2004) recommended to check if the observed richness of the smaller community lies within the 95% confidence limits of the rarefaction curve of the larger community. Accordingly, the observed species accumulation curve of Bishan Waka is out side the 95% confidence intervals of the species accumulation curves of Dushi (Fig. 3.10b) indicating significantly higher species richness in Dushi than in Bishan Waka.



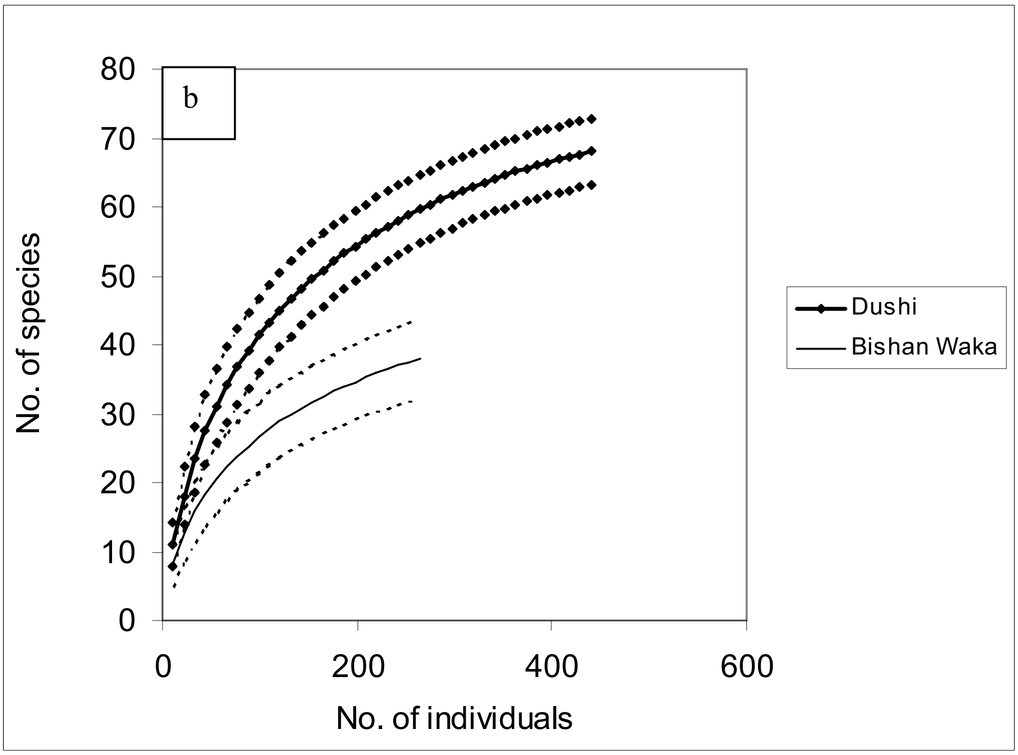


Fig. 3.10 Species accumulation (rarefaction) curves (solid lines) and 95% confidence intervals (dotted lines) for Dushi and Bishan Waka. a) Species density b) Species richness.

3.3.2.3 Estimation of species richness

The Chao 2, first and second order Jackknife, Incidence Based Coverage Estimator, Bootstrap and the Michaelis-Menten Mean species richness estimators estimated more species than the observed species (S_{obs}) for the study sites of Dushi and Bishan Waka. Table 3.1 presents the observed species number, the mean (and standard deviation for some) of estimated species. For the study site of Dushi, S_{obs} was 68 among 40 pooled samples, and for Bishan Waka 38 species were observed among 24 pooled samples.

For the data set of Dushi and Bishan Waka study sites, the second order Jackknife estimated the highest species richness of 82 for Dushi, and 55.2 for Bishan Waka. On the other hand, MMMeans estimated the lowest species number of 38.6 for Bishan Waka. Chao 2 estimated the lowest species number of 73.9 for Dushi. The difference between the highest and the lowest species estimates is 8.1 species for Dushi, and 11.9 species for Bishan Waka. In all cases, Jack 2 estimator gave the highest estimates. In Dushi 83-92% and in Bishan Waka 69-88% of the species richness estimated by the various estimators were collected in this study.

Table 3.1. Number of samples, number of individuals and species richness estimates values for the study sites of Dushi and Bishan Waka

	Dushi	Bishan Waka
No. of samples	40	24
No. of individuals	440	193
S_{obs}	68	38
MMMeans	76.6	38.6
Chao 2	73.9±4.3	50±9.2
Jackknife 1	81.7±4.5	49.5±4.2
Jackknife 2	82	55.2
ICE	78.2±0.01	50.8±0.03
Bootstrap	75.4	43.3
Collection degree	83-92 %	68.8-87.8 %

3.3.2.4 Shannon-Wiener diversity

The result of the α-diversity analysis of foliicolous lichens based on Shannon-Wiener index is presented in Table 3.2. Calculation of t-test showed a very high significant difference (t-value =3.56, $p<0.001$) in the Shannon index of Dushi and Bishan Waka evidencing a higher α-diversity in Dushi than in Bishan Waka.

Table 3.2 Values of Shannon-Wiener and Simpson diversity indices

	Dushi	Bishan Waka
Shannon index (H')	3.72	3.17
Shannon evenness index (J')	0.88	0.87

3.3.3 Beta-diversity and similarity in species composition

Total β-diversity, measured as total species number divided by mean number of species in samples, for Dushi and Bishan Waka is presented in Table 3.3. Total β-diversity is higher (6.2) for Dushi than for Bishan Waka (4.7). The similarity in species composition between Dushi and Bishan Waka computed from Sørensen index of similarity is not found to be high (S_s=0.58).

Table 3.3 β-diversity along the study sites of Dushi and Bishan Waka

	Number of species (a)	Mean number of species per sample (b)	β-diversity (a/b)
Dushi	68	11	6.2
Bishan Waka	38	8.04	4.7
Sørensen index of similarity (S_s) between Dushi and Bishan Waka			
Number of shared species		31	
S_s		0.58	

3.3.4 Ordination

The Detrended Correspondence Analysis (DCA) of the presence/absence data of Godere ordered the samples and species along the ordination axes. The first DCA axis with eigenvalue of 0.395 explained 11.9% of the variation and the second axis with eigenvalue of 0.192 explained 5.8% of the variation. Thus most of the variation in site condition and species composition can be explained by the gradient corresponding to the first DCA axis. Eigenvalues of the third and fourth axes are 0.158 and 0.116 respectively.

In the sample ordination plot (Fig. 3.11), samples from less disturbed sites are distributed along the left side of the first DCA axis, and samples from high disturbed sites are distributed along the right side. The variation in the distribution of samples along the first axis of DCA is thus explained by difference in disturbance level. Most of the samples from Bishan Waka are distributed along the gradient where disturbance is higher and the samples from Dushi are distributed along the gradient where disturbance is lower.

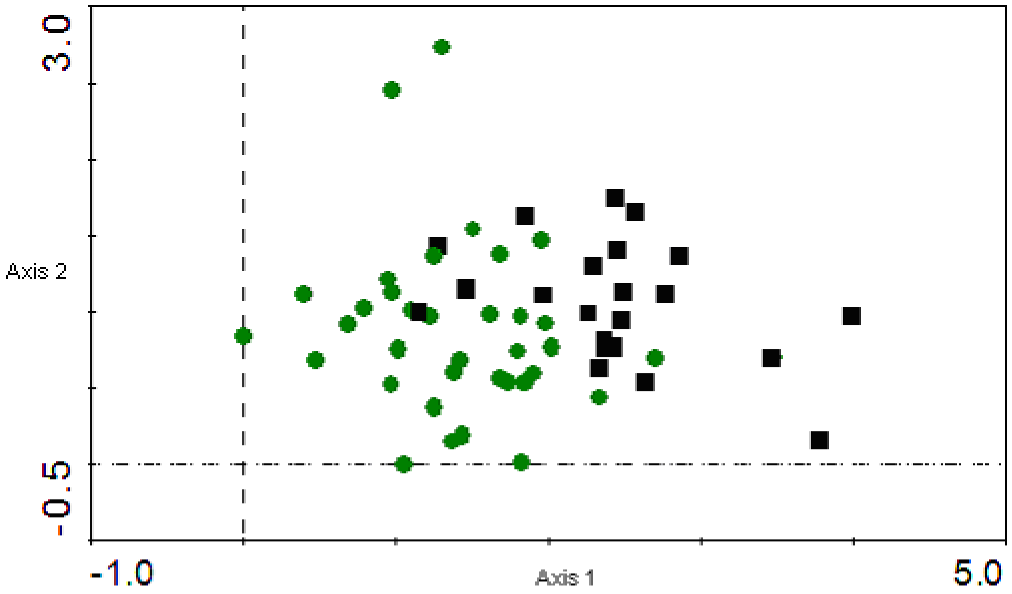


Fig. 3.11 DCA diagram of samples of Godere Forest. Circles = samples from Dushi, squares = samples from Bisahn Waka.

The species ordination diagram (Fig. 3.12) shows that species from highly disturbed samples are distributed on the right side of the first DCA axis and species from less disturbed samples are distributed on the left side of the first axis. The first group of species includes *Asterothyrium rotuliforme, A. octomerum, Gyalectidium filicinum, Calenia monospora, Calopadia puiggarii, Gyalectidium fuscum,* and *Fellhanera bouteillei.* Among the second group of species include *Porina leptosperma, P. rubescens, P. cupreola* var. *cupreola, Byssolecania hymenocarpa, Arthonia lividula,* and *Coenogonium dilucidum.*

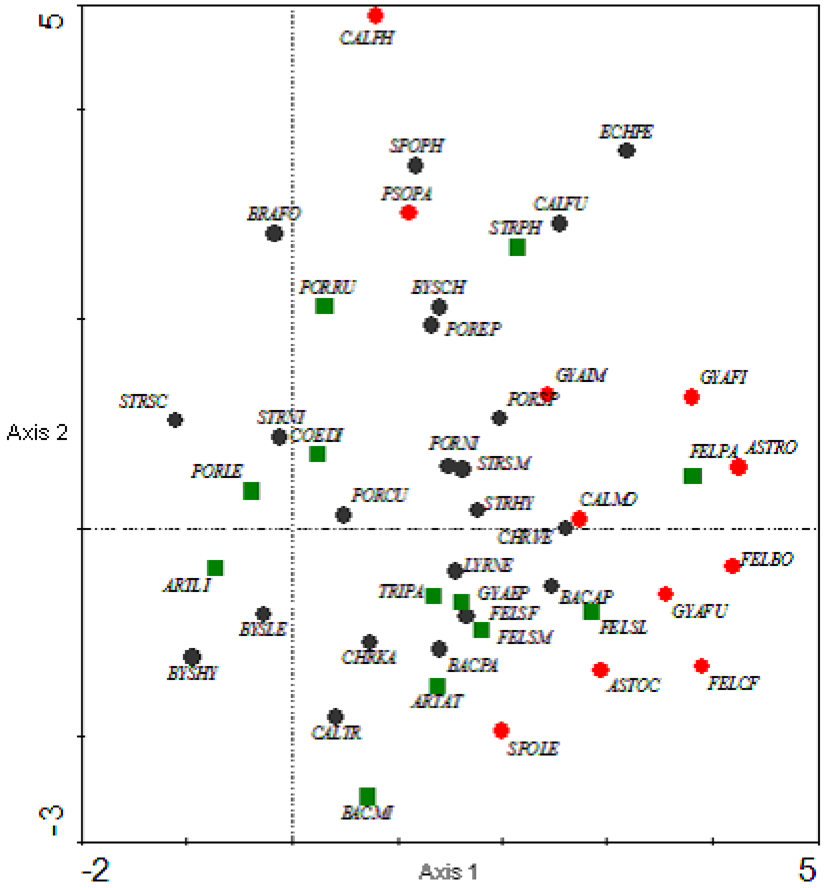


Fig. 3.12 DCA diagram of species of Godere Forest. Green squares = shady understorey species, red circle = light gap and canopy, black circle = species with wide amplitude. For clarity only some of the species are shown. For Acronyms see Appendix 1.

3.3.5 Phorophytes

Various phorophyte species were hosts of foliicolous lichens in Godere Forest including *Argomuellera macrophylla, Baphia abyssinica, Blighia unijugata, Coffea arabica, Dracaena fragrans, Hippocratea africana, Landolphia buchananii, Manilikara butugi, Olea capensis* ssp. *welwitschii* (=*O. welwitschii*), *Phoenix reclinata, Piper guineense, Rinorea friisii, Strychnos mitis, Tiliachoa troupinii,* and *Trilepisium madagascraiense*. Of these, *Argomuellera macrophylla* is the phorophyte that supported the highest species of foliicolous lichens (58 species). *Strychnos mitis supported* 28 species, *Dracaena fragrans* supported 25 species, *Diospyros abyssinica* supported 24 species, and *Trilepisium madagascariense* supported 22 species. *Coffea arabica*, the most abundant shrub in Dushi, supported only 10 species of foliicolous lichens.

3.4 Discussion

3.4.1 Foliicolous lichen flora

All the foliicolous lichens recorded in this study are the first record for Ethiopia. The checklist of lichens and lichenicolous fungi (Feuerer 2007), listed 279 species of lichens from Ethiopia. However, foliicolous lichens were not included in the checklist indicating that no foliicolous lichens were collected until this time. Ethiopia is a tropical country with varied climatic and topographic features resulting in diverse flora and vegetation types which could also support high lichen diversity. However, cryptogams in general and lichens in particular have been overlooked for so long that the lichen flora of the country is almost unknown. The book on macrolichens of East Africa (Swinscow and Krog 1988) incorporates some lichen species collected by Hildur Krog from the southern part of Ethiopia in 1971. This book is the first and the only available source of information for the lichens of Ethiopia.

Tropical rainforests are the suitable habitats for foliicolous lichens (Santesson 1952, Lücking 1995). In Ethiopia most of the natural forests are Afromontane type, distributed at altitudes above 1500 m. Forests of a lowland type are very restricted in parts of southwestern Ethiopia. Floristically, Godere Forest occupies a transitional position between a lowland Guineo-Congolean rainforest and afromontane rainforest of the higher altitude. However considering the topographic position and climatic features of the forest with high temperature and rainfall, it is the most suitable habitat for foliicolous lichens. However, due to shifting cultivation and the semi-forest coffee management system, no trace of undisturbed natural forest can be found in Godere. The foliicolous lichens recorded in this study came from a disturbed secondary forest and it is not known what the foliicolous lichen flora of an undisturbed primary forest would have looked like. A number of species (e.g *Coenogonium geralense, C. pocsii*) which would be expected in a primary or old growth forest were not recorded from the forest.

The tropical forests of Africa are the least explored in terms of their foliicolous lichens. This is reflected by the number of new species or species of interesting characters recorded from Godere. Considering the continuous anthropogenic disturbance affecting the forests, it is highly probable that several species of foliicolous lichens have locally been extinct.

Most of the samples in this study were from the study site of Dushi since it covers the most part of Godere Forest. The forest surrounding Bishan Waka Lake was selected for this study since it was not utilized for coffee development and large-scale logging did not take place. However, the forest is a fragment isolated from the large mass of forest in Godere and forms an island surrounded by human settlement and cultivation. In addition it covers a very small area around the lake and the distance between the forest edge and the interior is very small. Consequently, the available habitat for the growth of foliicolous lichens is considerably lower than in Dushi. Due to its isolation from the large main forest block, there are no enough sources of diaspore for the establishment of foliicolous lichens. These might be the reasons for the low foliicolous lichen diversity compared to the study site of Dushi.

In a natural forest, three major light regimes or microsites (the shady understorey, the natural light gap and the canopy) and two transition types (transition to light gap and transition to outer canopy) are distinguished (Lücking 1997). In Dushi, the shady understorey light regime is reduced due to removal of some canopy trees which the farmers assumed to have impact on the growth and quality of the coffee plant. In addition many possible phorophyte individuals were removed to enhance the growth of coffee beans. Therefore, the available microsite conditions and phorophyte individuals are fewer compared to undisturbed forest. However, the proportion of shady understorey species is higher in Dushi (52.4%) than in Bishan Waka (39.5%) and the proportion of light gap and canopy species are higher in Bishan Waka (50% light gap, 10.5% canopy) than in Dushi (42.6% light gap, 4.9% canopy).

3.4.2 Alpha-diversity

Ecologists often need to know the number of species (species richness) found in a given area or they need to compare the number of species in different areas (Colwell *et al* (2004). Complete enumeration of all species of a given area is often difficult for many groups of organisms including lichens. Various methods are now available for the estimation of species richness from available samples. These methods have mostly been applied for the estimation of the richness of animals (Toti *et al*. 2000, Longino et al. 2002, Schulz and Wagner, Sørenson 2004), plants (Butler & Chazdon 1998, Chazdon *et al.*1998, Chiarucci *et al*. 2003) and lichens (Nöske 2004). Using non-parametric species richness estimators the species richness of foliicolous lichens has been for the first time estimated in this study.

The sample sizes of Dushi and Bishan Waka are very different and comparison of species richness based on different sample size is misleading. Using the species accumulation curve (rarefaction curve), however, species richness can be compared at comparable sample size. The lowest sample size of the areas to be compared is usually selected as a basis for comparison. As it can be seem from the rarefaction curves and their 95% confidence intervals, there are significantly more foliicolous lichen species in Dushi than in Bishan Waka. The high diversity of foliicolous lichens in Dushi as compared to Bishan Waka is due to the availability of different microsite habitats in the former than in the latter.

The degree of foliicolous lichen collection or sample sufficiency can be evaluated based on the degree to which species accumulation curves approach a horizontal asymptote, the rate of accumulation of new species or using the predicted values of the species richness estimators. (Soberón and Llorente 1991, Gotelli and Colwell 2001). If the species accumulation curve reaches a stable asymptote, it is an indication of adequate sampling. As additional samples are pooled and the observed species richness curve stabilizes beyond a particular number of samples, then the observed species richness is considered as adequate estimate of community species richness for that number of samples (Longino *et al.* 2002). Although the species accumulation curves of Dushi and Bishan Waka did not reach an asymptote, the rates of accumulation of new species as more samples were pooled have decreased. From Dushi 83% of the species were collected based on the highest estimator and 92% of the species were collected based on the lowest estimator. From Bishan Waka 69% of the species were collected based on the highest estimator and 88% of the species were collected based on the lowest estimator. Heck *et al.* (1975) reported that collection of 50-75% of the total number of species of a given area might be satisfactory. Accordingly, the sampling efficiency for Dushi and Bishan Waka can be considered satisfactory.

The 95% confidence intervals of the species accumulation curves of Dushi and Bishan Waka (Fig. 3.18) did not overlap indicating the presence of significant difference in species richness. Colwell *et al.* (2004), comparing tropical rain forest sampling in old growth and second growth forests, concluded that when confidence intervals overlap, the differences in species richness is not significant and when confidence intervals do not overlap the differences in species richness is significant.

In Bishan Waka, the species richness estimators predicted that more species are yet to be sampled than from Dushi. This is due to the higher number (31.6 %) of uniques (species restricted to one sample only) in Bishan Waka. In Dushi uniques accounted for 20.6 % of the whole species. Species richness estimators use the frequency of rare species to predict the total sample species richness (Williams *et al.* 2007). The presence of many rare species means higher probability of encountering more new species with increased sampling effort.

Considering the results of the species accumulation curve and Shannon diversity index, it can be concluded that α-diversity is significantly higher in Dushi than in Bishan Waka.

3.4.3 β-diversity

The proportion of shared species of Dushi with the total foliicolous lichen flora of Godere is 91% and that of Bishan Waka 51%. Total β-diversity, calculated by dividing the total species number by a mean number of species in a sample, indicates the degree of turnover (species change). The higher total β-diversity of Dushi is an evidence for a higher species turnover than in Bishan Waka. The similarity in foliicolous lichens composition between Dushi and Bishan Waka, as measured by the Sørenson index, is medium (S_s=0.58) showing a medium species turnover.

3.5 Conclusion

The present study has shown that:

- both alpha and beta diversity are higher in Dushi than in Bishan Waka.
- low diversity in Bishan Waka is because of it is fragmented nature and isolation from the main forest by cultivations and settlement.
- the effect of human disturbance on foliicolous lichens diversity in Dushi is mainly due to the removal of phorpohytes from the shrub stratum.
- the variation in foliicolous lichens diversity between Dushi and Bishan Waka can be explained by the difference in the level of disturbance. This has been shown in the ordination diagram where samples distributed along the low disturbance gradient were from Dushi and samples from the high disturbance gradient were from Bishan Waka.
- the forest canopy is relatively closed in Dushi and thus there are more shady understorey species and low light gap species in Dushi than in Bishan Waka.
- semi-forest coffee management system maintains foliicolous lichen diversity than land uses such as cultivation and clear-cutting that may result in partial or complete removal of forest vegetation.

Chapter 4 DIVERSITY OF FOLIICOLOUS LICHENS IN BUDONGO FOREST, UGANDA

4.1 Study area

4.1.1. Location and physiography

Budongo Forest Reserve lies in western Uganda, in Masindi District, Bujenje, Buliisa and Buruli Counties (Muhereza 2003). It is situated on the top of the escarpment east of Lake Albert on the edge of the western rift valley (Howard *et al.* 1996; Sheil 1999, 2001, Sheil *et al.* 2000) between $1^0$37' and $2^0$03' N latitude and $31^0$22 and $31^0$46'E longitude (Sheil 1999, 2000, 2001; Reynolds 2005) (Fig. 4.1). The Budongo Forest Reserve is divided into two parts by the road connecting Masindi and Butiaba which is located on the shore of Lake Albert; the northeastern part is called the Budongo and the other is called the Siba (Sugiyama 1968). The reserve lies approximately 10 km west and north of Masindi and 10 km east of Lake Albert (Howard *et al.* 1996).

The gazetted area of Budongo Forest Reserve includes four forest blocks viz. Siba, Budongo, Kaniyo-Pabidi and Kitigo (Fig. 4.2). The reserve covers an area of almost 793 km^2, of which 428 km^2 is closed forest; the rest is savanna woodland or grassland (Howard *et al.* 1996; Sheil 1997, Sheil *et al.* 2000, Plumptre 2001).

The reserve lies at altitudes between 950 and 1200 m, with mean altitude of 1100 m (Plumptre 2001), on gently undulating terrain with a gentle NNW slope to the edge of the rift escarpment. There are few steep ridges and no deep gullies (Eggeling 1940). Several isolated hills of similar heights rise above the general level of the forest, the most prominent of which are Kasene (1171 m a.s.l.), Kaniyo (1187m a.s.l.), Lukoho (1160 m a.s.l.), Nyabyeya (1247 m a.s.l.), Little Kasenene (1173 m a.s.l.), and Busingiro (1201 m a.s.l.) (Howard 1991). The valley bottoms mostly contained 'swamp forest', but the ground there, though soft, is rarely swampy.

Budongo Forest is a catchment area for four small rivers which flow north-west through the forest, over the escarpment and into Lake Albert. (Eggeling 1947; Paterson 1991, Reynolds 2005). These rivers from east to west are the Waisoke, the Sonso, the Kamirambwa and the Siba (Reynolds 2005).

Fig. 4.1 Map of Uganda and the location of Budongo Forest (red square). Source: CIA World Factbook

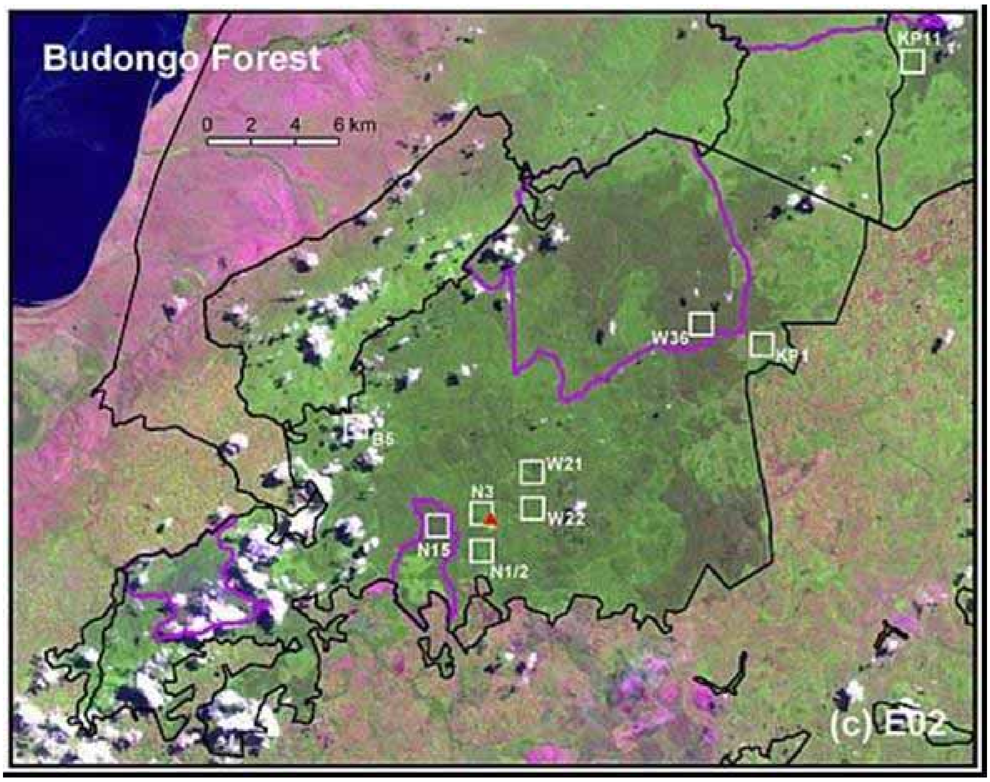


Fig. 4.2 Satellite imagery of Budongo Forest (Source: BIOTA E02).

4.1.2. Geology and Soil

Crystalline rocks of the Ancient Basement Complex of Pre-Camberian origin, intruded by granites, underlie Budongo Forest. The Basement Complex is an assemblage of schistose and gneissose rocks which are metamorphosed sandstones, shales, limestones, and eruptives. (Eggeling 1947). It is from these rocks that the soils are formed.

Advanced laterization in the Budongo area is likely to have coincided with peneplanation and the hills around and in the forest indicate the past level of the lateritic blanket which once covered the whole area. Following the Rift uplift, which resulted into the formation of the Western Rift Valley, it is probable that widespread erosion removed the greater part of the laterite and led to the formation of fresh soils from crystalline rocks, some of which were quickly colonized by forests (Philip 1996, Sheil 1996).

The soils of Budongo are predominantely tropical red earths (Eggeling 1947, Paterson 1991), of a type regarded as almost the final stage in tropical weathering. These soils are red in profile and vary from a heavy loam or sandy clay to a very sandy loam characteristic of the many of the valley bottoms (Eggeling 1947). These soils are termed as ‘ferralitic’ (Sheil 2001). A second much less common soil type called ‘murram’ is localized in the forest on low rounded ridges or gentle slopes and is always underlain by quartzose rocks. (Eggeling 1947). This soil has undergone laterization and varies from a red loam containing small concentrations of ironstone, capable of supporting forest, to tiny ridge-top pavements of solid cellular ironstone (Eggeling 1947).

4.1.3. Climate

Unlike many forest areas in Africa, there is a long-term climatic data for Budongo Forest. In 1937 five meteorological stations were established in Budongo Forest. Of these, four stations were established inside the forest and one outside the forest (Eggeling, 1947). The data are summerized by Eggeling (1947), Paterson (1991) and Sheil (1997).The Budongo Forest Project has been collecting rainfall and temperature data since 1993 (Reynolds 2005).

Rainfall in Budongo is bimodal with two peaks from March to May and from September to November with monthly rainfall more than 150 mm (see Fig.4.3). There is only one dry season from mid December to mid February with monthly rainfall not more than 50 mm. Annual rainfall is between 1200-1800 mm (Sheil 1995, 1997, 1998; Reynolds 2005). The annual minimum mean temperatures in Budongo Forest range from 17 to 20^0C and maximum mean temperatures range from 28 to 29^0C (Howard 1991).

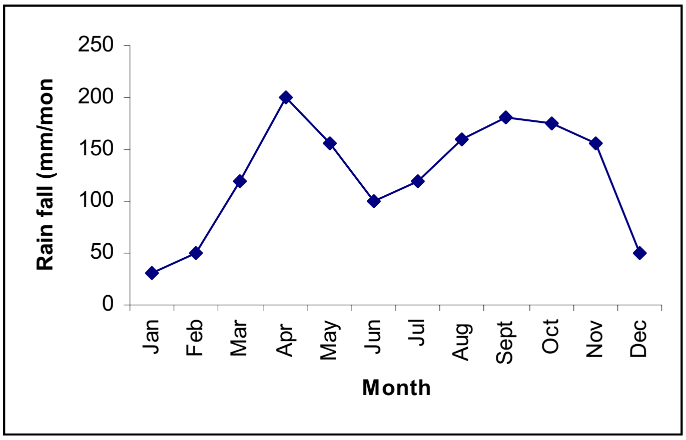


Fig.4.3 Mean monthly rainfall (mm) records from 1944 to 1989 in Nyabyeya meteorological station. Source: Sheil (1997)

4.1.4. Biotic attributes

4.1.4. 1 Vegetation and flora

Budongo Forest is among the easternmost outlier blocks of the Congo basin forest (Paterson 1991). Based on its structure and constituents, Eggeling (1947) described Budongo as lowland rain forest. Langdale-Brown *et al.* (1964) classified Budongo as a medium altitude moist semi-deciduous forest. Hamilton (1974) classified the lowland forests of Uganda into four zones, viz. the *Parinari*, the *Celtis-Chrysophyllum*, the *Cynometra-Celtis*, and the *Piptadeniastrum* zones. The *Celtis-Chrysophyllum* and the *Cynometra-Celtis* zones are represented in Budongo Forest. Philip (1965) and Howard (1991) classified Budongo as moist semi-deciduous tropical forest. According to Paterson (1991), the vegetation of Budongo Reserve consists of a rich mixture of rainforest communities and a broad intermixture or ecotone with the surrounding tree savannas and grasslands.

Eggeling (1947), Synnott (1985), Paterson (1991), and Sheil *et al.* (2000) described the flora of Budongo Forest. Of these, Synnott (1985) provided the full plant species composition including 240 species of trees, 123 species of shrubs, 19 species of scrambling shrubs, 66 species of woody climbers and lianas, 61 species of herbaceous climbers, 246 species of terrestrial herbs, 109 species of vascular epiphytes, 1 parasitic species and 1 saprophytic species. Howard *et al.* (1997) reported 465 species of trees and shrubs for Budongo Forest. Budongo Forest has the largest number of tree species recorded in the Ugandan forest (Howard 1991, Sheil 1996) and it is the richest mahogany forest in Uganda (Lind and Morrison 1974, Howard *et al.* 1997). *Artabotrys lastoursvillensis, Discoglypremna caloneura*, *Iodes africana*, *Mammea africana*, *Microdesmis puberula*, *Ritchiea aprevaliana* and *Telfairia occidentalis* are species limited to Budongo Forest in Uganda (Synnott 1985).

Based on the observations of earlier workers (Haris 1934, Brasnett 1946), Eggeling (1947) described the natural forest types of Budongo Forest and proposed succession from colonizing forest through mixed forest to climax forest. This successional model was later conformed by Sheil (1999) with objective measures of development.

According to Eggeling (1947), the Budongo Forest contains four forest types viz. colonizing forest, mixed forest, *Cynometra* forest, and swamp forest.

1. Colonizing forests are of two types: the *Maesopsis* and woodland forest. The *Maesopsis* colonizing forest is found in slightly better soil than the woodland forest. It is composed of a matrix of colonising species such as *Maesopsis eminii, Cordia millenii* and *Diospyros abyssinica*. *Maesopsis eminii* forms 50-80 percent of the canopy. The woodland forest is found on poorer or shallow soils, and is composed of *Olea welwitschii, Phyllanthus discoideus* and *Sapium ellipticum* in the upper story with a general domination of the understorey by *Calconcoba* and old remnant *Terminaila* derived from the tree savanna (Eggeling 1947; Paterson 1991).

2. Mixed forest is the richest of the forest type in number of tree species, covers much of the forest and contains the valuable mahoganies (Eggeling 1947, Paterson 1991, Plumptre 1994). The most common species are *Celtis mildbraedii, C. zenkeri, Chrysophyllum albidum*, *C. perpulchrum*, *Funtumia elastica* and the mahoganies *Khaya anthotheca*, *Entandrophragma cylindericum*, *E. angolense*, and *E. utile*.

3. *Cynometra* (Ironwood) forest is the climatic climax forest of Budongo (Eggeling 1947). It is characterized by the abundance of *Cynometra alexanderi*, which accounts for up to 35 percent of all trees and as much as 90 percent of all large trees. Other typical tree components include *Strychnos mitis, Celtis wightii*, and *C. mildbradeii*. The understorey is characterized by *Lasiodiscus mildbraedii.*

4. Swamp forest is found in valley bottoms in which the soil is flooded by permanent and seasonal slow running streams. The dominant tree is *Mitragyna stipulosa*. Others include *Pseudspondias microcarpa*, *Parkia filicoidea*, *Erythrina excelsa*, *Bombax bunopozense* subsp. *reflexum*, *Macaranga schweinfurthii* and *Bridelia micrantha*.

According to Eggeling (1947) the first three forest types follow an ecological succession from the colonizing forest to mixed forest and finally to *Cynometra* forest with colonising-mixed and *Cynometra*-mixed transitions. The *Cynometra* forest is an ecological climax and the swamp forest is an edaphic climax.

4.1.4.2 Fauna

Budongo Forest is known for its diversity of fauna with 24 species of small mammals including nine primates, 289 species of butterflies and 130 species of large moths (Howard *et al*. 1997). There are 366 species of birds out of which 197 species are forest dwellers (Friedmann & Williams 1973, Owiunji & Plumptre 1998).

Some of the mammals in the forest are tree hyrax (*Dendrohyrax buck*), red duikers (*Cephalophus rufilatus*), blue duikers (*C. monticoloa*), bush buck (*Tragelaphus scriptus*), bush pig (*Potamochoerus porcus*), porchpines (*Hystrix cristata*) and guines fowls (*Guttera edouardi*). Four species of monkeys live in Budongo Forest (Reynolds 2005) viz. baboon (*Papio anubis*), black and white colobus monkey (*Colobus guereza),* redtail monkey (*Cercopithecus ascanius*), and blue monkey (*C. mitis*). Potto (*Periodicticus potto*) is the commonest species of prosimian in Budongo Forest. Budongo is also home to one of the largest populations of chimpanzees (*Pantroglodytes schweinfurthii*) in Uganda with a population of about 700 (Tweheyo *et al.* 2004).

4.1.5. Management History

The management history of the Budongo Forest Reserve is well documented (Eggeling 1947, Paterson 1991, Plumptre, 1994, 1996; Reynolds 2005). The value of Budongo Forest had been recognized as early as 1905 when a permit was granted to a European firm for the tapping of wild rubber (*Funtumia*) (Eggeling 1946). In 1932 the British colonial administration gazetted the Budongo Forest an Undemarcated Forest reserved to the Crown (Eggeling 1947).

4.1.5.1 Forest administration

Since 1920 Budongo Forest was administered by the Forest Department of the colonial administration. After independence, it was administered by the Forest Department of the central government. Since 1993 forest management in Uganda has been decentralized to district and sub-county councils and Budongo Forest was administered by the Masindy District Council as Central Forest Reserve. Since 1998 the administration of central forest reserves was transferred to the central government and the management of Budongo Forest rested under the Forest Department which was later replaced by a semi-autonomous National Forestry Authority (Muhereza 2003).

4.1.5.2 Management plan

Management plans were prepared for Budongo Forest for the periods 1935-1945, 1945-1955, 1955-1965, and 1997-2007. The plans indicate the principles of management of the forest including ways of demarcation, licensing for timber cutting and silvicultural methods. For the sake of management, Budong forest was divided into 68 compartments in the Siba, Bullaba, Biiso, Nyakafunjo, Waibira, and Kaniyo-Pabidi forest blocks.

The current management plan (Kamugisha and Nsita 1997) which covers the period from July 1997 to June 2007 provides emphasis for biological conservation. The plan separates the forest into zones for conservation, commercial use, community use, recreation and research. The majority of Budongo Forest is earmarked as a production zone for the utilization of timber. The plan establishes 'Conservation Working Circle' which includes Strict Nature Reserve (SNR) and Buffer Zones. The SNR is maintained for biodiversity conservation and water catchment and tree felling is strictly prohibited. New compartments, mostly in the Waibira block, are included in the SNR raising the number of compartments to 17. The buffer zone which includes 14 compartments is established around the nature reserve to separate the SNR from the production zone. The total area allocated for the nature reserve is 11,722 ha and 5,293 ha for the buffer zones.

4.1.6. Human Impact

4.1.6.1 Fire

In the 19th century, anthropogenic fire used to control the spread of Budongo Forest into the surrounding savanna (Paterson 1991). Annually the local people who live around Budongo Forest set fire to clear away dry growth from the previous year and produce fresh grass for their cattle. The fire which started this way also cleared away the savanna and expanded to the edges of the forest. These fires kept the forest blocks of Budongo and Siba from spreading into the surrounding savanna land. This process continued until the arrival of Europeans who controlled fires and managed the forest for timber (Paterson 1991).

4.1.6.2 Logging

Logging in Budongo Forest started in a regular basis in 1917 (Paterson 1991). By then only small amounts of timber were cut on the southern side of the Budongo Forest block using pitsaws (Eggeling, 1947). Timber cutting became mechanized when the first sawmill was established towards the end of 1926 (Eggeling 1946). From this time onwards, there has been considerable exploitation by concession holders operating in two concessions, one in the Siba and another in the Budongo Forest block.

Of the 68 forest compartments, logging took place on the 60 compartments. One compartment in Nyakafunjo block (N15), 4 compartments in the Waibira block (W17, W30, W31, W32), and 3 compartments in the Kaniyo-Pabidi block (K11, K12, K13) were left unlogged. The compartments N15, W17, W30, W31, and W32 are protected as nature reserve (Plumptre 1996, Owiunji & Plumptre 1998).

The main timbers exploited were *Khaya anthotheca*, *Entandrophragma cylindericum, E. angolense*, *E. utile, Cynometra alexanderi, Erythrophleum guineense, Mildbraediodendron* *excelsum*., *Maesopsis eminii, Alstonia congensis, Ricinodendron africanum*, *Chlorophora excelsa*, and *Morus lactea*. Table 4.1 shows the volume of mahoganies and other timbers extracted from the various forest blocks of Budongo between 1928 and 1992. In the Biiso, Nyakafunjo, Waibira and Kaniyo forest blocks, more than 60 percent of the timbers extracted were mahoganies. In the Siba block 42 percent of the timbers extracted were mahoganies. In general, 872,627 m^3 of timber were extracted in the 60 years period (Plumptre 1996).

Paterson (1991) and Plumptre (1996) summarized the logging activities in Budongo Forest between 1930 and 1970. At the beginning, logging operations was aimed at extracting all the old timber trees above 1.3 m diameter at breast height (DBH) and creating a two-stage uniform crop of trees which would be felled at 40-year intervals (polycyclic felling). In the 1950s research showed that damage to the forest due to the logging operations and the slow growth rates of the trees meant that polycyclic felling would lead to lower yields than felling on longer cycles. Therefore the logging plans were changed to monocyclic felling at 80-year intervals and felling limits of timber trees were reduced to 85 cm DBH. Replanting of mahoganies was carried out in logged areas during the 1940s and early 1950s. However, research showed that natural regeneration was successful and replanting ceased by the mid 1950s.

Table 4.1 Volume of timber extracted in the Budongo Forest blocks between 1928 and 1992. (Source: Plumptre 1996).

Forest block	Area (ha)	Year logged	Volume of timber extracted (m^3ha^{-1})	Volume of mahogany extracted (m^3ha^{-1})
Biiso	4350	1935-1944, 1981-1992	219.7	152.9
Nyakafunjo	8134	1945-1954, 1956-1962	535.7	371.7
Waibira	21358	1960-1976, 1978-1980	448.9	282.7
Kaniyo	4818	1970-1972, 1977, 1985-1992	103.7	65.6
Siba	5288	1928-1935, 1963-1977, 1979, 1990	118.1	49.8

In addition to mechanized harvesting of timber, harvesting by pitsawing used to take place in some compartments in the 1980s (Plumptre 1996). After realizing that mechanized logging was harmful to natural regeneration, the Uganda Forest Department in the 1990s started providing license to organized pitsawyers to carry out selective extraction of mahoganies and other timber trees (Muhereza 2003). Between 1991 and 1996 the annual off-take of timber by pitsawyers and saw millers averaged 11,522.82 m^3 of round wood (Muhereza 2003). At present mechanized logging is not taking place as all the sawmills are not opereting. However, illegal pitsawing has been taking place in various parts of the forest including the SNR (Muhereza 2003; Reynolds 2005).

4.1.6.3 Silviculture

In the 1950s and 1960s, silvicultural measures were taken in order to promote the growth and regeneration of the most valuable timber species, such as *Khaya* and *Entandrophragna* spp (Plumptre 1996). It was found that opening up the canopy during the logging operation aided the growth of the mahoganies. Consequently, arboricide, made from 1:2 mixture of butyl esters 2,4,5-T and 2,4-D dissolved in diesel oil, was applied to trees that were not marketable, particularly *Cynometra*. A total of 34 blocks were treated with arboricide. In 1970 the treatment ceased when more trees became marketable and it became difficult to import the chemicals.

4.1.6.4 Wild animal control

Budongo Forest used to harbour a good population of elephants, buffalo, wild pigs and leopards. Control shooting and legal and illegal hunting have diminished the population of these animals to an alarming level. Rinderpest epidemic in 1889 in the Bunyoro area eliminated most of the cattle. (Paterson 1991). Epidemic of trypanosomiasis at the beginning of the 20th century initiated the colonial administration killing of most of the large wild mammals including buffaloes, wild pigs, bushbuck and Uganda kob (Harris 1934). The decline of these animals resulted in substantial increase of the elephant population in the areas of Budongo Forest to the extent that they converted most of the woody vegetation to treeless grasslands (Paterson 1991). Elephant control measures started in 1928 (Paterson 1991) under the Uganda Game Department in order to protect the young individuals of valuable timber species.

4.1.6.5 Population pressure

The population of Masindi District is growing at a high rate. It increased from 260,796 in 1991 to 466,204 in 2002 (Muhereza 2003). The populations of Budongo and Bwijanga sub-counties near Budongo Forest increased from 44,054 to 76,929 during the same period (Muhereza 2003). This population increase is leading to encroachment to the forest, increased fuelwood collection and, charcoal production and illegal pitsawing.

4.1.7 Effects of previous management measures

4.1.7.1 Effects on vegetation

The management history of Budongo Forest has resulted changes in the distribution of forest types and structure. Areas of colonizing-mixed forest in the Biiso area developed into mixed forest and areas of mixed forest in compartment N15 developed into

Cynometra-mixed forest. The ironwood forest which covered 32 % of the main Budongo Forest block in 1944 (Eggeling 1947) reduced to 15 to 20 % by 1970 (Paterson 1991). Comparison of the forest type maps of 1951 and 1990 (Plumptre 1996) shows that there was a marked increase in the spread of the mixed forest at the expense of *Cynometra* forest. The mixed forest increased by 41% while the C*ynometra* forest decreased by 24% (Plumptre 2001).

Logging and silvicultural treatment have also resulted change in the structure of the forest. Basal area, bole and crown heights, and crown position decreased in the logged than the unlogged compartments, while lianas were more abundant in the logged than unlogged compartments (Plumptre 1996). Logging and arboricide treatment, however, did not result changes in the tree species composition of the forest. Plumptre (1996) showed that geographical position of the forest compartment with in the forest influenced the forest composition before and after logging and arboricide treatment.

4.1.7.2 Effects on fauna

Plumptre (2001) studied the densities of primates, rodents, birds, and frogs in unlogged and selectively logged compartments in Budongo Forest. The result showed that the densities of blue monkey, redtail monkey and black and white colobus monkey increased in the logged compartments while the densities of olive baboon and chimpanzee showed no difference. The density of rodents was significantly higher in the unlogged than the logged compartment. The result on birds showed that most species did not show significant differences between logged and unlogged forest. Frugivore, bark-gleaning insectivore, nectarivore and omnivore birds constituted higher percentage in the logged than unlogged forest compartments. Leaf-gleaning and Sallying insectivore birds constituted higher percentage in the unlogged than the logged compartments. Diversity of frogs was higher in the logged than the unlogged compartments. Study of canopy ants and beetles in logged and unlogged compartments in Budongo Forest (Wagner 2000, Schultz and Wagner 2002) showed that canopy ant and beetle species are more diverse in the unlogged than logged compartments while abundance of phytophagus beetles is higher in the logged than unlogged compartments.

4.2 Study sites

In Budongo Forest, foliicolous lichen sampling took place in *Cynometra alexanderi* primary forest (hereafter called primary forest), primary swamp forest (hereafter called swamp forest), old secondary forest and young secondary forest (Fig. 4.4).

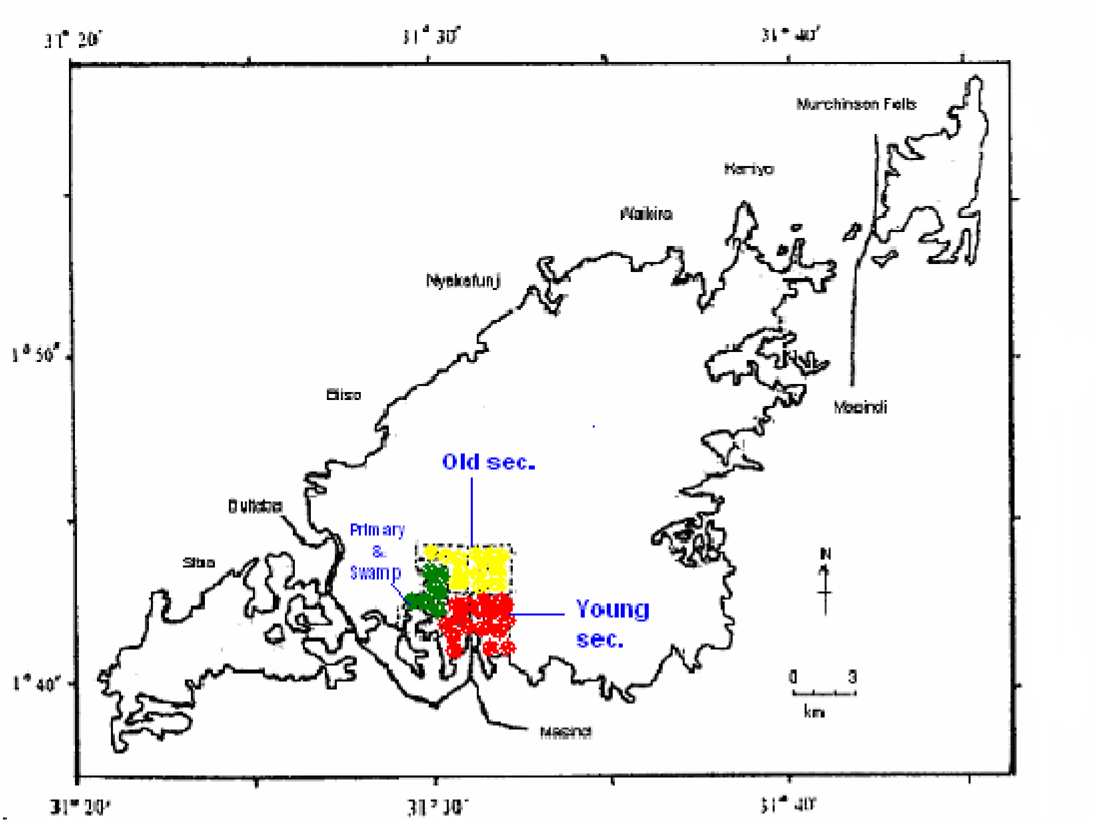


Fig. 4.4 Map of Godere forest and the location of the study sites

In the primary forest, the upper 30-40 m canopy is dominated by *Cynometra alexanderii, Khaya anthotheca* and *Entandrophragma utile*. *C. alexanderi* accounts for 35% of all trees and as much as 90% of all large trees (Paterson 1991). *Lasiodiscus mildbraedii* is a common understorey tree. Due to the closed canopy, no light reaches the forest interior. As a result, the shrub layer and the ground floor are sparse. The primary forest has never been logged and it is protected as nature reserve. From this site, 41 phorophyte individuals were sampled.

The swamp forest is a type of primary forest which is flooded in the wet season and waterlogged during the dry season (Eggeling 1947, Paterson 1991). It is the smallest asscociation in Budongo (Paterson 1991). It is two storied, with irregular canopy. Lianas and straggling figs are abundant. Logging did not take place in this forest type. From this site, 64 phorophyte individuals were sampled.

The old secondary forest has four tree layers, with abundance of large trees 25 to 55 meters high (Paterson 1991). The canopy is formed by evergreen trees and *Cynometra alexanderi* which is leafless for short time. Other common trees are *Chrysophyllum albidum, Khaya anthotheca* and *Trichilia.emetica*. In this site, trees were logged between 1947 and 1952. Twenty-two phorophytes individuals were sampled from this site.

The young secondary forest is two-storied, lacks tall and big trees and lianas are absent (Eggeling 1947). The forest is dominated by an even-aged growth of *Maesopsis eminii* which forms 50-80% of the canopy (Paterson 1991). *Calconcoba schweinfurthii* is the dominant species in the understorey. This site was mechanically logged between 1945 and 1947 and by pitsawing between 1990 and 2000 (Babweteera *et al*. 2000). Sixty-seven phorophyte individuals were sampled from this site.

4.3. Results

4.3.1 Floristic composition

A total of 129 taxa of foliicolous lichens and lichenicolous fungi belonging to 32 genera and 16 families were recorded from Budongo Forest (Fig. 4.5). Of these 125 were identified to the species level, one species was further identified to variety level (*Strigula nemathora* var. *nemathora* & *S. nemathora* var. *hypothelia*). Four were identified to the genus level only (*Calenia* sp., *Coenogonium* sp., *Opegrapha* sp. and *Biatora* sp.). Two species belonging to the genera C*hroodiscus* and *Tricharia* were found to be new to science. For the sake of simplicity, for the analysis of various parameters, all subspecific taxa and taxa identified to a genus level were treated as species. The foliicolous lichen and lichenicolous fungi species recorded from Budongo Forest is presented in Appendix 2.

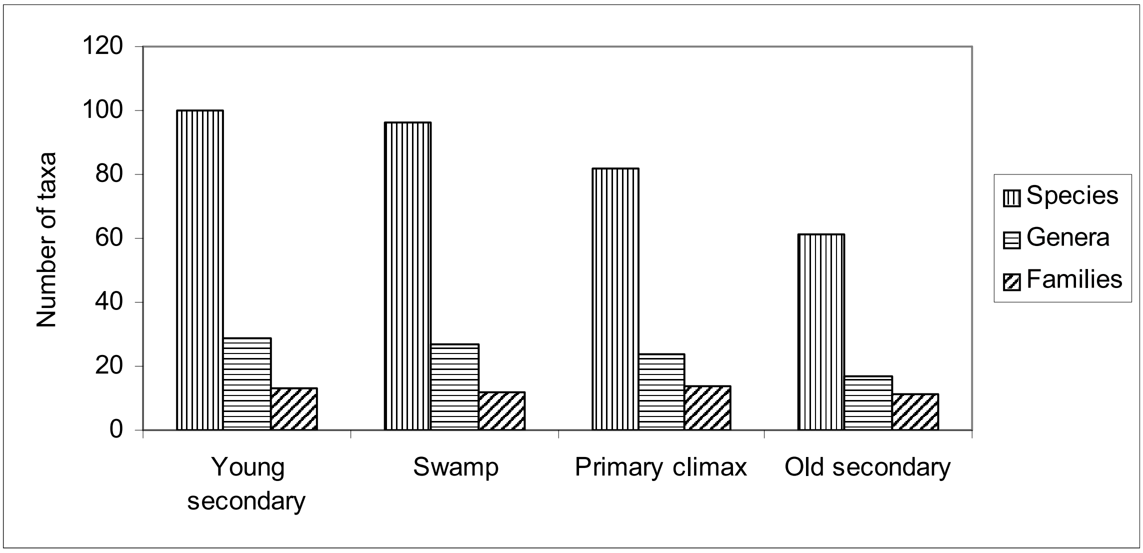


Fig. 4.5 Number of families, genera & species in the four forest types of Budongo

About 95 % of the species in Budongo Forest were typically foliicolous, 3 % were lichenicolous fungi growing on foliicolous lichens and 1.5 % was facultative foliicolous species and 0.8 % was ubiquitous species (Fig. 4.6).

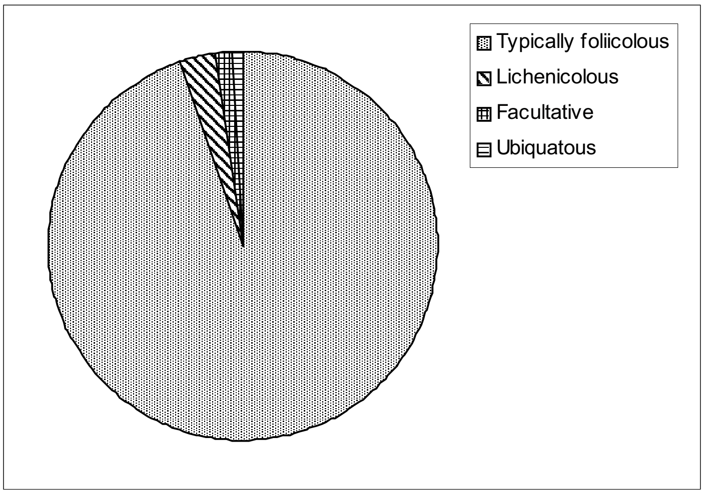


Fig. 4.6 Proportion of typical, facultative, ubiquitous foliicolous lichens and lichenicolous fungi

In the young secondary forest type, 100 species, 29 genera and 14 families were recorded making this forest type the richest in terms of generic and species diversity. With 96 species, 27 genera and 12 families, the swamp forest type is the second diverse. In the primary climax 82 species, 24 genera and 14 families were recorded. The old secondary forest is comparatively the poorest both in the number of families (12), genus (17) and species (61).

The family Pilocarpaceae is the most dominant in the number of genera (10 genera) and species (28 species). In the number of species, the family Porinaceae is the second dominant with 26 species. The family Gomphillaceae possessed 16 species and 5 genera. The families Coenogoniaceae and Strigulaceae both possessed 14 species and 1 genus each. Nine species and 2 genera were recorded in the family Roccellaceae. Seven species and 3 genera were recorded in the family Asterothyriaceae. In the family Thelotremataceae one genus and three species were recorded. The families Arthoniaceae and Aspidotheliaceae each possessed two species and one genus. The families Coccocarpiaceae, Microthyriaceae, Bacidiaceae and Lyrommataceae each possessed one species.

Fig. 4.7 presents the number of genera and species in each family in the four forest types of Budongo. In the primary climax forest type, the family Porinaceae had the highest species numbers (21 species), followed by Pilocarpaceae (17 species), Strigulaceae (10 species), Coenogoniaceae and Gomphillaceae (8 species), Roccellaceae (4 species), Asterothyriaceae, Ramalinaceae, and Thelotremataceae (3 species) and Arthoniaceae, Aspidotheliaceae, Lyrommataceae and Microthyriaceae had 1 species each. Pilocarpaceae is the family with the highest number of genera (8 genera), followed by Gomphillaceae (4 genera), Asterothyriaceae and Porinaceae (2 genera), the rest of the families had one genus each.

In the swamp forest type, Pilocarpaceae had the highest species number (20 species), followed by Porinaceae (19 species), Strigulaceae (14 species), Coenogoniaceae (13 species), Gomphillaceae (10 species) Roccellaceae (7 species); Asterothyriaceae (4 species), Ramalinaceae (3 species), Thelotremataceae (2 species), and Arthoniaceae, Aspidotheliaceae and Lyrommataceae each with one species. In terms of generic diversity, the family Pilocarpaceae had the highest number of genera (8 genera), followed by Gomphillaceae with 4 genera, Asterothyriaceae with 3 genera, Porinaceae and Roccellaceae with 2 genera each, and the families Arthoniaceae, Aspidotheliaceae, Coenogoniaceae, Lyrommataceae, Ramalinaceae, Strigulaceae and Thelotremataceae had one genus each.

In the old secondary forest the family Porinaceae possessed the highest number of species (17 species). The family Strigulaceae is represented by 12 species, Pilocarpaceae, Coenogoniaceae and Roccellaceae by 7 species each, Ramalinaceae by 3 species and Gomphillaceae by 2 species. The families Arthoniaceae, Asterothyriaceae, Lyrommataceae, Bacidiaceae and Microthyriaceae each possessed one species. The family Pilocarpaceae had 4 genera, Porinaceae and Roccellaceae 2 genera each and the families Arthoniaceae, Asterothyriaceae, Bacidiaceae, Coenogoniaceae, Gomphillaceae, Lyrommataceae, Microthyriaceae, Ramalinaceae and Strigulaceae had one genus each. The family Thelotremataceae which was represented in the other three forest types is not represented in the old secondary forest type.

The species rich family in the young secondary forest is Porinaceae (23 species), and it was followed by Pilocarpaceae (18 species). Thirteen species were recorded in the family Gomphillaceae, 12 species in Strigulaceae, 11 species in Coenogoniaceae, 7 species in Roccellaceae, 6 species in Asterothyriaceae, 2 species in Thelotremataceae, and 1 species in Arthoniaceae, Aspidotheliaceae, Bacidiaceae, Coccocarpiaceae, and Lyrommataceae. In the number of genera, the family Porinaceae is the richest with 9 genera and Gomphillaceae is the second with 5 genera. The family Asterothyriaceae is represented by 3 genera, Porinaceae and Roccellaceae by 2 genera each and the remaining families are represented by one genus each.

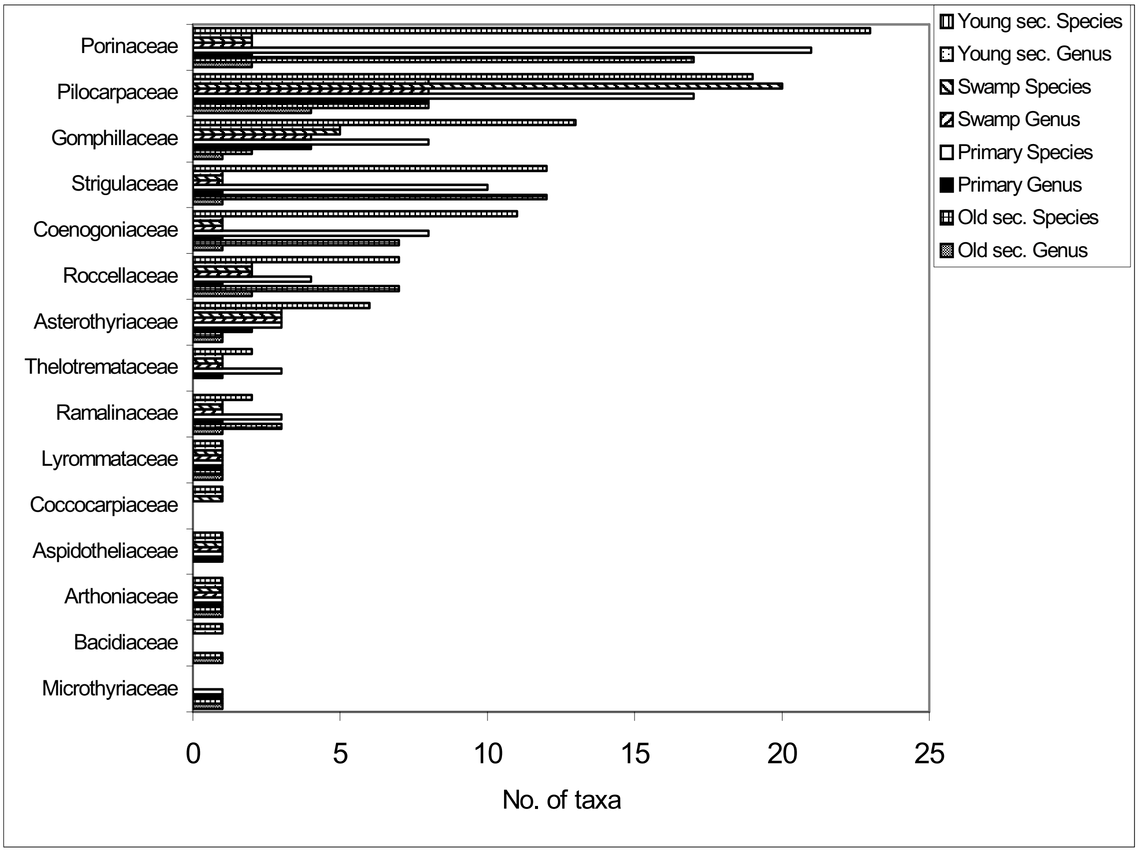


Fig. 4.7 Number of species and genera of foliicolous lichens per family per forest type of Budongo Forest

4.3.2 Species frequency

The frequency occurrences of the foliicolous lichens in the samples of the four forest types of Budongo Forest are presented in Fig. 4.8. In all study sites of Budongo Forest, the rare species constituted more than 57% of the whole species and 11-21% of the species were occasional. These two species groups constituted more than 80% of the species in the primary, swamp and young secondary forest types and about 71% of the species in the old secondary forest type. Comparatively the rare species in the old secondary forest type were fewer (57.4%) than those in the primary (64.2%), swamp (69.8) and young secondary forests (66%). Similarly, there were more dominant species (9.8%) in the old secondary forest type than in the other forest types which have less than 5% dominant species.

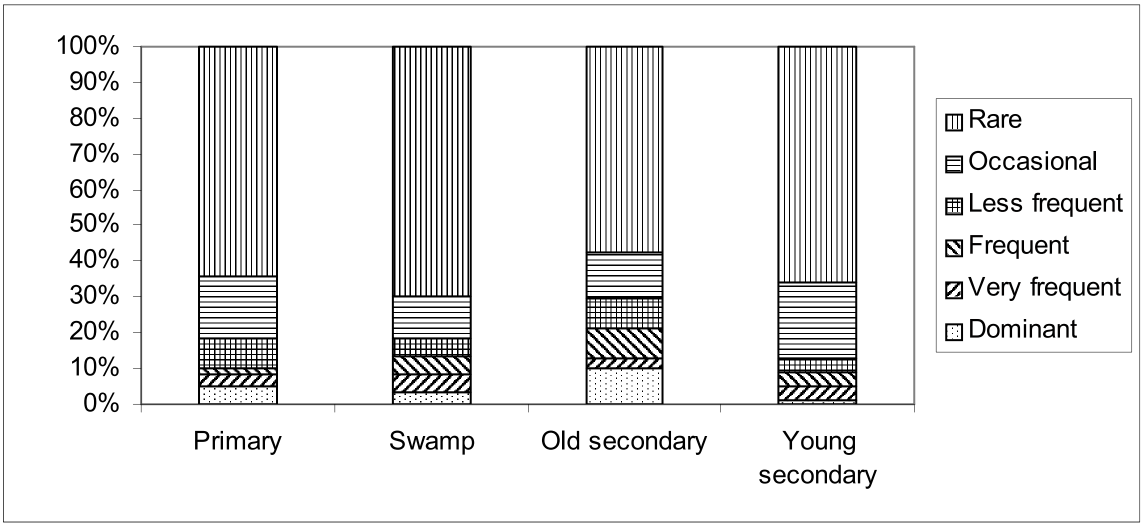


Fig. 4.8 Frequency distribution of species in the four forest types of Budongo Forest

In the primary forest type *Coenogonium dilucidum, Porina radiata, P. epiphylla* and *Mazosia melanopthalma* were the dominant species. *Mazosia rotula, Porina nitidula* and *Strigula phyllogena* were the most frequent species while *Porina semicarpi* was the only frequent species. The less frequent species were *Porina sphaerocephala, P. alba, Brasilicia foliicola, Byssolecania deplanata*, *Strigula microspora, S. nitidula* and *S. smaragdula*. The occasional species were *Byssolecania fumosonigricans, B. hymenocarpa, Bacidina mirabilis, Calopadia fusca, Coenogonium pocsii, C. subluteum, Echinoplaca pellicula, Lyromma nectandrae, Porina cupreola* var. *cupreola, P. epiphylloides, P. kamerunensis, P. rubentior, Sporopodium leprieurii* and *Strigula nemathora* var. *hypothelia.* The rare species were *Coenogonium fallaciosum, Arthonia lividula, Aspidothelium fugiens, Asterothyrium microsporum, A. monosporum, Bapalmuia ivoriensis, B. palmularis, Bacidina apiahica, Bacidina simplex, Byssoloma chlorinum, Byssoloma subpolychromum, Brasilicia dimerelloides, Byssolecania variabilis, Calenia depressa, Calenia graphidea, Calenia bullatinoides, Coenogonium geralense, C. pannosum, C. subdilucidum, C. usambarense, Chroodiscus australiensis, Chroodiscus kakamegensis sp.nov., Chroodiscus verrucosus, Fellhanera bouteillei, F. submicrommata, Gyalectidium filicinum, G. imperfectum, Gyalidea epiphylla, Lichenopeltella epiphylla, Mazosia dispersa, M. phyllosema, Phylloblastia pocsii, Porina* cf. *triseptata, P. conica, P. leptosperma, P. rubescens, P. rufula, P. sphaerocephaloides, P. subpallescens, Strigula janeriensis, S. macrocarpa, S. multipunctata, S. obducta, S. pilocarpoides, S. subtilissima, Sporopodium antonianum, Tapellaria nigrata, Tricharia nigriuncinata* sp. nov., *T. vainioi, Trichothelium africanum, Trichothelium pauciseptatum, T. alboatrum,* and *T. epiphyllum.*

In the swamp forest *Porina epiphylla, Strigula phyllogena,* and *Coenogonium dilucidum* were the dominant species. *Mazosia rotula, Porina alba, P. radiata, P. rubentior* and *P.*

nitidula were very frequent. The frequent species were *Porina semicarpi, Strigula nitidula, S. smaragdula, Mazosia melanopthalma* and *Porina sphaerocephala.* The less frequent were *Porina conica, Strigula nemathora* var. *hypothelia, S. microspora, S. obducta* and *Sporopodium leprieurii.* Occasionals were *Porina leptosperma, P. epiphylloides, P. rubescens, P. rufula, Brasilicia foliicola, Byssolecania deplanata, Gyalectidium filicinum, Lyromma nectandrae, Strigula nemathora* var. *nemathora, Tricharia vainioi,* and *Trichothelium pauciseptatum.* The rare species were *Arthonia orbygniae, Aspidothelium geminiparum, Asterothyrium microsporum, A. monosporum, Bacidina apiahica, B. mirabilis, B. pallidocarnea, Bapalmuia ivoriensis, Bapalmuia palmularis, Brasilicia dimerelloides, Byssolecania fumosonigricans, Byssolecania hymenocarpa, Byssoloma chlorinum, Byssoloma leucoblepharum, Calenia aspidota, Calenia depressa, Calenia graphidea, Calopadia fusca, Calopadia puiggarii, Chroodiscus australiensis, Chroodiscus verrucosus, Coenogonium barbatum, C. fallaciosum, C. geralense, C. lisowskii, C. pocsii, C. siquirrense, C. subdilucidum, C. subfallaciosum, C. subluteum, C. usambarense, C. zonatum, Echinoplaca pellicula, Fellhanera africana, F. rhaphidophylli, F. subfuscatula, F. submicrommata, Gyalectidium caucasicum, G. eskuchei, G. imperfectum, Gyalidea epiphylla, Lichenopeltella epiphylla, Loflammia epiphylla, Mazosia dispersa, M. paupercula, M. phyllosema, Opegrapha epiporina, O. phylloporinae, Porina mazosoides, P. sphaerocephaloides, P. subpallescens, Psorotheciopsis patellarioides, Sporopodium antonianum, S. phyllocharis, S. pilocarpoides, Strigula antillarum, Strigula janeriensis, Strigula macrocarpa, Strigula maculate, Strigula multipunctata, Strigula schizospora, Strigula subtilissima, Tricharia nigriuncinata* sp. nov., *Trichothelium africanum, Trichothelium alboatrum* and *Trichothelium epiphyllum.*

In the old secondary forest type the dominant species were *Porina epiphylla, P. kamerunensis, P. nitidula, P. rubentior, Mazosia melanopthalma* and *Strigula phyllogena. Porina cupreola* var. *cupreola* and *Strigula nitidula* were very frequent species. The frequent species were *Porina radiata, P. rubescens, P. sphaerocephala, Strigula nemathora* var. *hypothelia* and *Strigula smaragdula. Bacidina apiahica, Byssolecania hymenocarpa, Strigula multipunctata, S. microspora* and *Porina rufula* were the less frequent species. The occasional species were *Brasilicia foliicola, Byssoloma chlorinum, Coenogonium dilucidum, Lyromma nectandrae, Opegrapha epiporina, O. phylloporinae* and *Porina semicarpi.* The rare species were *Arthonia lividula, Asterothyrium microsporum, Bacidina mirabilis, Bacidina simplex, Brasilicia dimerelloides, Byssolecania deplanata, B. fumosonigricans, B. subdiscordans, Coenogonium geralense, C. pocsii, C. siquirrense, C. subluteum, C. usambarense, C. zonatum, Fellhanera submicrommata, Gyalectidium filicinum, G. imperfectum, Lichenopeltella epiphylla, Mazosia phyllosema, M. rotula, Opegrapha mazosiae, Porina alba, P. conica, P. leptosperma, P. subpallescens, Strigula janeriensis, S. macrocarpa, S. nemathora* var. *nemathora, S. obducta, S. schizospora, S. subtilissima, Trichothelium africanum, Trichothelium pauciseptatum* and *T. epiphyllum.*

In the young secondary forest type *Strigula smaragdula* is the only dominant species. *Porina nitidula, P. rubentior, Strigula nemathora* var. *hypothelia* and *S. nitidula* were the very frequent species. The frequent species were *Strigula phyllogena, Coenogonium dilucidum, Mazosia rotula* and *Porina epiphylla.* The less frequent species were *Porina radiata, P. sphaerocephala, Strigula microspora* and *Echinoplaca pellicula*. The occasional species were *Bacidina apiahica, Byssolecania deplanata, B. hymenocarpa, Byssoloma chlorinum, Calenia depressa, C. graphidea, Fellhanera submicrommata, Gyalectidium filicinum, G. imperfectum, G. microcarpum, Lyromma nectandrae, Mazosia melanopthalma, Porina cupreola* var. *cupreola, P. epiphylloides, P. kamerunensis, P. leptosperma P. rubescens, P. sphaerocephaloides, P. subpallescens,* and *Strigula multipunctata.*

The frequency of occurrences of foliicolous lichens in Budongo Forest and the primary, swamp, old secondary and young secondary forest parts are presented in Appendices 8, 9, 10, 11 and 12 respectively.

4.3.3 Foliicolous lichens from canopy trees

In the sampling site of the primary climax forest type, a recently fallen tree of *Celtis durandi* reaching a height of 35 m was encountered. Leaves carrying foliicolous lichens were collected from the branches at a height of 20 to 35 m. Only *Strigula smaragdula* was recorded from the leaves. This species covered upto 80% of the leaf areas. In addition, a recently fallen tree of *Ficus lutea* was encountered in a place called Susungiru, about 8 km from the Budongo Forest project office. The following foliicolous lichens were recorded from the leaves of this canopy tree: *Asterothyrium monosporum, Asterothyrium pittieri, Asterothyrium rotuliforme, Calenia aspidota, Psorotheciopsis patellarioides, Psorotheciopsis varieseptata, Strigula antillarum,* and *Strigula smaragdula*. From this forest site 68 species of foliicolous lichens were recorded from the understorey.

4.3.4 New species and new records of foliicolous lichens

The checklist of lichens and lichenicolous fungi of Uganda (Feuerer 2007) listed 362 species. Out of these 29 species are foliicolous lichens. Sixteen of the species recorded in this study have already been included in the checklist. The remaining 108 species are new records for Uganda.

4.3.4.1 Species new to science

Two species of foliicolous lichens belonging to the family Gomphillaceae and Thelotremataceae were found to be new to science. These are *Tricharia nigriuncinata* sp. nov. and *Chroodiscus kakamegensis* sp. nov.

1. *Tricharia nigriuncinata* sp. nov. (Gomphillaceae). Fig. 4.9A

This new species of *Tricharia* is distinguished from all other species of the genus by the presence of hooks on the sterile setae (see arrow in Fig. 4.9).

Specimen examined: Budongo Forest, 01^{0}43’22.9 N, 031^{0}31’45.3 E, 900 m, epiphyllous on *Argomuellera macrophylla* in the primary forest type, 2005, Kumelachew 16, 65, 66, 71, 75 (KOBL).

2. *Chroodiscus kakamegensis* sp. nov.

Chroodiscus kakamegensis is a facultative lichenicolous lichen growing on *Porina epiphylla*. It has been collected from Godere, Budongo and Kakamega forests. A brief description of the species was provided in section 3.3.3.1

Specimen examined: Budongo Forest, 01^{0}43’22.9 N, 031^{0}31’45.3 E, 1082 m, epiphyllous on *Argomuellera macrophylla*, Kumelachew 96 (KOBL)

4.3.4.2 Interesting records of foliicolous lichens

From the foliicolous lichen collection of Budongo Forest, the following interesting records were obtained.

1. *Brasilicia foliicoloa* (Pilocarpaceae)

The apothecia of the specimens cited below grew marginally hypophyllous which is untypical for *Brasilicia foliicola*.

Specimen examined: Budongo Forest, 01^{0}43’22.9 N, 031^{0}31’45.3 E, 1082 m, epiphyllous on an unidentified species of tree in the primary forest, 2005, Kumelachew 92, 93 (KOBL).

2. *Gyalidea epiphylla* (Asterothyriaceae)

The specimen cited below had smaller ascospores (10 x2.5 µm) than the typical species whose ascospore size is 13-25x3.5-4.5 µm (Vĕzda 1966).

Specimen examined: Budongo Forest, 01^{0}42’46.6 N, 031^{0}32’.31.7 E, 1038 m, epiphyllous on unidentified species of Sapindaceae in the young secondary forest type, 2005, Kumelachew 115 (KOBL).

3. *Calenia* sp. (Gomphillaceae) Fig. 4.9B

The collection of *Calenia* cited below has got pruinose apothecia, a single muriform, ellipsoid ascospore per ascus and a prosoplectenchymatous excipulum. This collection is assumed to be a new species of *Calenia* but the material is scanty for a proper description.

Specimen examined: Budongo Forest, Royal Mille, 01^{0}42’46.6 N, 031^{0}32’.31.7 E, 1038 m, epiphyllous on unidentified species, 2005, Kumelachew 117 (KOBL).

Difficult specimens

1. unknown taxon of Pilocarpaceae (Fig. 4.9C, D & E)

A single specimen belonging to the family Pilocarpaceae was difficult to identify even to the genus level. It had centrally continuous and marginally dispersed thallus, and black apothecia (Fig. 4.12a), single muriform ascospore per ascus, branched and anastomised pharaphyses, tubular campylidia (Fig. 4.12b) and simple and bacilliform conidia with thickened ends (Fig. 4.12c). Such types of conidia are unknown in the foliicolous members of Pilocarpaceae.

Specimen examined: Budongo Forest, Royal Mille, 01^{0}42’46.6 N, 031^{0}32’31.7, 1038 m, epiphyllous on an unidentified species of Rubiaceae, 2005, Kumelachew 118 (KOBL).

2. *Coenogonium* sp.

Several collections of the genus *Coenogonium* were difficult to identify. The recent worldwide key for *Coenogonium* (Rivas-Plata *et al*. 2006) doesn’t have sufficient information for the identification our collection. It is highly likely that some of these specimens could represent new taxa of *Coenogonium*. This shows that further investigation in the African *Coenogonium* is required.

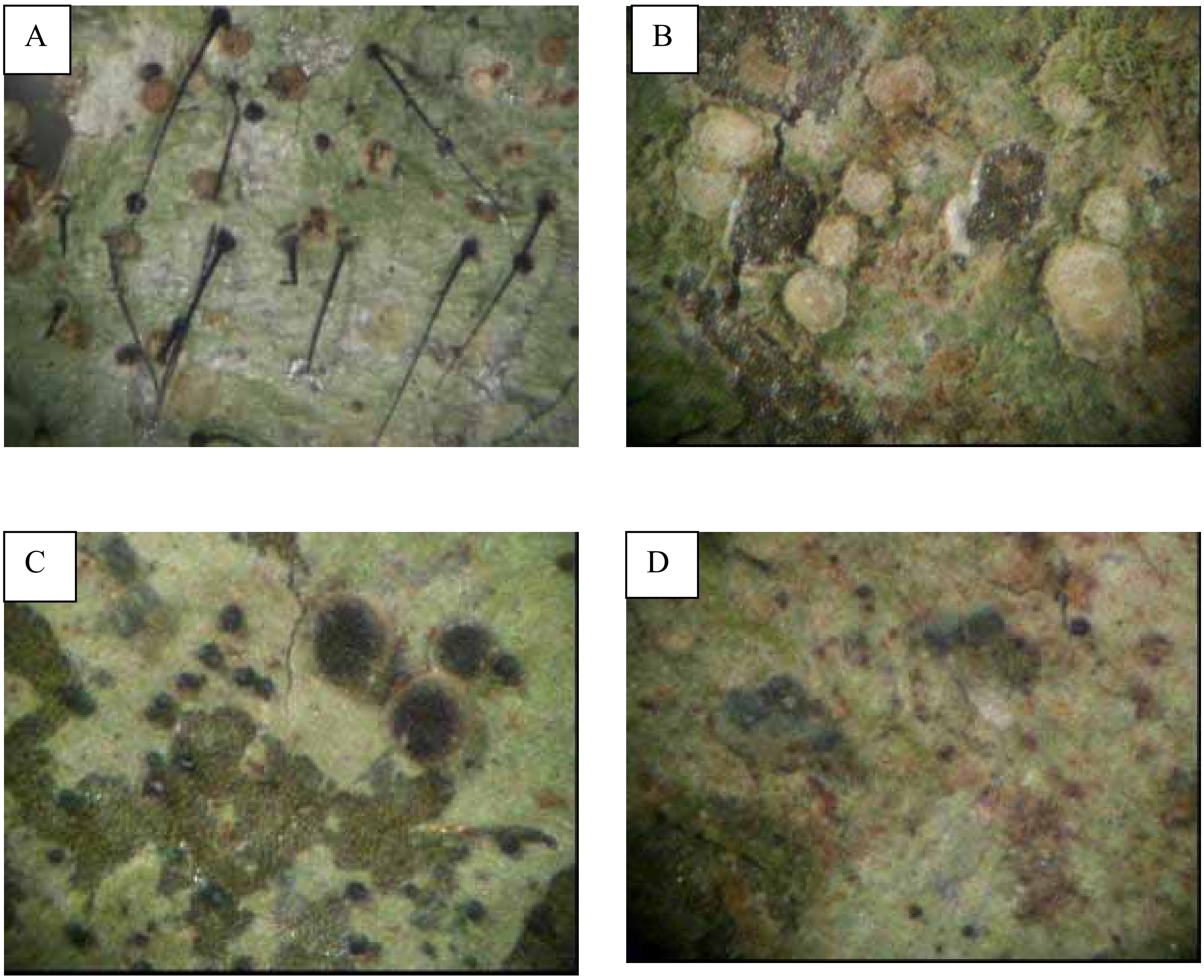


Fig. 4.9 Pictures of new secies and interesting records of foliicolous lichens from Budongo forest. (A) *Tricharia nigriuncinata* sp. nov., (B) *Calenia* sp., (C, D & E) an unknown specimen in Pilocaraceae in (C) thallus with apothecia (arrows), in (D) thallus with campylidia (arrows), in (E) conidia

3. aff. *Biatora sp.*

Three corticolous lichen specimens belonging to the family Bacidiaceae and growing facultatively on margins of living leaves were difficult to identify. They have simple and cylindrical ascospores and are close to the genus *Biatora*.

Specimen examined: Budongo Forest, Royal Mille, 01042’28.7 N, 031032’33.5 E, 1050 m, epiphyllous on *Rawsonia lucida*, 2005, Kumelachew 192, 193, 207(KOBL).

4.3.2 Alpha-diversity

4.3.2.1 Mean species number

The mean number of species recorded per sample was 10.5 for the primary forest type, 11.3 for the swamp forest type, 10.7 for the old secondary forest type and 10.3 for the young secondary forest type (Fig. 4.10). Kruskal-Wallis one-way analysis of variance test showed absence of significant differences (Chi square = 2.26, p > 0.05) among the four forest types in the mean number of species per sample.

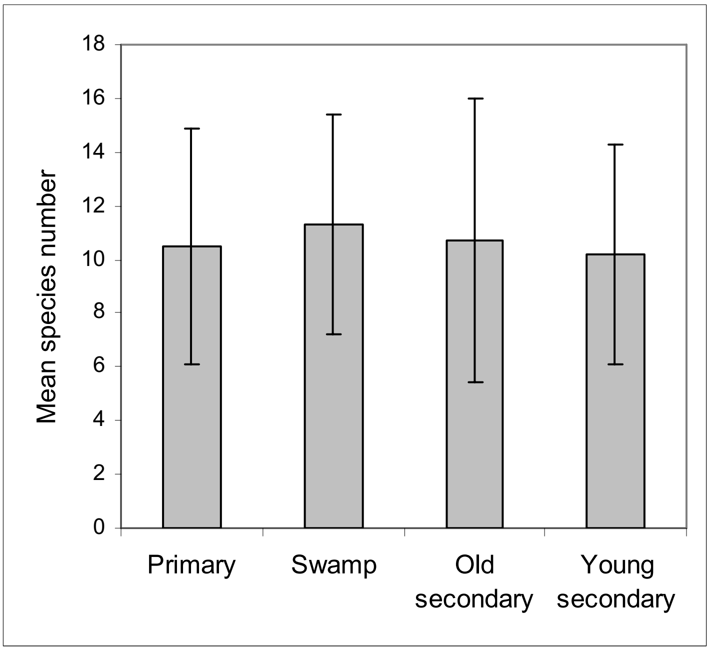


Fig. 4.10 Mean number of species per sample per forest type (values are mean ± SD)

4.3.2.2 Species accumulation curve

The species accumulation curves for the primary, swamp, old secondary and young secondary forests types of Budongo are presented in Fig. 4.11. The x-axis of the first graph is scaled by the number of accumulated samples and it compares species density between

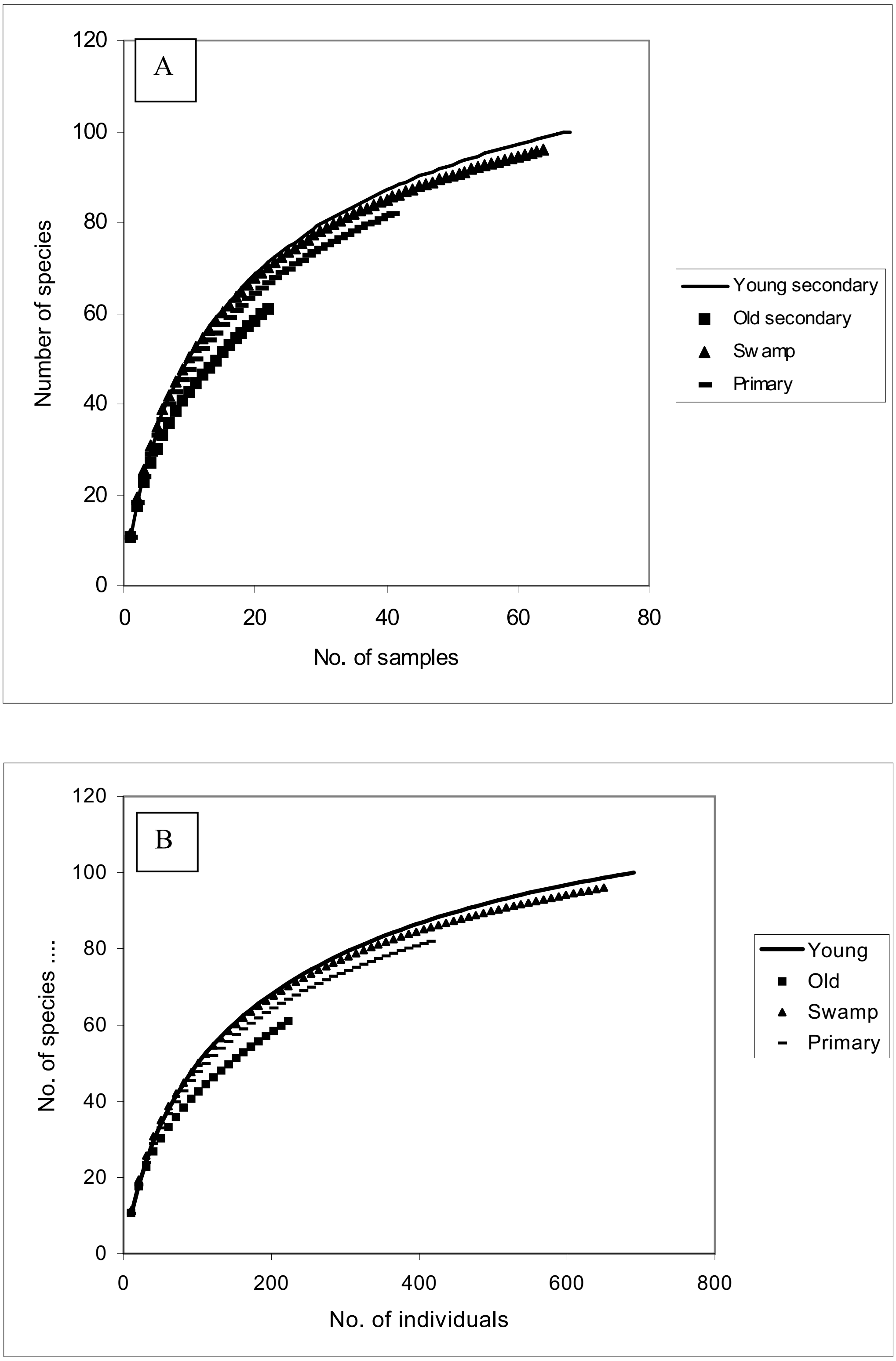


Fig. 4.11 Species accumulation curves for the primary, swamp, old secondary and young secondary forest types. A) Species density, B) Species richness

the forest types. The x-axis of the second graph is scaled by the number of individuals and thus compares species richness. The species accumulation curves for the four forest types did not approach an asymptote, but the rate of accumulation of species as successively more samples are accumulated to the total is decreasing.

As can be seen from the species accumulation curves, more species numbers are expected in the swamp and young secondary forest types than in the primary and old secondary forest types at all levels of sample accumulation (Fig. 4.11a). More species were observed in the swamp forest when lower samples were accumulated. At higher number of sample accumulation, however, more species were observed in the young secondary forest. The old secondary forest has the lowest number of species at all level of sample accumulation. The number of species expected from the species accumulation curves when 22 samples (the sample size of the old secondary forest type) were pooled is 71.1 for the young secondary forest type, 70.2 for the swamp forest type, 66.2 for the primary forest type and 61 species for the old secondary forest type. To see if there is significant difference in species richness, Magurran (2004) recommended to check if the observed diversity of the smaller community lies within the 95% confidence limits of the rarefaction curve of the larger community. Accordingly, the observed species accumulation curve of the primary forest is within the 95% confidence intervals of the corresponding species accumulation curves of the swamp and young secondary forests indicating absence of significant difference. Similarly, the observed species accumulation curve of the swamp forest is within the 95% confidence intervals of the young secondary forests. The observed species accumulation curve of the old secondary forest is within the 95% confidence intervals of the primary forest but outside the 95% confidence intervals of the swamp and the young secondary forests indicating absence of significant difference in species richness between the old secondary and the primary forest types but the swamp and young secondary forests are significantly more species richer than the old secondary forest type (Fig. 4.11b).

4.3.2.3 Estimation of species richness

The non-parametric species richness estimators for incidence data variously estimated the species richness of the four forest types of Budongo Forest (Table 4.3). For the primary and young secondary forest types, the Bootstrap estimator gave the lowest and the second order Jackknife estimator gave the highest estimate of species richness. The second order Jackknife estimator gave the highest species richness estimate for the swamp forest type and the Michalis-Menten Mean estimator gave the lowest estimate. For the old secondary forest type, Chao 2 estimator gave the highest estimate and Bootstrap the lowest estimate of species richness.

Table 4.3. Number of samples, number of individuals and species richness estimate values for the four forest types of Budongo.

	Primary forest	Swamp forest	Old secondary forest	Young secondary forest
No. of samples	41	64	22	67
No. of individuals	431	725	235	689
S_{obs}	81	96	61	100
MMMeans	94.7	105.5	74.4	112.3
Chao 2	103.4±6.8	113.8±9.8	117±30.9	117.8±9.8
Jackknife 1	104.4±6.8	118.6±5.5	87.7±6.9	122.7±5.4
Jackknife 2	117	128.5	107.1	132.6
Bootstrap	91.8	106.6	72.2	111
ICE	104.04±0.03	111.1±0.01	102.3	118.1±0.02
Degree of foliicolous lichen collection	69.2-88.2%	74.7-91%	52.1-84.5	75.4-90.1

Comparison of the number of species observed and the species richness estimated by the various richness estimators showed that 69.2-88.2% of the species have been collected from the primary forest, 74.7-91% of the species from the swamp forest, 52.1-84.5% of the species from the old secondary forest and 75.4-90.1% of the species were collected from the young secondary forests. The differences between the highest and the lowest species estimators were 15.2 species for the primary forest type, 23 species for the swamp forest type, 44.8 species for the old secondary forest type and 21.6 species for the young secondary forest type. The big difference in the old secondary forest type is due to the overestimation of Chao 2 estimator which relies on uniques (species restricted to one sample only) which accounted for 46% of the whole species in this forest type.

4.3.2.4 Shannon-Wiener diversity

The Shannon diversity index and evenness values in each forest type are shown in Table 4.4. Analysis of Variance (ANOVA) of the Shannon diversity values of the four forest sites showed the presence of significant difference (F-ratio = 3.49, $P<0.05$). Fischer's *post hoc* comparison test indicated that the old secondary forest type is significantly different from the other three forest types. There was no significant difference among the Shannon diversity of the primary, the swamp and the young forest types. Accordingly, the primary (H'=3.9), swamp (H'=4.0) and young secondary (H'=4.1) forest types have higher diversity than the old secondary forest type (H'=3.6). The Shannon evenness values are the same (J'=0.88) for the primary, old secondary and young secondary forests and slightly lower in the swamp forest type.

Table 4.4 Shannon-Wiener diversity and evenness index values.

	Primary	Swamp	Old secondary	Young secondary
Shannon index (H')[1]	3.9^a	4.0^a	3.6^b	4.1^a
Shannon evenness index (J')	0.89	0.88	0.89	0.89

[1] Different alphabetical letter designations indicate significant difference ($p<0.05$) among Shannon diversity values of the forest types

4.3.3 Beta-diversity and similarity in species composition

Total β-diversity, measured as total species number divided by mean number of species in samples, along forest types of Budongo Forest is presented in Table 4.5. This index of β-diversity is a measure of the species turnover or the degree of change in species composition. The young secondary forest had the highest β-diversity (9.8) and therefore high species turnover, followed by the swamp forest (8.5) and primary forest (7.8) and the old secondary forest has the lowest β-diversity value (5.7) and therefore low species turnover.

Table 4.5 β-diversity along the forest types of Buyangu

	Number of species (a)	Mean number of species per sample (b)	β-diversity (a/b)
Primary forest	82	10.5	7.8
Swamp forest	96	11.3	8.5
Old secondary forest	61	10.7	5.7
Young secondary forest	100	10.2	9.8

Table 4.6. Sørenson's index of similarity among the four forest types

	Primary	Swamp	Old secondary
Primary	-		
Swamp	0.77	-	
Old secondary	0.7	0.68	-
Young secondary	0.74	0.75	0.67

The similarity in foliicolous lichen species composition, as measured by Sørenson's index of similarity, shows generally a high similarity among the four forest types of Budongo with a mean Sørenson's similarity index of 0.72. The highest species composition similarity among the forest types was observed between the primary and swamp forest types (S_s=0.77) followed respectively by the young and swamp forest types (S_s=0.75), the primary and young secondary forest types (S_s=0.74), the primary and old secondary forest types (S_s=0.7), the old secondary and swamp forest types (S_s=0.68) and the least similarity was observed between the young and old secondary forest types (S_s= 0.67) (Table 4.6).

4.3.4 Ordination

Fig. 4.12 shows a graphic representation of the first two axes of a DCA ordination. The first axis of the ordination had eigenvalue of 0.401 contributing to 7.3% of the total variation. The second axis with eigenvalue of 0.217 contributed to 4% of the variation. The third and fourth axes had eigenvalues of 0.180 and 0.163 respectively, each contributing to less than 4% of the total variation. Therefore, most of the variation in the DCA ordination is explained by the first axis.

Along the first DCA axis, samples with low first axis scores are from the closed forest sites with dominating shady understorey micrositic conditions and they are arranged on the left side of the axis. Samples with high first axis scores are from open forest sites where light gap microsite conditions dominate and are arranged on the right side of the axis. Most of the samples from the swamp, primary forest and old secondary forest sites are located on the left side of the first ordination axis. While few samples of the young secondary forest site are distributed on the left side of the first DCA axis, the majority of the samples being distributed on the right side of this axis. These distribution patterns indicate that vegetation type (degree of anthropogenic disturbance; in the terminology of Lücking 1997b) seems to be the factor for the variation in the distribution of the samples.

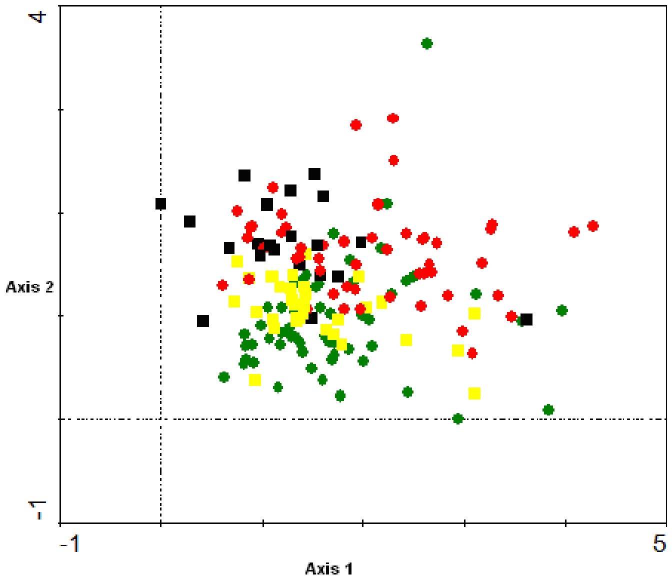


Fig. 4.12 DCA plot of samples of Budongo Forest. Black circles = samples from swamp, white squares = samples from primary, black squares = samples from old secondary, and red circles = samples from young secondary forest types.

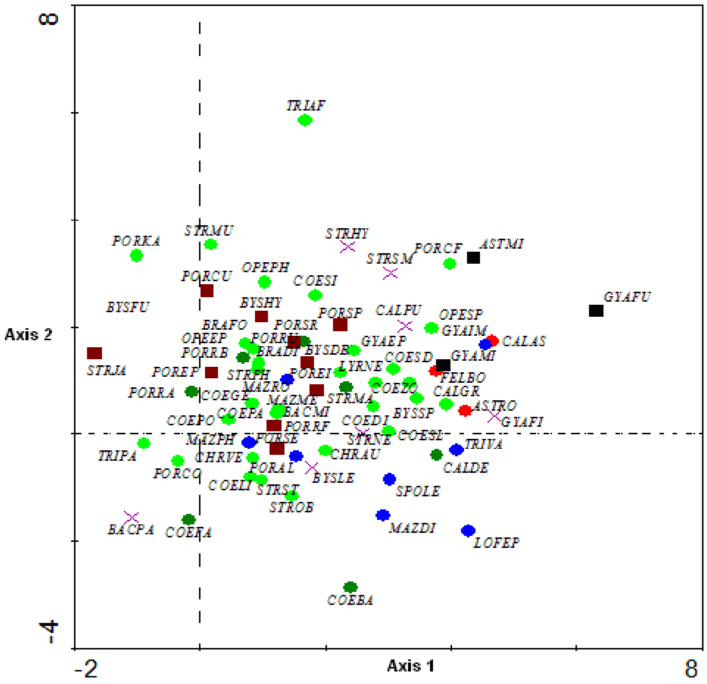


Fig. 4.13 DCA plot of foliicolous lichen species of Budongo Forest. Only species with high occurrences are shown. Green circles = species of undisturbed primary forest, light green circles = species of primary & old growth forest, brown squares = species of semi-open forest, blue circles = species of open forest (forest margin), black squares = species of open to exposed forest, red circles = species of exposed forest, x = species with wide amplitude. For acronyms, refer to Appendix 2.

For the interpretation of the species ordination (Fig. 4.13), the environmental index values of foliicolous lichens (Lücking 2000b, with addition of my personal observation) with respect to vegetation type (degree of anthropogenic disturbance) and light regime (microsite), was first determined. Species with high scores on the first DCA axis are canopy species distributed in the open to exposed forest parts. Species with low scores are from shady understorey and light gap of closed forests and semi-open forest.

4.3.5 Phorophytes

Argomuellera macrophylla, Cynometra alexandri, Trichilia emetica, Maranthacloa sp., Rawsonia lucida, Rinorea ardisiaeflora, Hippocratea sp., *Antiaris toxicaria, Chrysophyllum albidum, Campylospermum* sp., *Memecylon jasminoides, Teclea nobilis, Pterygota mildbraedii, Aframomum* sp., *Oxyanthus lepidus, Tabernaemontana holstii, Trichilia rubescens, Celtis mildbraedii, Chionanthus mildbraedii, Funtumia africana, Blighia unijugata, Coffea canephora, Conarus longistipitatus, Dracaena fragrans, Lasiodiscus mildbraedii, Ouratea densiflora, Schefflera* sp., *Alchornea florubinda, Khaya anthotheca, Macaranga* sp., *Citropsis articulate, Melianthus westii, Turreantus africanus, Agelaea ugandensis, Commelina* sp., *Pollia condensate, Acalypha* sp., *Leptaspis cochleata, Uvariopsis congensis, Lychnodiscus cerospermus, Bequaertiodendron oblanceolatum, Kigelia africana, Strychnos* sp., *Ficus asperifolia, Mitragyna stipulosa* and some unidentified species in the family Euphorbiaceae, Rubiaceae, Sapindaceae, Annonaceae, Sapindaceae and ferns were the phorophytes that supported foliicolous lichens in Budongo Forest. *Argomuellera macrophylla* was the phorophyte that supported the most species (75 species) and the highest record (229 records of foliicolous lichens). *Cynometra alexanderi* supported 5 species and 124 records of foliicolous lichens, *Trichilia emetica* supported 43 species and 43 records of foliicolous lichens, *Maranthacloa* sp. supported 39 species and 9 records of foliicolous lichens, *Rawsonia lucida* supported 34 species and 47 records of foliicolous lichens and *Rinorea ardisiaeflora* supported 33 species and 50 records of foliicolous lichens.

4.4 Discussion

4.4.1 Sample size sufficiency

Sufficiency of sampling can be evaluated using species accumulation curves and by comparing the values of various species richness estimators. Sampling is said to be sufficient when the species accumulation curve reach a horizontal asymptote (Soberón & Llorente 1993). The species accumulation curves for the observed species of the four forest types of Budongo did not reach a horizontal asymptote indicating more species could be recorded with additional sampling effort. Soberón & Llorente (1993) have indicated that in evaluating species accumulation curves, the rate of accumulation of new species should be compared. The rate of accumulation of new species as more samples were pooled has very much reduced for the primary, swamp, and young secondary forest types and less reduced for the old secondary forest type.

According to the estimates of the various species richness estimators, 69-88% of the species from the primary forest part, 75-91% from the swamp forest, 52-85% from the old secondary forest and 75-90% from the young secondary forest were collected in this study. According to the report of Heck *et al*. (1975) which considers collection of 50% to 75% of the total species richness of an area as satisfactory, the numbers of foliicolous lichen species collected from the four study sites are quite satisfactory.

4.4.2 Diversity of foliicolous lichen families and genera in the four forest types

In terms of family diversity the young secondary and the primary forest types are comparatively more diverse than the swamp and the old secondary forest types. The families Aspidotheliaceae, Thelotremataceae and Verrucariaceae were not represented in the old secondary forest type. The families Aspidotheliaceae and Verrucariaceae were not represented in the swamp forest. In terms of generic diversity, the young secondary forest is the most diverse and the old secondary forest is the least diverse. The genera *Aspidothelium, Bapalmuia, Calenia, Calopadia, Chroodiscus, Echinoplaca, Gyalidea, Loflammia, Psorotheciopsis, Phylloblastia, Tapellaria* and *Tricharia* were not represented in the old secondary forest. Most of these genera are represented in the primary, swamp and young secondary forest types.

4.4.3 Species richness in the four forest types of Budongo

At all levels of sample accumulations, the species accumulation curves showed higher estimate of species richness for the young secondary and swamp forests than for the primary and old secondary forest types. When comparing the absolute number of species, the young secondary forest type is the most species rich, followed respectively by the swamp forest, the primary forest and the old secondary forest is the least species rich. Observation of the species accumulation curves and their 95% confidence intervals, however, shows that the young secondary and the swamp forest types are not significantly different in species richness. Considering this statistical significance, the young secondary and the swamp forest are the most species rich forest type; the primary forest is the second species rich and the old secondary forest type is the least species rich forest type.

Alpha diversity, as measured by the species accumulation curves, species richness estimators and Shannon index, and β-diversity of foliicolous lichens were found to be high in the young secondary and swamp forest types. The primary forest assumes an intermediate position and the old secondary forest has the lowest α-diversity and β-diversity of foliicolous lichens. The similarity in foliicolous lichen species composition of the four forest types of Budongo is mainly due to similar microclimatic conditions. Shady understorey and transition to light gap species accounted for 62% of the species in the primary, 60% in the swamp, 58% in the old secondary and 55% of the species in the young secondary forest.

Previous studies on the diversity of foliicolous lichens in the Neotropics (Lücking 1992b, Lücking 1998b) observed high species richness in undisturbed forests and a reduced richness in disturbed and secondary forests. Our study, however, showed that secondary forests could also support similar or even higher foliicolous lichen diversity than undisturbed primary forests. The high diversity in the swamp and young secondary forest is due to occurrence of the whole microsite habitats which are suitable for the growth of foliicolous lichens. In addition to the shady understorey and light gap microsite species, canopy specialists (e.g. *Asterothyrium pittieri, A. rotuliforme, Psorotheciopsis patellaroides, Canlenia aspidota*) are also recorded in the understorey of the young secondary forest type. The most recent selective logging by pitsawing in the period between 1990 and 2000 (Babweteera *et al*. 2000) might have contributed for the appearance of such species in the understorey of this forest type. Lücking (1998d) postulated that diversity of microsites with different microclimate provoked by strong gap dynamics is important for the diversity of foliicolous lichens.

The finding from this study is in line with the Intermediate Disturbance Hypothesis (Connell 1978) which states that species diversity in a landscape is highest in areas with an intermediate level of disturbance. The effect of disturbance on foliicolous lichen diversity is dependent on the frequency and intensity of disturbance. When the intensity of disturbance is high leading to wide canopy openings, the increasing light intensity and the reduced atmospheric moisture affect the shady understorey and the transition to light gap species thereby reducing the diversity of foliicolous lichens. Under moderate level of disturbance, for example small scale logging by pitsawing, partial canopy openings could enhance the establishment of light demanding species without seriously jeopardizing the shade loving species.

4.4.4 β-diversity

Total β-diversity, measured by the total number of species divided by the mean species number per sample, is relatively high in the young secondary forest (β-diversity = 9.8) with a relatively higher species turnover and low in the old secondary forest (β-diversity = 5.7) with a relatively lower species turnover. The high Sørenson indices (0.67-0.77) among the four forest types are evidence for a low species turnover and therefore low β-diversity in Budongo Forest. The low β-diversity in turn is an indication of comparable microenvironmental conditions in the forest types.

4.5 Conclusion

- The foliicolous lichen species richness of Budongo Forest is considerably high.
- Diversity of foliicolous lichens in Budongo Forest is high not only in the primary forest parts, but in the young secondary forests as well.
- High foliicolous lichen diversity in Budongo Forest is due to the availability in close proximity of forest types with different succession stages and disturbance history.
- The high proportion (> 55% of species) of shady understorey and transition to light gap species in the four forest types is due to closed forest canopy which is indicative of minimal forest disturbance.

Chapter 5. DIVERSITY OF FOLIICOLOUS LICHENS IN KAKAMEGA FOREST, KENYA

5.1 Study area

5.1.1 Location and physiography

Kakamega Forest is located in Shinyalu Division of Kakamega District in the Western Province of Kenya. It is situated about 40 km northwest of Lake Victoria between $0^{0}10'$ and $0^{0}21'$ N latitudes and $34^{0}47'$ and $34^{0}58'$ E longitudes (Fig. 5.1).

The Kakamega District is situated in the Lake Victoria Basin and most of the forest lies on flat to undulating terrain with only few steep hills including Buyangu and Lirhanda (Blackett 1994). The forest has an area of 240 km^2 though only approximately 100 km^2 still consists of indigenous forest (Fashing & Gathua 2004). The remaining portion of the reserve consists of plantations, tea field, and grasslands (Wass 1995). The official forest boundary of Kakamega Forest lies between 1460 and 1765 m a.s.l. (Lung & Schaab 2006). Two major rivers pass through the forest, each with several tributaries, particularly in the eastern blocks of the forest (Kokwaro 1988). In the northern section of the forest is the Isiukhu River, which rises in the North Nandi Forest and the Nandi Escarpment. The southern section of the forest is dissected by the Yala Rivers, together with its many tributaries with sources mainly in the Tinderet Forest and South Nandi Forest.

Kakamega Forest covers 8,500 ha of a main forest block surrounded by five forest fragments of various sizes (130-1,400 ha): Malava and Kisere in the north, and Yala, Ikuywa and Kaimosi in the south (Farwig *et al*. 2006) (Fig. 5.2).

5.1.2 Geology and Soil

Kakamega Forest is located in the Lake Victoria Basin whose underlying bedrock is the Precambrian rock (Lovett & Waser 1993). The Precambrian rock is composed of basalt, phenolites and ancient gneiss which are associated with gold-bearing quartz veins (Blackett 1994). The underlying rock is overlain by soils of low fertility ferralo-chromic/orthic acrisols, which are well-drained, deep, heavily leached, medium to heavy texture clay-loams and clays, usually with pH below 5.5 (Blackett 1994). The soils to the east and north-east of the forest are humic cambisols and acrisols (Blackett 1994, Tattersfield *et al*. 2001, Glenday 2006). To the south-east of the forest, there is an area of more fertile nitosols (Blackett1994). Musila (2007) identified four soil classes in Kakamega Forest: Ferralsols (in Salazar and Kisere), Cambisols (in Isecheno, Kaimosi and Yala), Phaeozems (in Ikuywa), and Lixisols (in camp site).

Fig.5.1 Map of Kenya showing the location of Kakamega Forest (red square). (Source: www.village-sanctuary.com)

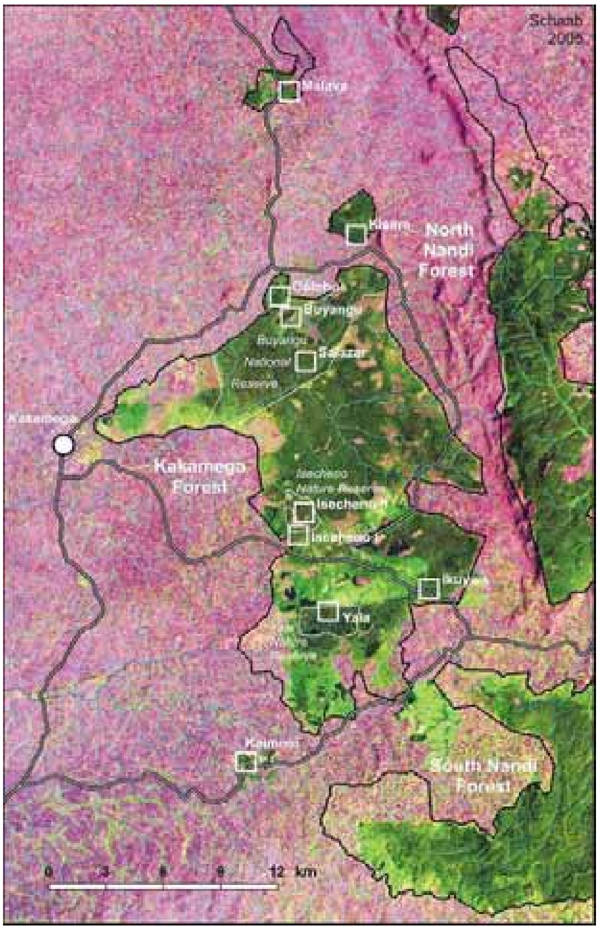


Fig. 5.2. Satellite image (Landsat 7 ETM+, 05 Feb 2001) of Kakamega Forest and its fragments (source: BIOTA-E02, G. Schaab).

5.1.3.Climate

The area around Kakamega Forest has one of the highest levels of annual rainfall in Kenya. Rainfall in Kakamega is bimodal, the long rains falling in April and May and the short rains falling in September and October. The dry season is from the end of December to February. The Forest Department records rainfall at Isecheno forest station and the average annual rainfall between the period 1982 and 2006 was between 1343 and 2638 mm. The average annual temperature of the forest is between 10.6 and 27.7 ^{0}C and the average monthly maximum temperature ranges from 18 to 29^{0}C while the corresponding minimum temperature varies from 4 to 21^{0}C (Muriuki & Tsingalia 1990).

5.1.4. Vegetation, flora and plant communities

The vegetation of Kakamega Forest contains a mosaic of primary rainforest, secondary forests of different seral stages, swamp and riverine forest, selectively logged forest, plantations of indigenous and exotic tree species, natural glades, and clearings made following human disturbances (Mutangah et al. 1994, Tattersfield *et al* 2001).

The forest type of Kakamega has been classified differently by various authors: upland rainforest (Greenway 1973), transitional rainforest (White 1983), tropical rainforest (Beentje 1990), mid-altitudinal tropical rainforest (Bleher *et al*. 2005) and dry peripheral semi-evergreen Guineo-Congolian transitional rainforest (Althof 2005). Kokwaro (1988) described Kakamega Forest as the easternmost relic of the equatorial forests that stretch across the Congo basin and the only tropical rainforest of the Guineo-Congolian type found in Kenya. It occupies a transitional position between the Guineo-Congolian lowland forests and the afromontane forests of the highlands to the west of the Rift Valley (Blackett 1994). Floristically, the forest consists of species from the Guineo-Congolian floral region, from the Afromontane floral region and species which fall neither in the former nor in the latter regions, and are thus transitional.

Several authors documented the flora of Kakamega Forest. Kokwaro (1988) recorded 147 species of woody plants and 227 species of herbaceous plants. Blackett (1994) recorded 132 tree species. Althof (2005) recorded 112 species of trees, 62 species of shrubs, 58 species of climbers and 165 species of herbaceous plants (including ferns).

Among the 212 woody species recorded in Kakamega Forest (Althof 2005), 41% were Guineo-Congolian origin, 33% were related to the Afromonatne forest system and 26% were transitional species. The Guineo-Congolian species include *Pouteria* (*Aningeria*) *altissima, Antiaris toxicaria, Argomuellera macrophylla, Artabotrys likimensis, Bequaertiodendron oblanceolatum, Blighia unijugata, Celtis gomphophylla, C. mildbraedii, Clerodendrom buchholzii, C. johnstoni, Coffea eugenioides, Craterispermum schweinfurthii, Culcasia falcifolia, Dracaena fragrans, D. laxissima, Entandophragma angolense, Ficus asperifolia, F. exasperate, F. vallis-choudae, Funtumia africana, Gouania longispicata, Harungana madagascariensis, Hippocratea africana, Jasminum* *fluminense, Landolphia buchananii, Maesopsis eminii, Monodora whitei, Premna angolensis, Pseuderanthenum ludovicianum, Rothmannia longiflora, Trichilia emetica, Uvariopsis congensis* and *Venronia conferta*.

The Afromontane species include *Albizia gummifera, Allophylus abyssinicus, Apodytes dimidiata, Cassipourea ruwensorensis, Chaetacme aristata, Chyrsophyllum albidum, C. viridifolium, Croton macrostachyus, C. megalocarpus, Deinbollia kilimandscharica, Diospyros abyssinica, Ekebergia capensis, Lepidotrichilia volkensii, Macaranga kilimandscharica, Neoboutonia macrocalyx, Nuxia congesta, Olea capensis, Oncoba spinosa, Oxyanthus speciosus, Polyscias fulva, Prunus africana, Rapanea melanophloeos, Ritchiea albersii, Stombosia scheffleri, Syzigium guineense, Teclea nobilis, Trichocladus ellipticus, Urera hypselodendron*, and *Vangueria apiculata*.

The transitional species include *Alangium chinense, Alchornea laxiflora, Bridelia micrantha, Clausena anisata, Clematis brachiata, Croton sylvaticus, Dalbergia lactea, Dombeya burgessiae, Dovyalis macrocalyx, Ehretia cymosa, Erythrococca atrovirens, Ficus natalensis, F. sur, F. thonningii, Flacourtia indica, Grewia similes, Kigelia africana, Maesa lanceolata, Margaritaria discoidea, Maytenus heterophylla, Morus mesozygia, Pavonia urens, Rawsonia lucida, Rothmannia urcelliformis, Sapium ellipticum, Stereospermum kunthianum, Strychnos usambarensis, Tinnea aethopica, Trema orientalis, Trilepisium madagascariense*, and *Vitex fischeri*.

Twenty-seven woody species recorded by Althof (2005) were not recorded in other parts of Kenya. These include *Acacia montigena, Achyrospermum parviflorum, Pouteria* (*Aningeria*) *altissima, Bequaertiodendron oblanceolatum, Cassipourea ruwensorensis, Chionanthus mildbraedii, Chrysophyllum albidum, Clerodendrum buchholzii, Craterispermum schweinfurthii, Dracaena fragrans, Entandophragma angolense, Illigera pentaphylla, Leea guineense, Maesopsis eminii, Monodora myristica, Oreobambus buchwaldii, Ouratea densiflora, Ouratea hiernii, Piper guineense, Premna angolensis, Pseuderanthenum ludovicianum, Rothmannia longiflora, Rothmannia sp., Uncaria africana, Uvariopsis congensis*, and *Vernonia conferta.* In addition, Althof (2005) recorded the endemic herb *Commelina albiflora* and 15 woody species for the first time in Kakamega Forest including *Agelaea pentagyna, Artabotrys likimensis, Basella alba, Connarus longistipitatus, Dregea abyssinica, Leptaspis cochleata, Meyna tetraphylla, Monanthotaxis buchananii, Smilax anceps, Suregada procera,* and *Turraea abyssinica.*

Althof (2005) described the plant communities Kakamega Forest based on the Braun-Blanquet method. In total, thirteen plant communities and subcommunities belonging to two alliances, i.e., *Antiaris toxicaria–Diospyros abyssinica* alliance representing the mature forest stage and *Harungana madagascariensis–Desmodium adscendens* alliance representing the young forest stage, were identified from the main forest block and fragments.

Plant communities and subcommunities of the *Antiaris toxicaria–Diospyros abyssinica* alliance:

1. *Trichocladus ellipticus* subcommunity is named from the differential species and is said to represent a climax stage of development in the near-primary Kisere forest.
2. *Ficus cyathistipula* subcommunity is characterized by the presence of *Ficus cyathistipula* and *F. bubu* and is localized in Ghostisland part of the Buyangu National Reserve.

3. *Uvariopsis congensis* community can be distinguished by the differential species *Uvariopsis congensis* and is restricted to the study sites at Kisere, Buyangu Hill, Colobus and Ghostisland.

4. cf. *Fernandoa magnifica* community occurs in places at Kisere, Buyangu Hill and Colobus and is characterized by the differential species cf. *Fernandoa magnifica* and *Rawsonia lucida* and *Strychnos usambarensis*. *Deinbollia kilimandscharica* and *Markhamia lutea* are the associated species in the shrub layer.

5. Degraded *Rapanea melanophloeos* community is found in a disturbed area along Isiukhu river. It is distinguished by the characteristic species *Rapanea melanophloeos* and *Nuxia congesta*.

6. Pure *Deinbollia kilimandscharica – Markhamia lutea* community is found in Buyangu Hill. It is a middle-aged secondary forest community characterized by *Rawsonia lucida*, *Strychnos usambarensis* and *Coffea eugenioides*.

7. *Deinbollia kilimandscharica – Markhamia lutea* transitional subcommunity is found in the Udo camp site and Vihiga area and is characteristic of young forests.

8. In *Suregada procera* subcommunity, *Suregada procera* is the differential species and the liana *Landolphia buchananii* is the characteristic species. The community is found in Yala and Ikuywa forests.

9. *Pseuderanthemum ludovicianum* subcommunity is found in parts of Salazar, Busambuli, Isecheno, Yala and Ikuywa and is described as a middle-aged secondary community.

10. *Strombosia scheffleri* community is a middle-aged secondary community and is found in parts of Isecheno forest.

11. In Pure *Celtis mildbraedii – Craibia brownii* community, *Celtis mildbraedii* and *Craibia brownii* are characteristic species in the tree layer and *Bequaertiodendron oblanceolatum* and *Chrysophyllum albidum* are the characteristic species in the shrub layer.

Plant community and subcommunity of the *Harungana madagascariensis–Desmodium adscendens* alliance:

1. *Maesa lanceolata* subcommunity is characteristic of a disturbed forest and is found in the forest around the Udo camp site. The community is characterized by the abundance of *Maesa lanceolata*, *Acanthus pubescens*, and *Pavonia urens*.

2. *Pittosporum viridiflorum* community is the youngest of all investigated succession stages in Kakamega Forest.

5.1.5 Fauna

Kakamega Forest is known for its animal diversity. It is home to five diurnal primate species: the Black and White Colobus (*Colobus guereza*)*,* the Red-tailed Monkey *(Cercopithecus ascanius*)*,* the Blue Monkey (*Cercopithecus mitis*)*,* the De Brazza's Monkey (*Cercopithecus neglectus*)*,* and *the Olive Baboon* (*Papio anubis*) (Fashing & Cords 2000). Other large mammals in the forest include the Bushbuck (*Tragelaphus scriptus*), the Waterbuck (*Kobus ellipsiprymnus*), the Bushpig *(Potamochoerus larvatus)*, the Blue Duiker (*Cephalophus monticola*), the Red Duiker (*Cephalophus harveyi*), and the Common Duiker (*Sylvicarpa grimmia*) (Blackett 2004).

The avifauna of Kakamega Forest is quite remarkable with a unique combination of central African lowland species and highland species, the lowland species being the dominat. Zimmerman (1972) shows that the avifaunal affinities of Kakamega Forest relate with the lowland Congo and western Uganda forests, as indicated by the 107 species they share in common. More than 350 species of birds are found in Kakamega Forest (KIFCON 1994). Sixty-two birds of Kenya are restricted to Kakamega Forest including Turner's Eremomela (*Eremomela turneri*) and Chapin's Flycatcher (*Muscicapa lendu*) which are globally threatened species (Sayer *et al*. 1992).

Kakamega Forest is rich in amphibians and reptiles. Many of the snakes in Kakamega Forest are from West Africa including the Forest Cobra (*Pseudonaje goldii*), the Black-lipped Cobra (*Naja melanoleuca*), Jameson's Mamba (*Dendroaspis jamesoni*), the Bush Viper (*Atheris squamigera*), the Rhinoceros-horned Viper (*Bitis nasicornis*) and the Gaboon Viper (*Bitis gabonica*). Veith (2004) recorded 28 species of frogs from Kakamega forest.

Insects, especially butterflies (Lepidoptera) are diverse in Kakamega Forest with a total of 515 species, representing 60% of the total butterfly species in Kenya (Häuser 2004). In addition, 71 species of dragonflies (Clausnitzer 2004) and more than 190 species of bees (Kraemer & Naumann 2004) have been recorded from the forest.

5.1.6. Management Status

Historical records (Mitchell 2004) indicate that the first forest boundary of Kakamega was physically established around 1908-1910. This boundary was later modified in1912-13 and in 1929-1932. During these periods, the forest used to be managed by the local people and village elders until its management was taken over by the Forest Department in 1931 (Mitchell 2004). In 1933, Kakamega Forest was first gazetted as a Trust Forest under Proclamation No. 14 and it was declared as a Central Forest in 1964 (Blackett 1994). In 1967, the Isecheno, Kisere and Yala Nature Reserves were established and gazetted. In 1986, the northern part of Kakamega Forest (Buyangu area) and Kisere forest were gazetted as Kakamega National Reserve and fell under management of the Kakamega Wildlife Reserve (KWS) which is a quasi-government body operating under the Ministry of Environment and Natural Resources. The southern part of the main forest block (Isecheno), and the fragments Malava, Yala, Ikuywa, and Kaimosi are managed by the Forest Department (FD) under the Ministry of Environment and Natural Resources.

The aim of the KWS is to conserve, protect and sustainably manage wildlife resources (Wass 1995). The areas under KWS managements are kept for conservation and tourism only and people are not allowed to collect any forest products. The aim of the FD is to enhance conservation and protection of indigenous forest, to improve the production of timber and fuelwood and to establish a framework for the long-term development forestry (Wass 1995). Cattle grazing, collection of dead firewood, medicinal plants and thatching grass are permitted in FD controlled area, while logging and charcoal burning is illegal (Glenday 2006).

5.1.7. Human Impact

Kakamega Forest is found in an area with one of the highest human population densities in Kenya (Tsingalia 1990) with an average of 600 people per square kilometer (Blackett 1994). Human settlement inside the forest was widespread until its gazettement. This high population density has led to considerable long-term human influence on the forest (Wass 1995). The local people have long used the forest for shamba system farming, as a thoroughfare for herding cattle to grasslands in the forest interior and as a source of charcoal, fuelwood, gold, honey, medicinal plants, timber, and construction materials and hunting of wild animals (Kokwaro 1988, Wass 1995, Mitchell 2004). The area surrounding the forest is used for growing maize, tea and sugar cane. Illegal logging, charcoal burning and grazing by domestic animals is prevalent in the forest (see Figs. 5.3 to Fig. 5.6). Bleher *et al.* (2005) conducted an assessment of human impact in Kakamega Forest and showed a high level of human impact throughout the forest with illegal logging and extraction of commercially valuable timber being most widespread.

Fig. 5.3 Cattle grazing in Kaimosi forest

Fig. 5.4. Firewood collection in Ikuywa forest

Fig. 5.5 Charcoal making place in Ikuywa

Fig. 5.6. Tee plantation near Isecheno forest

5.1.7.1 Fragmentation

Kakamega Forest is a highly fragmented and disturbed forest (Tsingalia 1990, Bleher *et al*. 2006) and what is known as Kakamega Forest at present consists of the main forest block with an area of 8,537 ha, surrounded by five forest fragments (Kisere, Malava, Yala, Ikuywa & Kaimosi) with area of 132 to 1,370 ha (Farwig *et al*. 2007).

To what extent the Kakamega Forest was extending and contiguous to the various fragments is debatable. Brooks *et al*. (1999) argued that at the time of British colonization of Kenya in 1895, Kakamega Forest was contiguous with what are now the peripheral fragments of Yala, Ikuywa, Kisere, and Malava, and eastwards up the Nandi Escarpment to the Nandi forest above 1800 m. According to these authors, Malava forest was isolated from Kakamega Forest between 1895 and 1917, Kisere forest was isolated around 1933, Yala forest was isolated at the beginning of 1970, and Ikuywa forest was isolated in 1976.

Mitchell (2004), who conducted a detail analysis on the fragmentation and disturbance history of Kakamega Forest, argued that Kakamega Forest was contiguous only with the forests of Yala and Ikuywa in the southern part and the forests of Malava, Kisere and North Nandi have always been separate from Kakamega Forest. The fragments Yala and Ikuywa have been separated from the main forest block since the early 1960s and Kaimosi was separated between 1913 and 1959 (Mitchell 2004).

5.1.7.2 Logging

Commercial logging in Kakamega Forest started after the gold rush of the 1930's and its pit prop and fuel wood requirements (Mitchell 2004). Licenses for timber extraction were given to sawmills in 1933 and since then the forest was logged by clear-felling and selective logging. Clear-felling of indigenous forest to make way for fast-growing exotic tree and softwood plantations as well as for settlement and tea plantation was extensive under colonial forest service (Bleher *et al.* 2006). Clear-felling was officially halted in 1975 but selective logging for a wide range of species continued till the mid-1980's when the exploitation of indigenous trees was banned by presidential decree (Mitchell 2004).

5.1.7.3 Plantation

Plantation of indigenous trees in Kakamega Forest started south of Isecheno around 1934 (Mitchell 2004). The trees planted include *Prunus africana, Olea capensis, Markhamia lutea, Croton megalocarpus, Spathodea campanulata, Zanthoxylum gillettii, Cordia africana, Funtumia africana* and *Maesopsis eminii*. Since the late 1940s, vast area of Kakamega Forest has been converted to forestry plantations including coniferous trees of *Pinus patula, P. caribaea,* and *Cupressus lusitanica* (Tattersfield et al. 2001). Blackett (1994) estimated 1,700 ha of plantations concentrated around Isecheno forest station whereas Mitchell (2004) estimated 1,700 to 2,400 ha of plantations in Kakamega Forest.

5.1.7.4 Change in land cover and forest area

As a result of the continuous human pressure in the previous century, Kakamega Forest has undergone a change in land cover resulting in a reduction of the indigenous forest cover. In addition, the observed difference in the floristic composition and structure within Kakamega Forest is partly attributed to the exploitation history of the forest (Kiama & Kiyiapi 2001, Althof 2005).

An assessment of land cover development trends since the early 1970's (Glenday 2006, Lung & Schaab 2006) has revealed severe forest loss in the north-western and the southern parts of Kakamega Forest and succession in the north-eastern and north-central parts of the forest. Lung & Schaab (2006) reported a reduction of the near-natural and old secondary forests from 15,000 ha in 1972 to 12,200 ha in 2001, and an increase in bushland from 1,000 ha to 4,000 ha. Table 5.1 presents changes in areas of Kakamega main forest block and fragments for a period of 70 years since the forest was gazetted in 1933. Malava forest showed the highest forest loss with 73% of its forest area being lost in 70 years time. Kisere forest, on the other hand, had lost only 8.4% of its forest area. The main forest block, which also included Ikuywa and Yala forest during the time of forest gazettment, has lost 53% of its forest area.

Table 5.1 Area of Kakamega main forest block and fragments in 1933 and 2001 (Source: BIOTA East- Phase I Final Report)

Main forest block/fragment	Area (ha) in 1933	Area (ha) in 2001
Malava	703	190
Kisere	458	420
Kakamega main forest block	23,632 (including Yala & Ikuywa)	8,537
Ikuywa	Included in the main forest block	1,370
Yala	Included in the main forest block	1,199
Kaimosi	-	132

5.2 Study sites

Foliicolous lichens were collected from Kakamega main forest block (Colobus, Buyangu, Bukhaywa, Busambuli, Campsite, Isiukhu, Ghostisland, Salazar, and Isecheno) and from the surrounding forest fragments in the northern (Kisere and Malava) and southern (Yala, Ikuywa, and Kaimosi) part of Kakamega (Fig. 5.7). Table 5.2 presents the management regime, conservation status, forest type, disturbance history and plant community types of the study sites of Kakamega Forest.

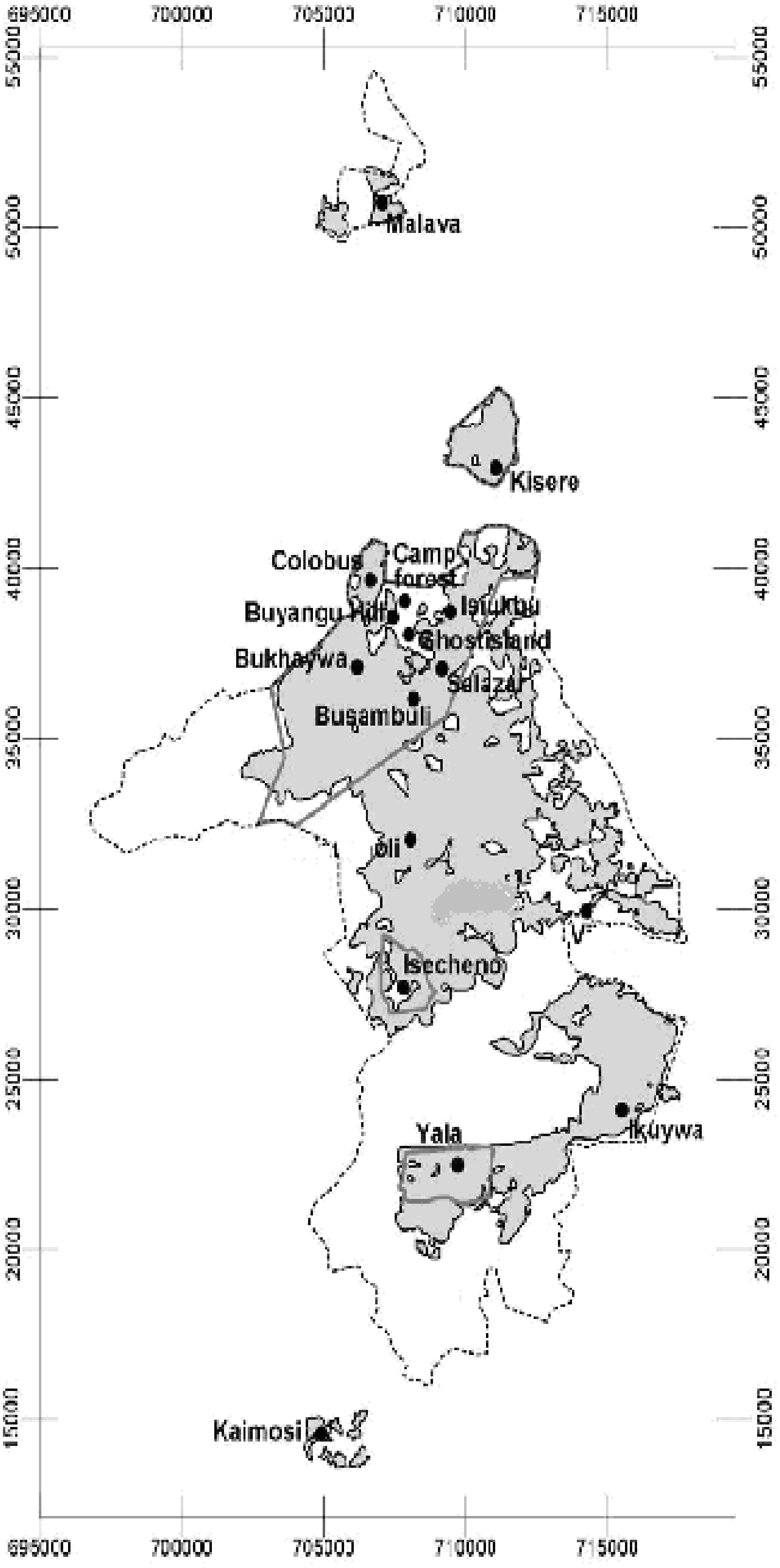


Fig. 5.7 Map of Kakamega forest and the location of the study sites

Table 5.2 Characterization of the study sites in Kakamega Forest

Study site	***Management regime/Protection status***	***Forest type/ Succession stage (Althof 2005)***	***Plant community (Althof 2005)***	***Disturbance history/level (Mitchell 2004, Althof 2005)***
Bukhaywa	*KWS/National Reserve*	*Middle-aged secondary*		*The forest is disrupted by several gaps. The heterogenous forest structure could be a result of selective logging. Disturbance high.*
Busambuli	*KWS/National Reserve*	*Middle-aged secondary*	*Pure* Celtis mildbraedii-Craibia brownii, Pseuderanthemum ludovicianum	*Small stature vegetation. Several gaps in the canopy and very young secondary forest sites present. Disturbance high.*
Buyangu	*KWS/National Reserve*	*Middle-aged secondary*	*cf.* Fernandoa magnifica, Uvariopsis congensis, Fernandoa magnifica	*Forest growth colonized much of the grassland areas since the early 20th century. Pitsawing of* Olea capensis, Cordia africana, Canthium schimperanum, Croton megalocarpus, Prunus africana, Funtumia africana *and* Croton sylvaticus *took place between1969 and mid 1970's. Disturbance intermediate.*
Camp site	*KWS/National Reserve*	*Young secondary*	Deinbollia kilimandscharica - Markhamia lutea transitional	*The vegetation is about 10 to 20 years old and the tree layer is up to 12 m high. Over 60 % of the canopy is closed, but only thin crown layers exist. Disturbance very high.*
Colobus	*KWS/National Reserve*	*Middle-aged secondary*	Uvariopsis congensis, Fernandoa magnifica	*It was with full forest in 1913/16. In the early 1920s part of the forest was cleared and converted to farmland. From 1943 sawmills cut timber mainly* Olea capensis, Cordia africana, Canthium schimperanum, Trichilia emetica, Premna angolensis, Celtis africana, Chrysophyllum albidum, Funtumia africana, Prunus africana, *and* Zanthoxylum gillettii. *Until 1989 there was a decrease in near-natural and secondary forest, but afterwards secondary forest expanded. Disturbance intermediate.*
Ghostisland	*KWS/National Reserve*	*Old secondary*	Ficus cyathistipula, Uvariopsis congensis	*It is a small forest island in the middle of a* Psidium guajava *and* Harungana madagascariensis – bushland. *Disturabnce intermediate*.
Ikuywa	*FD/Forest Reserve*	*Middle-aged secondary*	*Pure* Celtis mildbraedii-Craibia brownii, Strombosia scheffleri, Suregada procera, Pseuderanthemum ludovicianum	*Commercial logging started in late 1950s and continued in 1970s and 1980s. Main trees logged:* Prunus aficana, Cordia africana, Aningeria altissima, Zanthoxylum gillettii, Fagaropsis angolensis, Olea capensis, Cordia africana, *and* Trichilia emetica. *Disturbance low.*

Table 5. 2. contd.

Study site	***Management regime/Protection status***	***Forest type/ Succession stage (Althof 2005)***	***Plant community (Althof 2005)***	***Disturbance history/level (Mitchell 2004, Althof 2005)***
Isecheno	*FD/Forest Reserve*	*Middle-aged secondary*	*Pure* Celtis mildbraedii-Craibia brownii, Strombosia scheffleri, Pseuderanthemum ludovicianum	*In 1913/16 the forest west of Isecheno was seriously fragmented. In 1930s the forest was used for gold prospecting and subsequently logging to supply the gold mines with fuel and pit props. In 1940s part of the forest was group planted with* Olea capensis, Milicia excelsa, Acrocarpus fraxinifolius, Zanthoxylum gillettii *and* Khaya anthotheca. *Disturbance high.*
Kaimosi	*FD/Forest Reserve*	*Heavily logged and planted*	*Disturbed* Deinbollia kilimandscharica-Markhamia lutea	*The1913/16 map shows Kaimosi attached to Kakamega and Kapwaren forest. Between 1913 and 1959 the forest to the south-east gradually eroded. The 1950s maps show half of the forest deforested. In 1965 the local people were pitsawing* Olea capensis, Trichilia emetica, Zanthoxylum gillettii, Celtis mildbaredii, *and* Croton megelocarpus. *Disturbance high.*
Isiukhu	*KWS/National Reserve*	*Young secondary*	*Degraded* Rapanea melanophloeos–riverine community	*The forest is found along Isiukhu river. The tree layer is about 15 m high and a dense shrub layer exists. The plant community belongs to the middle-aged secondary forest, but species characteristic for disturbed and young stages also occur. Disturbance high.*
Kisere	*KWS/National Reserve*	*Near-primary*	Trichocladus ellipticus, Uvariopsis congensis, *cf.* Fernandoa magnifica	*Large-scale logging absent, only pitsawing of* Olea capensis, Prunus africana, Funtumia africana, Cordia africana *since 1960. Most part of the forest under near-natural and old secondary forest. Disturbance low.*
Malava	*FD/Forest Reserve*	*Heavily logged and planted*	*Disturbed* Deinbollia kilimandscharica-Markhamia lutea	*Heavy timber exploitation of Olea capensis and Prunus africana since 1940. Between 1945 and 1957 it has been intensively group planted with* Cordia africana, Prunus africana and O. capensis and exotic trees of Khaya anthotheca *and* Bischoffia javanica*. Disturbance high.*
Salazar	*KWS/Nature Reserve*	*Middle-aged secondary*	*Pure* Celtis mildbraedii-Craibia brownii, Pseuderanthemum ludovicianum.	*In 1913/16 part of the forest was covered by grassland with scattered trees. In 1977/78 logging of* Croton megalocarpus, Antiaris toxicaria, Celtis mildbraedii, Funtumia africana, Aningeria altissima, Olea capensis, Prunus africana, Cordia africana, Celtis mildbraedii, *and* Canthium schimperanum. *After 1989 secondary forest expanded. Disturbance low.*
Yala	*FD/Nature Reserve*	*Old secondary*	*Pure* Celtis mildbraedii-Craibia brownii, Pseuderanthemum ludovicianum, Suregada procera	*It became disconnected from indigenous forest on the northern half of its boundary in 1950s and 1960s. No large-scale logging but pit-sawing of a few species took place. It has a mature forest profile of a very low stem density. Disturbance low.*

5.3 Results

5.3.1 Floristic composition

A total of 146 taxa belonging to 41 genera and 17 families were recorded from Kakamega Forest. Out of these 137 species were fully identified to the species level. Eight taxa were identified to the genus level only. One species was further identified to a subspecies level and three species were further identified to a variety level. Five species new to science were discovered. For the sake of simplicity, in the subsequent presentation, all subgeneric taxa (species, subspecies and variety) will be treated as species. The full species list of Kakamega Forest is presented in Appendix 3.

Ninety-two per cent of the lichens recorded from Kakamega Forest were typically foliicolous, 5% were lichenicolous fungi growing on foliicolous lichens, 3% facultative foliicolous and 1% ubiquitous (Fig. 5.8)

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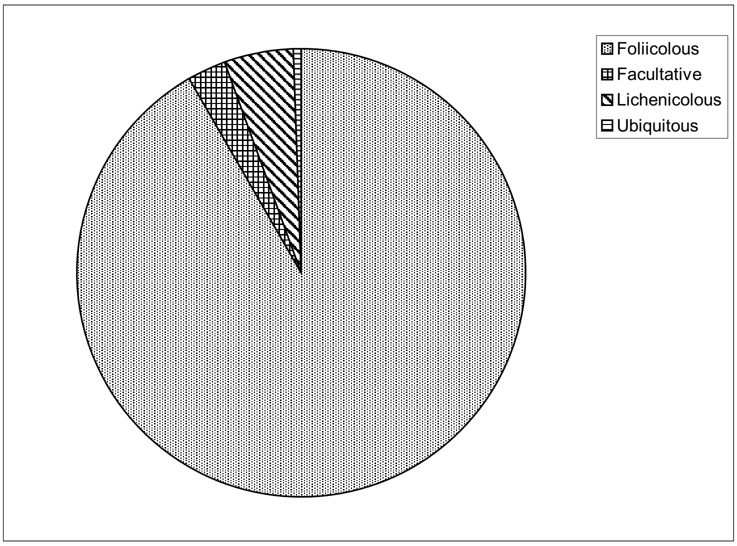


Fig. 5.8 Proportion of typical, facultative, ubiquitous foliicolous lichens and lichenicolous lichens

In Kakamega Forest, Pilocarpaceae was the dominant family both in terms of the number of genera (11) and species (30). The family Porinaceae was the second dominant in terms of the number of species (25) but with only two genera. The family Gomphillaceae comprised 7 genera and 19 species. The family Asterothyriaceae was represented by 3 genera and 12 species. The families Strigulaceae and Coenogoniaceae which have only one genus comprised 14 species and 12 species respectively.

Among the study sites, the highest number of families of foliicolous lichens were recorded from Kisere (14 families) followed by Buyangu, Isecheno, Isiukhu, and Salazar with 13 families each. Eleven families were recorded from Bukhayawa, Busambuli and Kaimosi. From Colobus and Ghostisland 9 families were recorded and the least family was recorded from Camp site (7 families). Fig. 5.9 shows the number of families, genera and species recorded in each forest part of Kakamega.

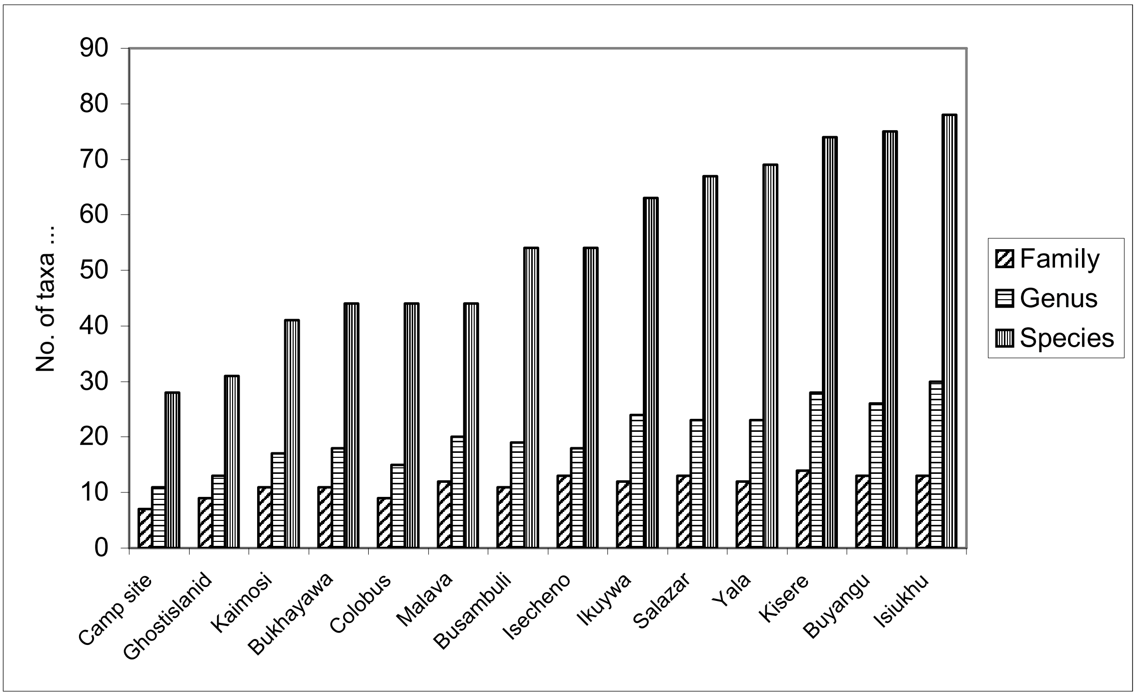


Fig. 5.9 Number of families, genera and species in the study sites of Kakamega Forest

The highest numbers of genera (30) were recorded from Isiukhu, followed respectively by Kisere (28 genera), Buyangu (26 genera), Ikuywa (24 genera), Salazar and Yala (23 genera each), Malava (20 genera), Busambuli (19 genera), and Bukhayawa and Isecheno (18 genera). The lowest number of genera were recorded from Colobus (15 genera), Ghostisland (13 genera) and Camp site (11 genera) (Fig. 5.11).

The highest numbers of species were recorded from Isiukhu (78 species), Buyangu (75 species) and Kisere (74 species). From Yala, Salazar, Ikuywa, and Busambuli, Isecheno 69, 67, 63, 54, and 54 species were recorded respectively. Forty-four species were recorded from Bukhayawa, Colobus, and Malava and the least number of species were recorded from Ghostisland (31 species) and Camp site (28 species).

Certain families of foliicolous lichens dominated both in the number of genera and species in the various study sites of Kakamega (see Figs. 5.10 & 5.11). In the number of species, the family Porinaceae was the most dominant in Bukhayawa, Buyangu, Colobus, Ghostisland, Isecheno, Salazar, Malava and Kaimosi. The family Pilocarpaceae was the most dominant in Busambuli, Kisere, Yala and Ikuywa. In Isiukhu both Porinaceae and Pilocarpaceae were equally dominant. In the Camp site forest, the family Asterothyriaceae was the most dominant.

The family Strigulaceae was the second dominant in Bukayawa, Busambuli, Ghostisland, Isecheno and Malava. In Buyangu and Kaimosi the family Pilocarpaceae was the second dominant. Gomphillaceae was the second dominant family in the Camp site, Isiukhu, and Ikuywa. In Colobus Coenogoniaceae and Strigulaceae were the second dominant while in Salazar Coenogoniaceae was the second dominant. In Kisere and Yala Porinaceae was the second dominant.

The distribution of species in the various forest parts of Kakamega is not uniform. Many species are restricted to some forest parts and not to others. Only seven species were common for the 14 forest parts. These species were *Calenia monospora, Gyalectidium filicinum, Porina epiphylla, P. nitidula, P. rubentior, Trichothelium pauciseptatum* and *Strigula smaragdula.* Seven species recorded from 13 forest parts were *Calopadia fusca, C. puiggarii, Porina cupreola* var. *cupreola, P. subpallescens, Strigula phyllogena* (all absent from Camp site), *Strigula microspora* (absent from Kaimosi), and *S. nitidula* (absent from Ghostisland). *Coenogonium geralense, Byssoloma leucoblepharum, Strigula macrocarpa*, and *Strigula schizospora* were recorded from 12 forest parts, all being absent from Camp site, the first three were absent from Kaimosi and the last species was absent from Bukhayawa. Six species recorded from 12 study sites were *Calenia aspidota* (not recorded from Bukhayawa, Camp site & Malava), *Lyromma nectandrae* (not recorded from Busambuli, Camp site, & Malava), *Bacidina apiahica* (Isecheno, Isiukhu & Yala), *Opegrapha phylloporinae* (not recorded from Camp site, Ghostisland and Salazar), *Strigula obducta* (not recorded from Camp site, Ghostisland and Kaimosi) and *Chroodiscus verrucosus* (not recorded from Bukhayawa, Colobus and Kaimosi).

Twenty-eight species were recorded from one study site only. *Fellhanera parvula, Arthonia flavoverrucosa, Arthonia fuscocyanea, Musaespora kalbii, Porina lucida* var. *lucida* (all recorded from Buyangu only). *Asterothyrium septemseptatum* ssp. *africanum*, *Asterothyrium* sp., and *Psorotheciopsis gyalideoides* were recorded from Camp site only. *Fellhanera encephalarti, Strigula janeriensis*, and *Chroodiscus australiensis* were recorded from Ikuywa. *Eremothecella calamicola, Aspidothelium geminiparum, A. scutelicarpum, Aderkomyces dilatatus, Aulaxina opegraphina, Calenia* sp., *C. thelotremela, Gyalideopsis cochlearifer*, and *Porina atrocoerulea* were recorded from Isiukhu only. *Arthonia atropunctata, Aspidothelium hirustum* sp. nov., *Byssolecania hymenocarpa* and *Tapellaria nigrata* were recorded from Kisere only. *Lichenopeltella epiphylla* and *Porina pallescens* were recorded from Salazar. *Porina kamerunensis* and *Bacidia medialis* was recorded from Colobus and Malava respectively.

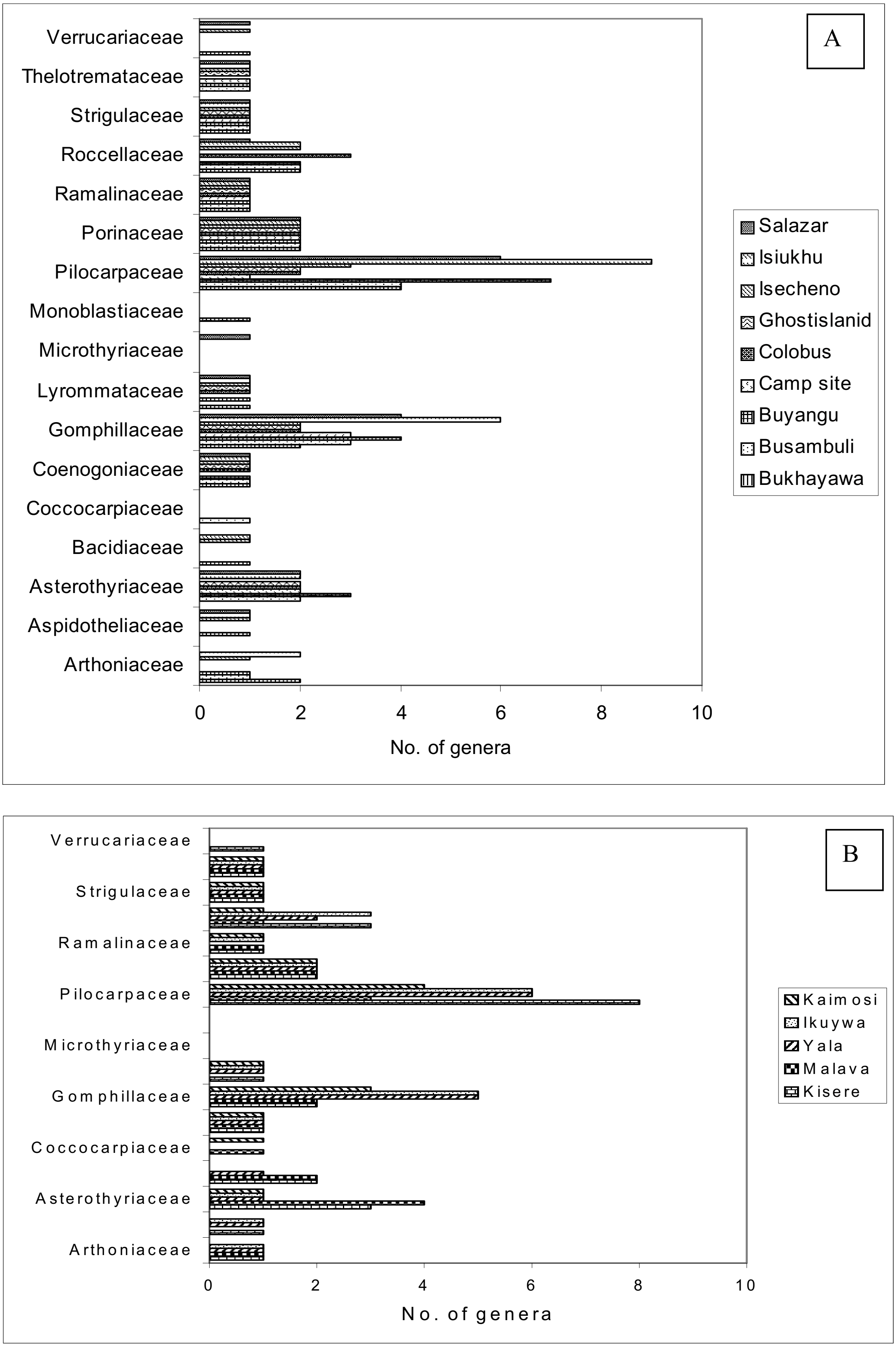
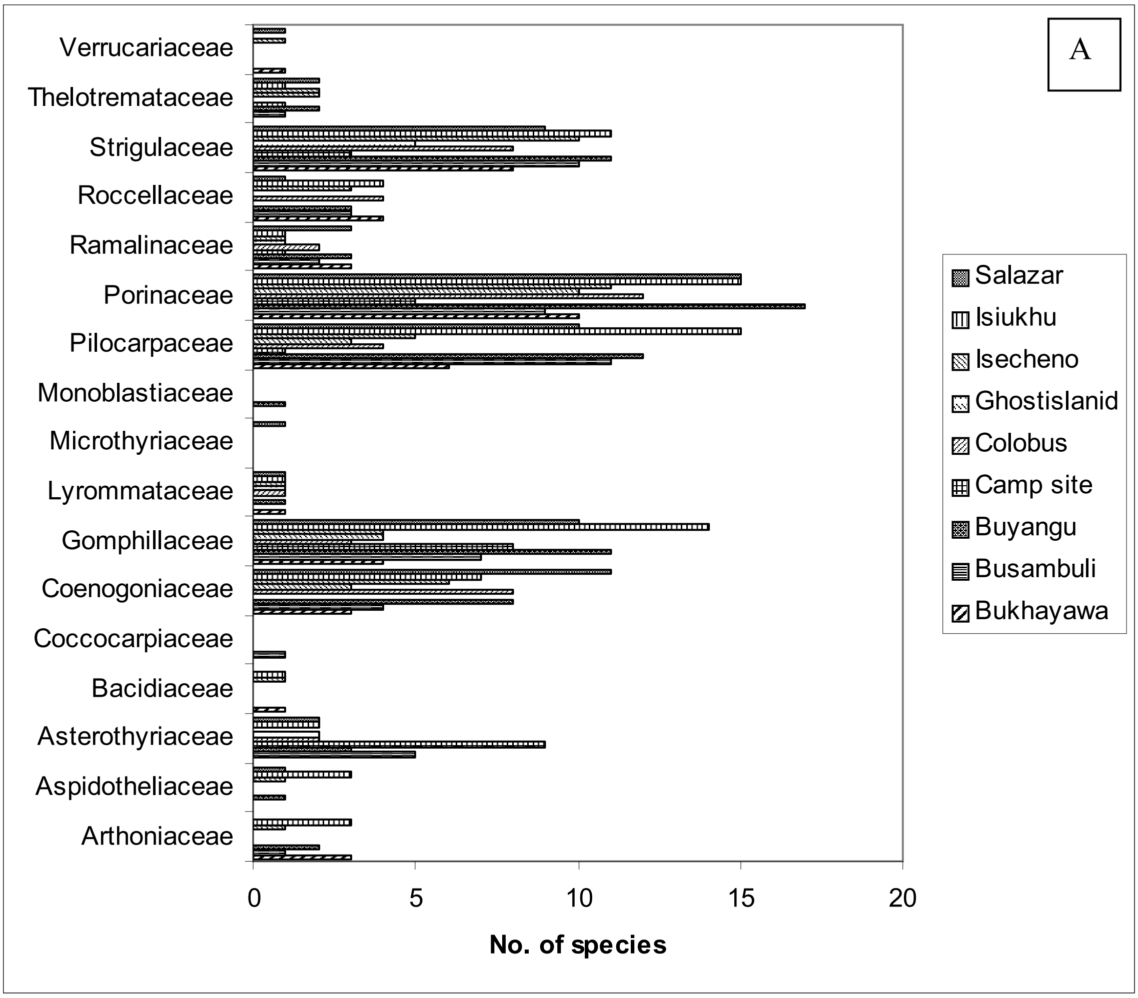


Fig. 5.10 Number of genera per family in the main forests (A) and fragments (B) of Kakamega



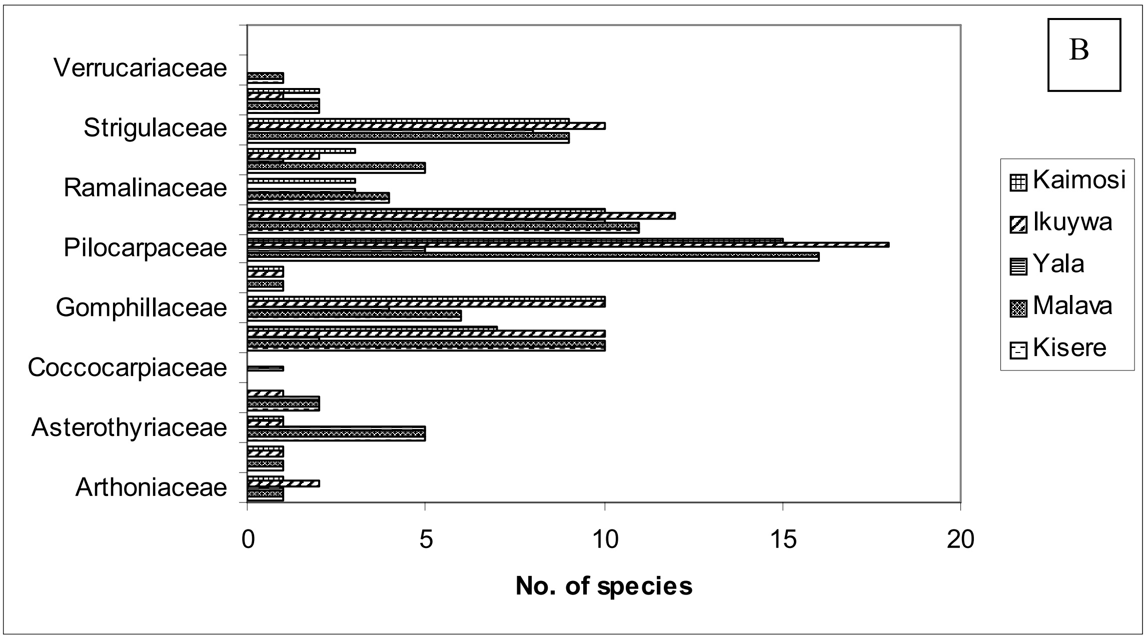


Fig.5.11 Number of species per family in the main forest parts (A) and fragments (B) of Kakamega

5.3.2 Species frequency

The frequency of occurrence of species in the various study sites of Kakamega is presented in Fig. 5.12. In all study sites except in Isecheno, Ghostisland and Kaimosi, species classified as rare constituted the highest proportion. The highest proportion of rare species was recorded from Buyangu (80%). In Isecheno species classified as occasional constituted the highest proportion (31%) and rare species constituted 25% of the whole species. In Ghostisland and Kaimosi, species classified as rare are absent and occasional species have the highest proportion. Species classified as occasional constituted the second largest proportion in Busambuli, Bukhayawa, Camp site, Colobus, Isiukhu, Kisere, Malava and Salazar. Dominant species constituted the second highest proportion only in Bukhayawa.

Porina nitidula is the dominant species in all study sites except in the camp site forest. *Porina epiphylla* is the dominant species in Bukhayawa, Busambuli, Buyangu, Colobus, Isecheno, Isiukhu, Kaimosi, Kisere, Malava, Slazar and Yala. Except in Busambuli, Camp site, Ghostisland, and Kaimosi, *Porina rubentior* is the dominant species in the remaining study sites. *Porina cupreola* var. *cupreola* is the dominant species in Bukhayawa, Ghostisland, Ikuywa, Isiukhu, Kisere, Malava, Salazar and Yala.

Species which are dominant in only one study site were *Asterothyrium rotuliforme* in Camp site, *Bacidina apiahica* and *Coenogonium lisowski* in Malava, *Calenia aspidota, Strigula antilarum* and *S. microspora* in Busambuli, and *Strigula obducta* and *Calopadia puigarii* in Bukhayawa. *Coenogonium geralense* is the only species which became dominant in two forests, in Bukhayawa and Isecheno. The frequency occurrences of all species in the study sites of Kakamega are presented in Appendices 15.

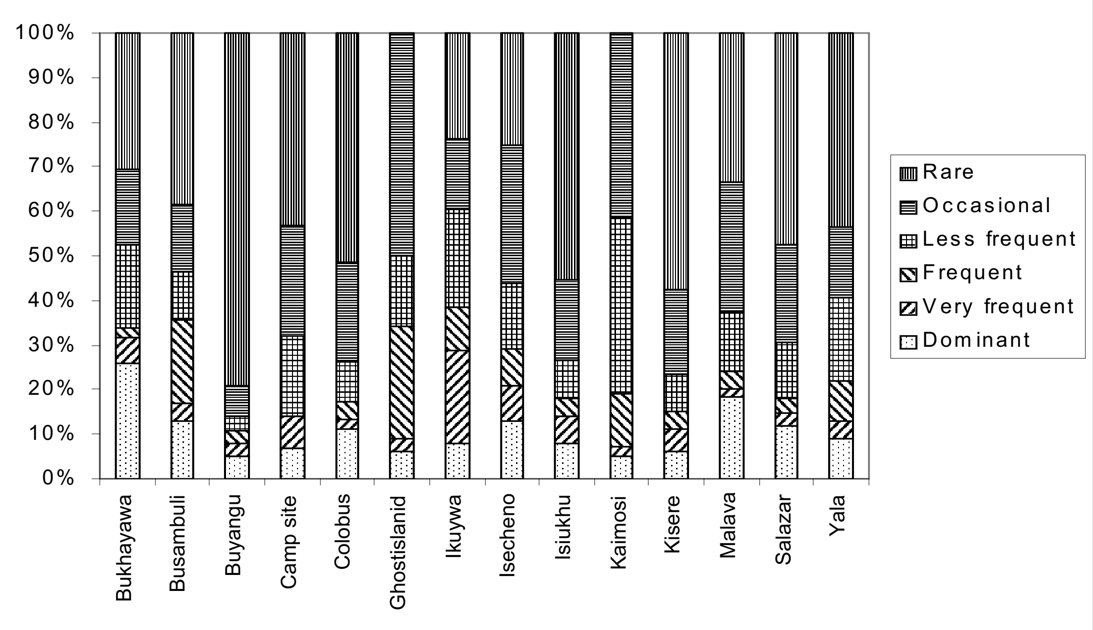


Fig. 5.12 Proportion (%) of species in the various frequency classes in the study sites of Kakamega

5.3.3 New and interesting records and new species of foliicolous lichens

In the course of the present study many new species and new records of foliicolous lichens were discovered. Among the total list of foliicolous lichens and lichenicolous fungi of this study, 5 species are new to science and 75 species are new records for Kenya. In addition three specimens belonging to the genera *Asterothyrium, Calenia* and *Fellhanera* seem to be new to science. However, further collection is needed to verify their identity.

5.3.3.1 Species new to science

1. *Aspidothelium hirsutum* sp.nov. (Aspidotheliaceae)

This new species is described from Godere Forest. The second record of this species was collected from Kakamega Forest. See Fig. 3.9 for pictures of the species.

2. *Chroodiscus kakamegensis* sp.nov. (Thelotremataceae)

Several specimens of this facultative lichenicolous species were collected from Godere, Budongo and Kakamega forests. For the description of the species see section 3.3.3.1.

Specimens examined: Malava fragment of Kakamega Forest, 00^{0}27'.072'' N and 034^{0}51'542'', 1630 m, on living leaves of *Peddiea fischeri* Engl., *Strychnos usambarensis* Gilg; 18.8.2006, Kumelachew 433, 434, 436, 438 (KOBL); Kaimosi fragment of Kakamega Forest, 00^{0}07'.743'' N and 034^{0}50'.458'' E, 1630 m, on living leaves of *Hippocratea* sp., 19.8.2006, Kumelachew 447 (KOBL); Ghostisland, Kakamega Forest, 00^{0}21'.057'' N and 034^{0}51'.668'' E, 1600 m, on living leaves of *Chrysophyllum albidum* G. Don., Kumelachew 477 (KOBL); Isecheno site of Kakamega Forest, 00^{0}14'.522 N and 034^0 51'.959''E, 1580 m, on living leaves of *Heinsenia diervilleoides* K.Schum. and *Dracaena fragrans*, Kumelachew 489 & 491 (KOBL); Kisere fragment of Kakamega Forest, 00^{0}23'.151'' N and 034^{0}53'.595'' E., 1580 m, on living leaves of *Diospyros abyssinica*, Kumelachew 541 (KOBL); Salazar, Kakamega Forest, 00019'.935'' N and 034052.649'', 1560 m, on living leaves of *Cassipourea ruwensorensis* (Engl.), Kumelachew 578 (KOBL).

3. *Enterographa fellhaneroides* sp. nov. (Roccellaceae) Fig. 5.13A

This new species is closely related to *Enterographa perez-higaredae* described from Mexico (Herrera-Campos & Lücking 2002) in having shortly lirelliform ascomata, excipuloid tissue and hypothecium filled with grayish crystals and hypothecial socle. They differ in the size of apothecia, number of ascospore septa and size of ascospores and asci. Morphologically, *E. fellhaneroides* looks similar to *E. seawardii*, a foliicolous species described in Sparrius (2004) from the Seychelles Islands, because of similar prominent, open, angular-rounded to shortly lirellate ascomata with pale orange discs.

Specimens examined: Kakamega Forest, Kisere fragment, 00^{0}22'.966 N, 034^{0}53'.751 E, 1594 m, on living leaves of *Chrysophyllum albidum* G.Don., 15. 08. 2006, Kumelachew 373 (KOBL); Kisere fragment, 00^{0}23'.151 N, 034^{0}53'.595 E, 1580 m, on living leaves of

Teclea nobilis Del., *Dracaena fragrans* and *Cassipourea ruwenzorensis* (Engl.) Alston, 24 August 2006, Kumelachew 538, 539 & 537 (KOBL); Kakamega Forest, Isecheno, 00^{0}14’.522 N, 034^{0}51’.959 E, 1580 m, on living leaves of *Cassipourea ruwenzorensis*, 21. 08. 2006, Kumelachew 484 & 493 (KOBL).

4. *Enterographa meklitiae* sp. nov. (Roccellaceae) Fig. 5.13B

This new species of *Enterographa* is different from the other species of the genus by the presence of punctiform ascomata arranged in groups in pseudostromata. In the genus this type of ascomata is so far recorded from the lichenicolous fungi *Enterographa epiphylla* (Ertz *et al*. 2005).

Specimen examined: Kakamega Forest, Isecheno, 00^{0}14’.522 N, 034^{0}51’.959 E, 1580 m, on living leaves of *Cassipourea ruwensorensis*, 21 08. 2006, Kumelachew 484 (KOBL).

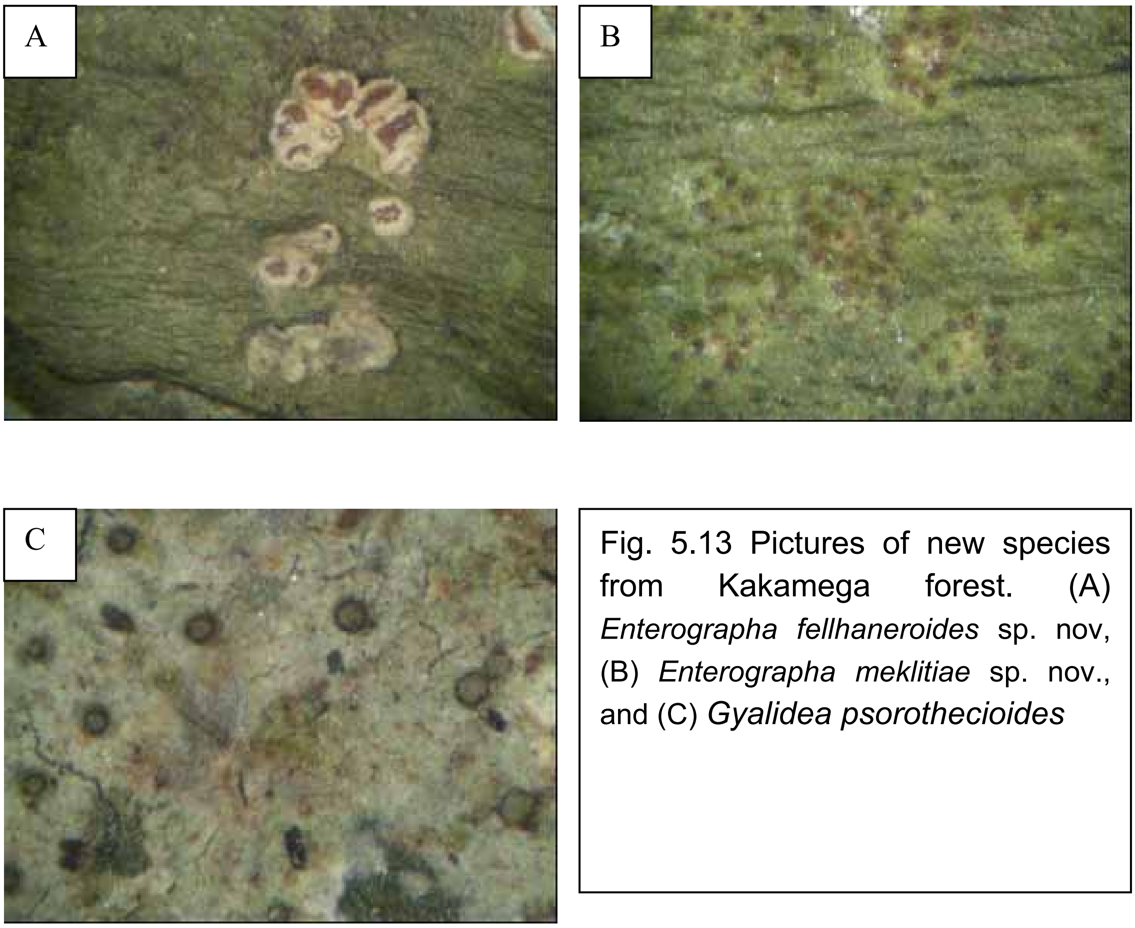


Fig. 5.13 Pictures of new species from Kakamega forest. (A) *Enterographa fellhaneroides* sp. nov, (B) *Enterographa meklitiae* sp. nov., and (C) *Gyalidea psorothecioides*

5. *Gyalidea psorothecioides* sp. nov. (Asterothyriaceae) Fig. 5.13C

This new species is characterized by marginally black apothecia and 1-septate ascospores. The two foliicolous *Gyalidea* (*Gyalidea epiphylla* & *G. phyllophila*) hitherto described have apothecial margin concolorous with the disc and ascospores are 3(4-5)-septate in *G. epiphylla* and 3-6 septate in *G. phyllophila*. The presence of black apothecia margin makes this new species similar to *Psorotheciopsis* (Asterothyriaceae) but unlike the later genus, this new species has no cellular cortex.

Specimen examined: Kakamega Forest (Colobus, Mukangu trail) 00^{0}21’276’’ N and 034^{0}51’519 E, 1609 m, 14.08.2006, on living leaves on *Tiliacora funifera* (Miers) Oliv., Kumelachew 350 (KOBL, holotype).

5.3.3.2 Interesting records of foliicolous lichens

In addition to the above five foliicolous lichen species described as new to science, certain specimens belonging to the genera *Asterothyrium, Calenia, Fellhanera, Strigula* were found to be interesting records which require further collection to identify their taxonomic status.

1. *Asterothyrium* sp. (Asterothyriaceae) Fig. 5.14A

The specimen cited below is an unknown taxon of the genus *Asterothyrium* having a green thallus, typical cortex, 1-septate spores. I presume it is new to science, but the material is scanty to describe it as new species.

Specimen examined: Kakamega Forest, camp site, 00^{0}21.134 N, 034^{0}51.923 E, 1581 m, 20.08.06, Kumelachew 458, (KOBL)

2. *Calenia* sp. (Gomphillaceae) Fig. 5.14B

Thallus is pale green, non dispersed, slightly applanate verrucae, apothecia medium sized, marginally slightly raised, with triangular lobules towards the center, disc grayish, slightly pruinose; ascospores 5-9 septate, 30-40 x 8-10 µm, 4-8 per ascus. The specimen looks like *Calenia obtecta* or *Calenia pernambucensis* to be described by Robert Lücking in Flora Neotropica (Lücking 2008).

3. *Fellhanera* aff. *bouteillei* (Pilocarpaceae) Fig. 5.14C

Fellhanera bouteillei is a ubiquitous species having a bluish white to bluish gray thallus, apothecia disc pale flesh-coloured to yellowish, margin indistinct and ascospores 10-15(-18) x 3-5(-6) µm (Santesson 1952). The specimens cited below are close to *Fellhanera bouteillei* but with some differences. Thallus green, rather coherent, apothecia medium sized, pale orange to brownish orange, with a thin but distinct margin, spores 1-septate, 18-25 x 4-4.5 µm.

Specimens examined: Kakmega forest, Ikuywa, 00^{0}12.628 N, 034^{0}55.931 E, 1550 m, epiphyllous on *Dracaena fragrans* and *Teclea nobilis*, 23.08.06, Kumelachew 190 & 192 (KOBL).

4. *Sporopodium* sp. (Pilocarpaceae) Fig. 5.14D

Three collections from Kisere and Isiukhu forests of Kakamega were close to *Sporopodium leprieurii* but the thallus of these specimens are smooth.

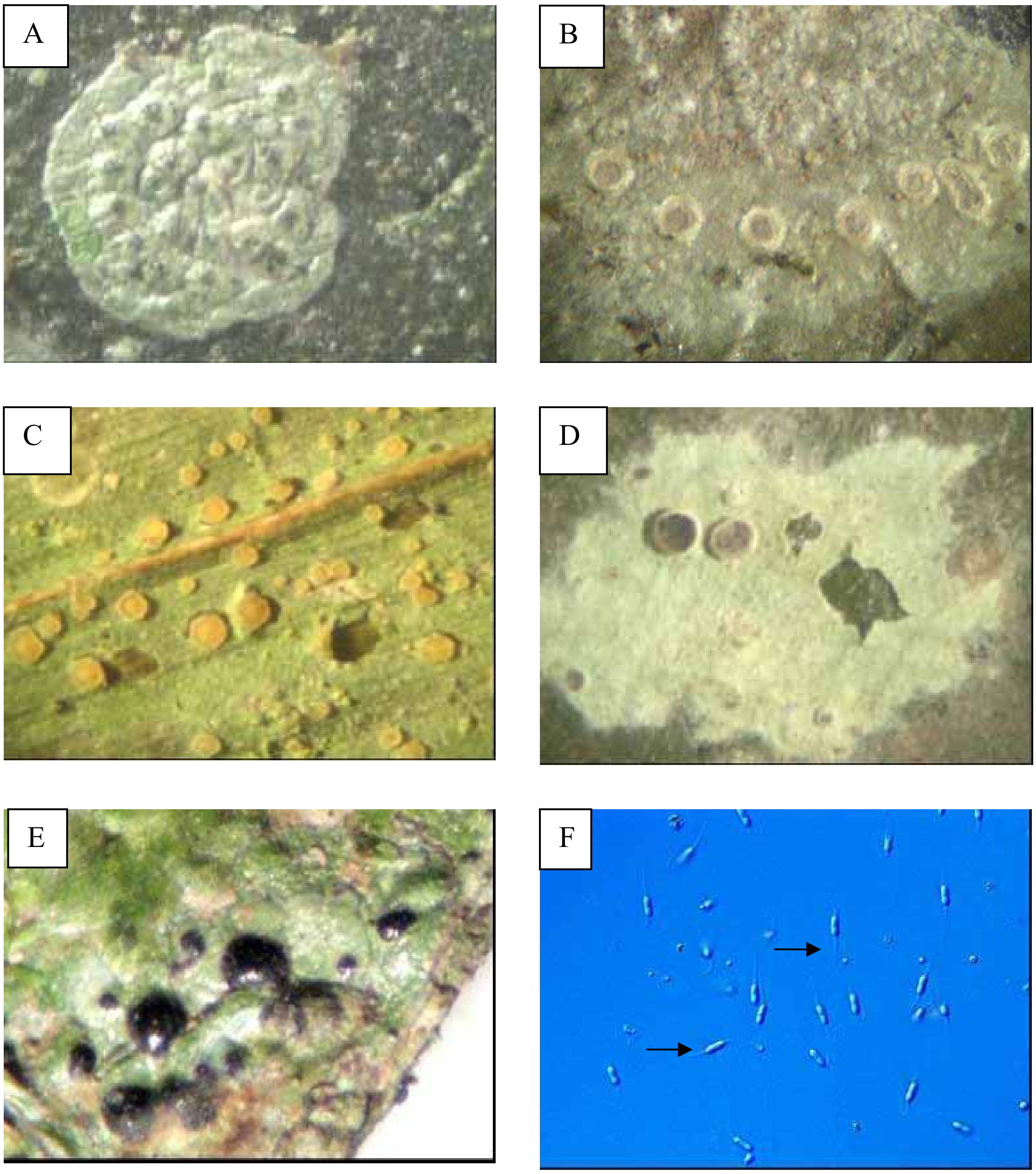


Fig. 5.14 Some interesting species of foliicolous lichens from kakamega forest. (A) *Asterothyrium* sp., (B) *Calenia* sp., (C) *Fellhanera* aff. b*outeillei,* (D) *Sporopodium* sp., (E) *Strigula microspora,* (F) Conidia with appendages (arrows) of *Strigula microspora*

5. Strigula microspora **(Strigulaceae) Fig. 5.14E & Fig. 5.15F**

The specimen of *Strigula microspora* cited below has got microconidia with long appendages on both ends. Like the typical species, the microconidia are 1-septate, bacilliform, 5 x 1.5 µm. Ascospores are 10-12 x 2.5-3 µm. In the description of *Strigula microspora* by Lücking (1991), there is no mention of presence of appendages on conidia.

Specimen examined: Kakamega Forest, Kisere, $00^{0}23.053$ N, $034^{0}53.562$ E, 1580 m, epiphyllous on *Rawsonia lucida*, 24.08.06, Kumelachew 547 (KOBL).

5.3.2 Alpha diversity

5.3.2.1 Mean species number

Species richness per sample of the various forest parts of Kakamega is variable ranging from a mean of 5.1 species to a mean of 17.4 species. The mean species number per sample is highest in Ikuywa and lowest in Camp site (Fig. 5.15). Kruskall-Wallis test of analysis of variance showed the presence of significant difference among the medians of species number among the various forest parts (Kruskall-Wallis Chi-square =61.8, P<0.05). To determine which medians were significantly different from which others, the Kruskal-Wallis multiple comparison test was performed. The result of this analysis is presented in Table 5.3.

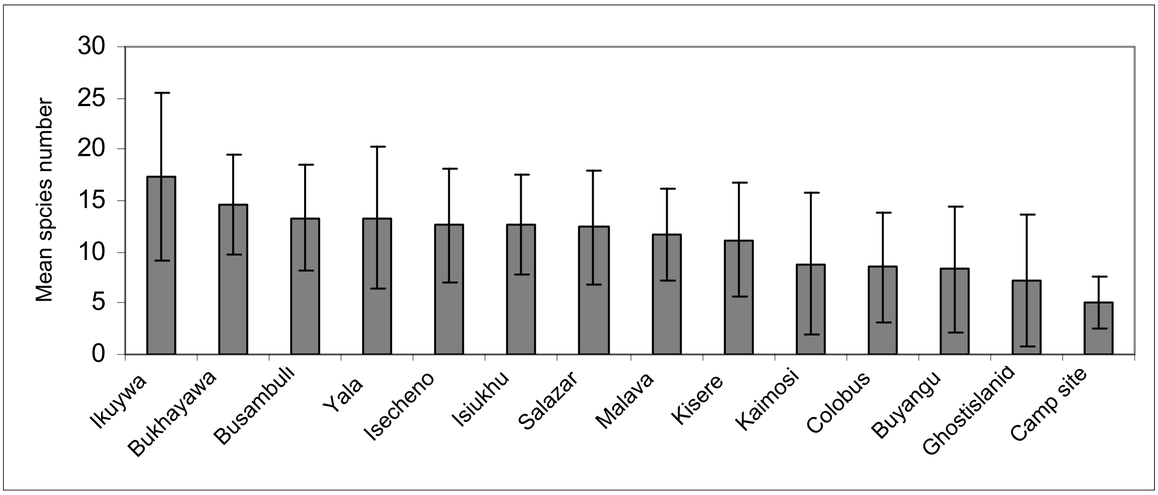


Fig. 5.15 The mean species number per study site in Kakamega Forest (values are mean ± SD).

Except with Ghostisland and Kaimosi, the mean species number of Camp site forest is significantly different from the mean of the other forest parts. Buyangu is significantly different from Ikuywa, Bukhayawa, Busambuli, Yala, Isecheno, Isiukhu, Salazar, Malava, and Kisere. Colobus is significantly different from Ikuywa, Bukhayawa, Busambuli, Yala, Isecheno, Isiukhu, and Salazar. Ghostisland is significantly different from Ikuywa, Yala, Isecheno, Isiukhu, Salazar, and Malava. Isiukhu, Kaimosi and Kisere are significantly different from Ikuywa.

Table 5.3 Kruskal-Wallis Multiple-Comparison test between medians of species numbers of the study parts of Kakamega Forest. * significant (P<0.05), ns= not significant

	Bukhayawa	*Busambuli*	*Buyangu*	*Camp site*	*Colobus*	*Ghostisland*	*Ikuywa*	*Isecheno*	*Isiukhu*	*Kaimosi*	*Kisere*	*Malava*	*Salazar*
Busambuli	ns	-											
Buyangu	*	*	-										
Campsite	*	*	*	-									
Colobus	*	*	ns	*	-								
Ghostisland	*	*	ns	ns	ns	-							
Ikuywa	ns	ns	*	*	*	*	-						
Isecheno	ns	ns	*	*	*	*	ns	-					
Isiukhu	ns	ns	*	*	*	*	*	ns	-				
Kaimosi	*	*	ns	ns	ns	ns	*	ns	ns	-			
Kisere	*	ns	*	*	ns	ns	*	ns	ns	ns	-		
Malava	ns	ns	*	*	ns	*	ns	ns	ns	ns	ns	-	
Salazar	ns	ns	*	*	*	*	ns	ns	ns	ns	ns	ns	-
Yala	ns	ns	*	*	*	*	ns	ns	ns	ns	ns	ns	ns

5.3.2.2 Species accumulation curve

Species accumulation (rarefaction) curves were plotted for the foliicolous lichens observed from each study site in Kakamega Forest (Fig. 5.16). The curves show the mean number of species for each sample accumulated. Since the unit of the x-axis is number of samples, the resulting rarefaction curves are measures of species density (Gotelli & Colwell 2001). The 95% confidence intervals of the respective curves allow to test if there is significant difference in species richness among the study sites (Table 5.4).

Foliicolous lichen species richness is significantly higher in Isiukhu, Kisere, Buyangu, Yala and Salazar than the remaining study sites. However, Ikuywa is not significantly different from Isiukhu and Yala. Species richness is significantly higher in Ikuywa than in Bukhayawa, Busambuli, Isecheno, Kaimosi, Malava and Colobus. Similarly, there is significantly higher species richness in Isecheno and Bukhayawa than in Colobus and Ghostisland. Species richness is also significantly higher in Kaimosi than in Ghostisland. The foliicolous lichen species richness of Camp site is significantly lower than all the other study sites.

Table 5.4 Significance of species richness differences at 95% confidence limit. ns = not significant, * = significant difference in species richness

	Bukhayawa	Busambuli	Buyangu	Camp site	Colobus	Ghostisland	Ikuywa	Isecheno	Isiukhu	Kaimosi	Kisere	Malava	Salazar
Busambuli	ns	-											
Buyangu	ns	ns	-										
Camp site	*	*	*	-									
Colobus	*	*	ns	*	-								
Ghostisland	*	*	ns	*	ns	-							
Ikuywa	*	*	*	*	*		-						
Isecheno	ns	*	ns	*	*	*	*	-					
Isiukhu	ns	ns	ns	*	*	*	ns	*	-				
Kaimosi	ns	ns	ns	*	ns	*	*	ns	*	-			
Kisere	ns	ns	ns	*	*	*	*	ns	ns	*	-		
Malava	ns	*	ns	*	ns	ns	*	ns	*	ns	ns	-	
Salazar	ns	ns	ns	*	*	*	*	ns	ns	*	ns	ns	-
Yala	ns	ns	ns	*	*	*	ns	ns	ns	*	ns	*	ns

The species accumulation curves could be used to compare the observed species richness of sites at similar sample size (usually the smallest). Comparison of the expected species richness of the study sites of Kakamega by the rarefaction curve after 9 samples (the sample size of Ghostisland and Kaimosi) provided a mean species richness of 56.3 for Ikuywa, 49.8 for Isiukhu, 49.5 for Yala, 46.8 for Busambuli, 43.3 for Salazar, 42.3 for Kisere, 41.6 for Bukhayawa, 41 for Kaimosi, 39.7 for Isecheno, 37.5 for Buyangu, 35.7 for Malava, 32.5 for Colobus, 32 for Ghostisland and 20.7 for Camp site forest.

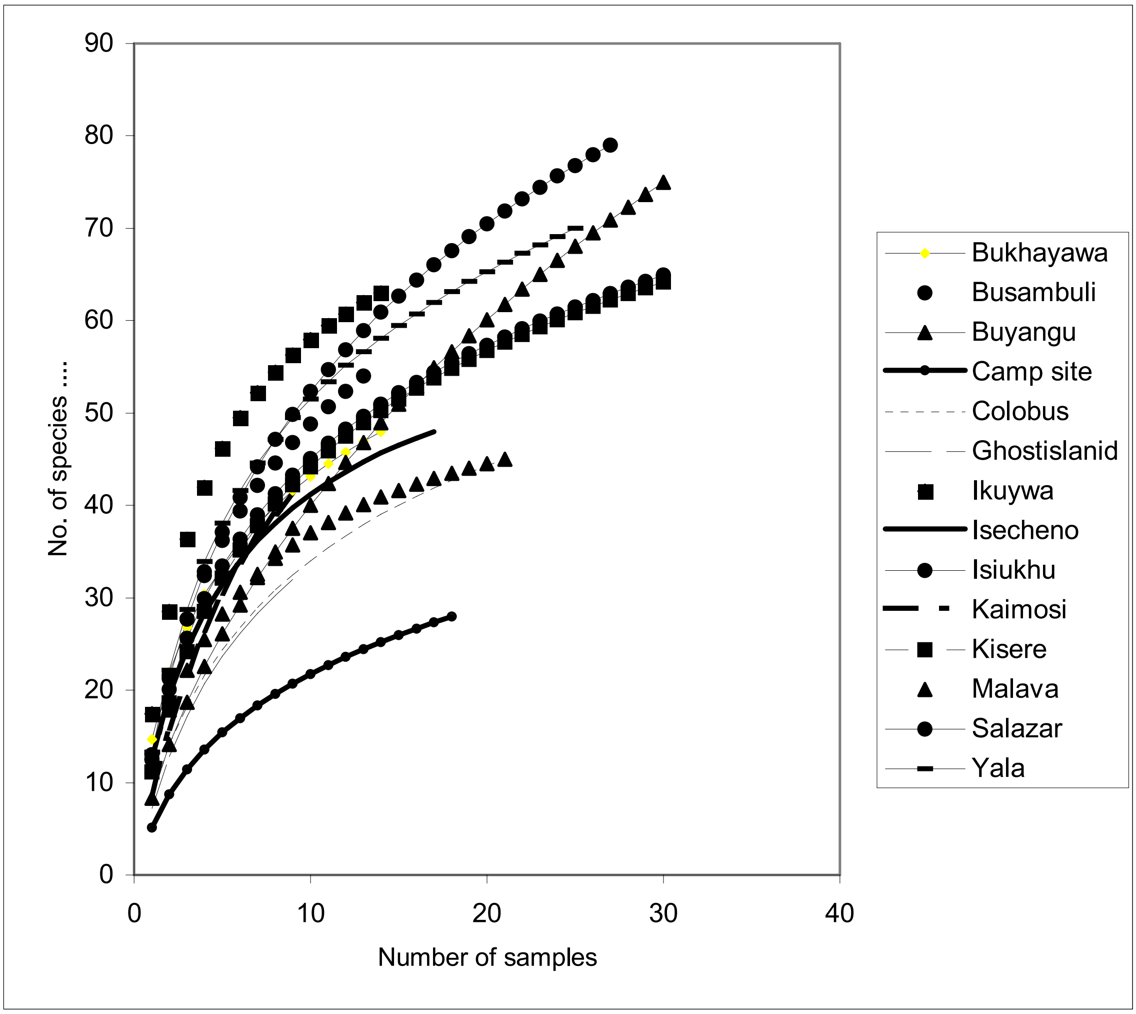


Fig. 5.16 Species accumulation curve (rarefaction) of the foliicolous lichens in the study sites of Kakamega Forest.

5.3.2.3 Estimation of species richness

The various non-parametric species richness estimators for incidence data provided different values for the estimate of the species richness of the study sites of Kakamega Forest (Table 5.5). In Bukhayawa, Busambuli, Camp site, Colobus, Ghostisland, Ikuywa, Isecheno, Isiukhu, Kaimosi, Malava, Salazar and Yala, the second order Jackknife estimator provided the highest estimate of species richness. In Buyangu and Kisere the ICE and Chao 2 provided the highest estimate respectively. The Bootstrap estimator provided the lowest estimate of species richness for Bukhayawa, Busambuli, Buyangu, Camp site, Colobus, Ghostisland, Ikuywa, Isiukhu, Malava and Yala. In Isecheno both the Bootstrap and Chao 2 estimators provided the lowest estimation and the Michalis-Menten Mean provided the lowest estimate of species richness for Kisere and Salazar. The difference between the highest and lowest richness estimator varied from 11.5 species (in Isecheno) to 52 species (in Kisere). The highest difference for Kisere is due to the very high Chao 2 estimate.

Table 5.5 Number of samples, number of individuals and species richness (with standard deviation for some) estimate values for the study sites of Kakamega

	No. of samples	No. of individuals	S_{obs}	MMMeans	Chao 2	Jack 1	Jack 2	Bootstrap	ICE	Degree of collection (%)
Bukhayawa	14	204	48	56	62.1±9.6	61.9±4.4	68.5	54.5	63.8	70 –88
Busambuli	13	173	54	71.1	81.6 ±16.4	73.4±6.2	85	62.3	75.4	64 –87
Buyangu	30	249	75	100.2	136.6 ±27.1	113.7 ±12.4	139.3	91.4	148.7	50 –82
Camp site	18	92	28	36.7	52±20.2	39.3±3.6	47.5	32.8	43.9	54 –85
Colobus	21	177	45	56	59.1±9.6	59.3±4.6	66	51.7	60.2	68- 87
Ghostisland	9	65	32	55.5	49.8±12	46.2±5.9	55.3	38.3	50	58-84
Ikuywa	14	243	63	78.3	71.9±6.2	76.9±4.6	81.9	69.8	72.3	77-90
Iaecheno	17	214	48	57.2	53.7±4.5	59.3±3	61.6	53.7	57	78-89
Isiukhu	27	339	79	95.2	107±13.7	106.9±4	120.4	91.7	113	70 –86
Kaimosi	9	79	41	77.2	48.1±4.8	56.1±5.6	58.4	48.7	55.9	53 -85.2
Kisere	55	613	77	81.5	181.2 ±73.9	101.6 ±6.1	122.8	86.9	101.4	43-95
Malava	21	246	45	54.1	52.1±6.1	54.5±2.6	59.3	49.6	51.3	76-91
Salazar	37	461	69	75.3	91.2 ±13.3	88.5±5.1	99.1	77.7	87.7	70-92
Yala	25	332	70	82.3	96.9 ±15.5	91.1±5.6	103.4	79.4	89.2	68-88

5.3.2.4 Shannon-Wiener diversity

The Shannon-Wiener diversity and evenness values for the study sites of Kakamega Forest is presented in Table 5.6. Analysis of variance (ANOVA) of the Shannon diversity index values of the study sites confirmed the presence of significant differences (F=2.91, p<0.001). Fischer's least significant difference *post hoc* test (Table 5.7) showed that Shannon diversity of Camp site (H'=2.97) is not significantly different from Colobus (H'=3.42), Ghostisland (H'=3.29) and Malava (H'=3.42) but significantly lower than the Shannon diversity of the other forest parts. The highest value of Shannon diversity is computed for Isiukhu but it was not significantly different from Bukhayawa, Busambuli, Buyangu, Ikuywa, Isecheno, Kaimosi, Kisere, Salazar, and Yala. Shannon diversity of Colobus is significantly lower than those of Ikuywa, Isiukhu, Kisere and Yala. Similarly Shannon diversity of Ghostisland is significantly lower than those of Ikuywa, Isiukhu, and Yala. Shannon diversity of Malava is also significantly lower than the diversity of Ikuywa, Isiukhu, Kisere and Yala.

Table 5.6 Shannon diversity (H') and evenness (J') values of the study sites

	Shannon index (H')	Shannon evenness index (J')
Bukhayawa	3.53	0.91
Busambuli	3.69	0.93
Buyangu	3.71	0.86
Camp site	2.97	0.89
Colobus	3.42	0.89
Ghostisland	3.29	0.94
Ikuywa	3.93	0.95
Isecheno	3.52	0.91
Isiukhu	3.92	0.89
Kaimosi	3.57	0.96
Kisere	3.8	0.88
Malava	3.42	0.89
Salazar	3.73	0.88
Yala	3.87	0.91

Table 5.7 Fischer's least significant difference (LSD) multiple comparison of Shannon diversity index values among the study sites. ns= not significant, * = significant ($p<0.001$)

	Bukhayawa	Busambuli	Buyangu	Camp site	Colobus	Ghostisland	Ikuywa	Isecheno	Isiukhu	Kaimosi	Kisere	Malava	Salazar
Busambuli	ns	-											
Buyangu	ns	ns	-										
Camp site	*	*	*	-									
Colobus	ns	ns	ns	ns	-								
Ghostisland	ns	ns	ns	ns	ns	-							
Ikuywa	ns	ns	ns	*	*	*	-						
Isecheno	ns	ns	ns	*	ns	ns	ns	-					
Isiukhu	ns	ns	ns	*	*	*	ns	ns	-				
Kaimosi	ns	ns	ns	*	ns	ns	ns	ns	ns	-			
Kisere	ns	ns	ns	*	*	ns	ns	ns	ns	ns	-		
Malava	ns	ns	ns	ns	ns	ns	*	ns	*	ns	*	-	
Salazar	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	-
Yala	ns	ns	ns	*	*	*	ns	ns	ns	ns	ns	*	ns

5.3.3 β-diversity and similarity in species composition

Total β-diversity measured by Whittaker's index of β-diversity (β_w) for the study sites of Kakamega is presented in Table 5.8. This index of β-diversity is a measure the degree of turnover or species changes. The highest species turnover is seen in Buyangu (β-diversity=9). The next highest species turnover is found in Kisere (β-diversity = 6.9) and Isiukhu (β-diversity = 6.3) respectively. The lowest turnover is registered in Bukhayawa (β-diversity = 3.3).

Table 5.8 Total β-diversity values along the study sites of Kakamega

	Number of species (a)	Mean species number per sample (b)	β-diversity (a/b)
Buyangu	75	8.3	9.0
Kisere	77	11.2	6.9
Isiukhu	79	12.6	6.3
Salazar	69	12.4	5.6
Camp site	28	5.1	5.5
Yala	70	13.3	5.3
Colobus	45	8.5	5.3
Kaimosi	41	8.8	4.7
Ghostisland	32	7.2	4.4
Busambuli	54	13.3	4.1
Isecheno	48	12.6	3.8
Malava	45	11.7	3.8
Ikuywa	63	17.4	3.6
Bukhayawa	48	14.6	3.3

Analysis of β-diversity among the study sites based on Sørensen index of similarity is presented in Table 5.9. The values of the Sørensen index varied from 0.27 to 0.81 indicating variation in β-diversity among the study sites. High similarity, and thus low β-diversity, is observed between forests of different succession stages like the middle-aged secondary and the old secondary forest sites e.g. Salazar and Yala (S_s=0.81) and Ikuywa and Yala (S_s=0.78); the near-primary forest of Kisere and the old secondary forest of Yala (S_s=0.69). High similarity (low β-diversity) is also observed between forests of similar development stages, e.g. between the middle-aged secondary forests of Salazar and Buyangu (S_s=0.72) and Salazar and Ikuywa (S_s=0.7). Low β-diversity could also be seen between the young secondary forest of Isiukhu and middle-aged secondary forest of Buyangu (S_s=0.69). The lowest similarity in species composition, and thus high β-diversity is observed between the young secondary Camp site forest and the middle-aged secondary forest of Salazar (S_s=0.27) as well as between the young secondary forests of Camp site and Isiukhu (S_s=0.28). In general, the Camp site forest shows the least similarity with all other forest sites.

Table 5.9 Values of Sørensen index of similarity among the study sites

	Bukhayawa	Busambuli	Buyangu	Camp site	Colobus	Ghostisland	Ikuywa	Isecheno	Isiukhu	Kaimosi	Kisere	Malava	Salazar
Busambuli	0.61	-											
Buyangu	0.55	0.56	-										
Camp site	0.37	0.46	0.37	-									
Colobus	0.69	0.59	0.53	0.30	-								
Ghostisland	0.53	0.51	0.54	0.50	0.62	-							
Ikuywa	0.58	0.63	0.65	0.40	0.63	0.55	-						
Isecheno	0.63	0.53	0.55	0.29	0.66	0.63	0.63	-					
Isiukhu	0.54	0.59	0.69	0.28	0.55	0.40	0.62	0.55	-				
Kaimosi	0.47	0.57	0.52	0.38	0.56	0.58	0.58	0.58	0.43	-			
Kisere	0.62	0.6	0.62	0.32	0.66	0.51	0.66	0.67	0.60	0.53	-		
Malava	0.67	0.65	0.53	0.49	0.62	0.65	0.59	0.65	0.45	0.56	0.62	-	
Salazar	0.56	0.54	0.72	0.27	0.6	0.53	0.7	0.68	0.61	0.56	0.67	0.53	-
Yala	0.54	0.58	0.65	0.29	0.57	0.49	0.78	0.66	0.64	0.52	0.69	0.52	0.81

5.3.4 Ordination

The PCA ordination of the forest sites of Kakamega Forest is presented in Fig. 5.17. The first four axes of PCA explain 51.6% of the total variation in species composition. The first two axes explain 32.4% of the total variation. The first axis alone contributes to 18.9% of the total variation. Therefore, the highest variation is explained by the first PCA axis.

In the ordination diagram, forest sites that are close to each other are more related in species composition. Forest sites with high species diversity are positively correlated with the first PCA axis and sites with low diversity are negatively correlated with this axis. Forest sites with high disturbance are positively correlated with the second PCA axis and sites with low disturbance are negatively correlated with this axis. The ordination diagram shows that the Camp site and Isiukhu forest sites are different from the other forest sites and explain much of the variation in the data set. Like Yala, Salazar, Ikuywa, Kisere and Buyangu forest sites, Isiukhu has high species diversity and is positively correlated with the first PCA axis. Like the Camp site forest site, it is a disturbed forest and is positively correlated with the second PCA axis.

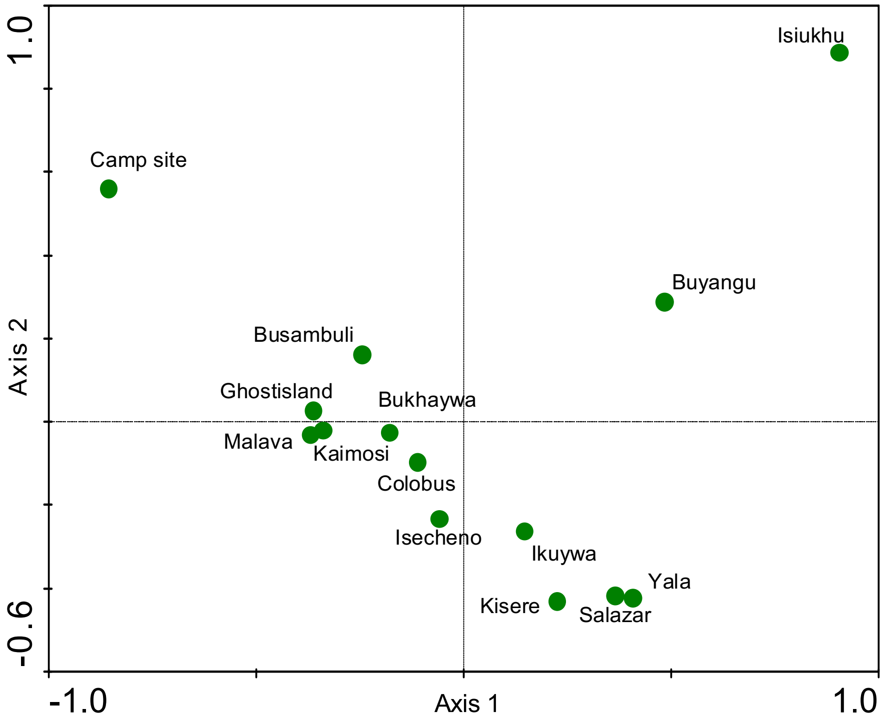


Fig. 5.17 PCA ordination of the study sites of Kakamega Forest.

5.4 Discussion

5.4.1 Sufficiency of sample size

Complete enumeration of all species of a given community is difficult for many organisms. Therefore, the most important question in sampling is the sufficiency of sample size. This is evaluated in this study with the help of a species accumulation curve and comparison with the species richness estimated by the various non-parametric richness estimators. Except for the species accumulation curves for Buyangu and Isiukhu which are rising as more samples are pooled, the curves for the other forests are leveling off and the rate of species accumulation as samples are successively pooled is highly reducing.

One of the reasons for estimating species richness is to know how much of the species richness estimated were observed in the sampling, i.e. how much is the degree of collection of a site. Accordingly, on average 64 up to 88% of the foliicolous lichens estimated by the various richness estimators have been collected from the study sites of Kakamega. Heck *et al.* (1975) reported that collection of 50% to 75% of the total number of species known to occur in a given area is satisfactory. In Kisere only 42.5% of the maximum estimated species richness was collected. However 94.5% of the minimum estimates species richness was collected.

5.4.2 Alpha-diversity

Lücking and Kalb (2002) reported 92 species of foliicolous lichens and 5 species of lichenicolous fungi from Kenya. In the present study, 53 of the species already reported have been encountered in Kakamega Forest. In addition, 77 new records of foliicolous lichens including 3 lichenicolous fungi and 5 species new to science are reported from this study, raising the number of foliicolous lichens of Kenya to 171 and the number of lichenicolous fungi to 8. As far as my knowledge is concerned, this is the highest number of foliicolous lichens so far recorded for a single country in tropical Africa. Reported numbers of foliicolous lichens include 161 species from Ivory Coast, 124 species from Guinea, 124 species from DR Congo (Santesson & Lücking 1999) and 144 species from Tanzania (Pócs 1978, Farkas 1987, Farkas & Vĕzda 1987, Farkas 1991, Farkas & Vĕzda 1993, Feuerer 2007)

High family, generic and species diversity was mostly observed in the forests with low level of disturbances in both the near-primary (Kisere), old aged secondary forest site (Yala) and middle-aged secondary forest sites (Ikuywa, Salazar and Buyangu). In addition high diversity was also recorded in the disturbed forest site of Isiukhu. Low diversity, on the other hand, was observed in the old secondary forest of Ghostisland, the middle-aged secondary forest of Colobus, the logged and planted forests of Kaimosi and Malava and the disturbed young secondary forest of Camp site. Forest sites where high species diversity were recorded have relatively closed canopy (e.g. Yala, Buyangu, Kisere) and forest sites with lower diversity have open or semi-open canopy (e.g. Malava, Kaimosi). The high diversity at Isiukhu is due to the existence of both semi-open and closed canopy forests.

The observed species number of a community is mostly biased (Brose *et al.* 2003) and excludes rare species, underestimating the true species richness (Palmer 1990, Baltanás 1992). Species accumulation curves and non-parametric estimators reduce this bias (Soberón &Llorente 1993, Colwell & Coddington 1994). The estimation of the expected species richness of the study sites by rarefying all study sites down to the smallest sample size indicated high species richness in forests of different seral and/or disturbance stages. High species richness was respectively estimated for Ikuywa, Isiukhu, and Yala (Fig. 5.24). Low richness was respectively estimated for Colobus, Ghostisland and Camp site. In general, the species accumulation curves estimated high foliicolous lichen species richness for forest sites with low level of disturbance and low species richness for forest sites with high level of disturbance. Isiukhu is the only forest with high level of disturbance but with high expected species richness.

Various studies (Sérusiaux 1989, Lücking 1992b, Aptroot 1997, Lücking 1998b) have reported high foliicolous lichen diversity in undisturbed primary forests and low diversity in disturbed and secondary forests. In the present study high foliicolous lichen species diversity was recorded both in a near-primary, slightly disturbed forest site of Kisere; old secondary, slightly disturbed forest site of Yala; middle-aged secondary, slightly disturbed forest sites of Salazar and Ikuywa; middle-aged, intermediately disturbed site of Buyangu and a highly disturbed young secondary forest site of Isiukhu. Although Isiukhu is a disturbed forest, there are parts with closed forest creating shady understorey and light gap microsite conditions. In addition, the riverine atmosphere and the relatively high humidity inside the forest provide suitable microclimatic conditions for many foliicolous lichens. As a result characteristic foliicolous lichens of the various light regimes are well represented in Isiukhu making this forest type one of the highest in foliicolous lichen diversity in Kakamega. In the Buyangu study site forests with closed canopy and semi-open canopy have been observed. As a result of diversity of microsites in this forest, the species diversity is also high. Low species diversity was observed in forest sites with relatively high disturbance (Camp site, Malava, Kaimosi) and in Ghostisland. Although Ghostisland is said to be an old secondary forest with little disturbance (Althof 2005), signs of human disturbance and canopy openings were seen in several places.

The results from this study show that the effect of disturbance on foliicolous lichen diversity is dependent on the type, frequency and intensity of disturbance (Petraitis *et al.* 1989). The diversity of foliicolous lichens is dependent on the availability of different microsite conditions (Lücking 1997d). If disturbance maintains or enhances the whole microsite gradient of a forest (e.g. Isiukhu) then there would be high foliicolous lichen diversity. Contrarily, if disturbance results severe change in microclimatic conditions and loss of microsites (e.g. Camp site) then diversity of foliicolous lichens would be reduced. Due to an open canopy in the Camp site forest, the intensity of light reaching the understorey is high and this reduces the humidity inside the forest. Althof (2005) recorded the lowest humidity (21.7%) in this forest type. The most affected by the increased light intensity and reduced atmospheric humidity are shady understorey species. Many of the foliicolous lichens recorded from the understorey of Camp site forest are canopy specialists which have made use of the increased light condition. In Kaimosi, Bukhayawa, Busambuli, and Malava because of high disturbance, the forest canopy is open in many places affecting shady understorey species. In these forests light gap species constituted the highest proportion.

5.4.3 Non-parametric species richness estimators

The speed with which the species accumulation curve of an estimator reaches an asymptote as sample sizes increases indicates the usefulness of an estimator (Colwell & Coddington 1995). The Michaelis-Menten Means is the only estimator that appeared to reach an asymptote (curves not shown). The curves of Jack 1 and Bootstrap estimators, though not clearly approaching an asymptote, are leveling off and predicted comparable species number to the MMMeans. The Chao 2 and ICE estimators did not seem to be a good estimator as they estimated high species richness when fewer samples were pooled and the curves did not stabilize. The curve for the second order Jackknife estimator is rising as more samples were accumulated. Except the Bootstrap estimator, all the other estimators of Buyangu predicted high species richness than the observed species. This is due to the high number of uniques (species restricted to one sample only) which constituted 53% of the whole species.

The variation in the number of species estimated by the species richness estimators is due to the dependence of the non parametric estimators on rare species (uniques and doubletons). In Kisere, for example, based on 77 observed species, the estimators estimated as low as 82 species and as high as 181 species. Based on the highest estimate 2.4 times more species is expected from this forest site, which is an unreliable estimate. This is due to the high number of uniques which accounted for 32.5% of the whole species. Therefore, for the comparison of species richness of forest sites the rarefaction method is more reliable than the species richness estimators.

5.4.4 β-diversity

Total β-diversity, computed by dividing the observed number of species of a study site by the mean number of species, is generally low suggesting low species turnover in the study sites of Kakamega. A relatively high turnover could only be seen for Buyangu (β-diversity = 9.0).

There is a wide variation in the values of Søresnson's index (S_s =0.27-0.81), indicating variation in species composition (β-diversity). The lowest species similarity and thus highest β-diversity is to be observed between Camp site forests and the remaining forests. Since the camp site forest is very disturbed having open canopy, many species which are restricted to canopy of closed forests have grown in the understorey. Furthermore, shady understorey species which are abundant in the other forest types are scarcely represented in the understorey. Foliicolous lichen similarity is high between forests of different seral stages (e.g. Yala vs. Salazar, Yala vs. Ikuywa, Buyangu vs. Isiukhu) as well as between forests of similar seral stages (e.g. Buyangu vs. Salazar, Salazar vs. Ikuywa). These results showed no uniform pattern of change in species composition along succession gradient.

5.5 Conclusion

Kakamega Forest, as the only Guineo-Congolian transitional rainforest in Kenya, is naturally expected to be the best habitat for foliicolous lichens. Due to various levels of disturbance and fragmentation, the vegetation of Kakamega Forest consists of a mosaic of forests of different seral stages, anthropogenic vegetation, and grasslands, with differing impact on the diversity of organisms. From the result of this study it can be concluded that:

- The overall diversity of foliicolous lichens in Kakamega Forest is considerably high.

- Differences in diversity of foliicolous lichens among the various forest types have been shown to depend on the level of disturbance rather than on the seral stage of forest development.
- Forest sites with similar seral stages have been shown to differ in their foliicolous lichen diversity (e.g. Yala vs. Ghostisland, Isiukhu vs. Camp site, Colobus vs. Ikuywa).
- Forest sites with closed canopy have high diversity and sites with semi-open and open canopy have low diversity. Canopy openness in Kakamega Forest is related to the level of disturbance.
- Foliicolous lichen diversity has been found to be high in the forest sites of Yala, Isiukhu, Kisere, Salazar, Buyangu and Ikuywa.

Chapter 6. DIVERSITY OF FOLIICOLOUS LICHENS ALONG DISTURBANCE GRADIENT: A COMPARATIVE ANALYSIS OF GODERE, BUDONGO AND KAKAMEGA FORESTS

6.1 Introduction

Due to over exploitation by the local people, and state and private enterprises, the natural forests of Ethiopia, Uganda and Kenya have declined both in size and quality. The most serious threats to the natural forests come from forest clearance due to an increasing human population which require new land for agriculture and settlement, and from forest degradation due to timber logging and other unsustainable exploitative activities. As a result, most of the natural forests in these countries are secondary with different level of disturbances.

Forest destruction and degradation has an obvious, deleterious effect on biodiversity and environment. If the present trends of deforestation continue, then many plant and animal species could locally be extinct. Since tropical biodiversity is not fully explored, many undiscovered taxa could have been or will be lost even before we discover and name them. The situation is more serious for some organisms whose diversity and distribution are not known. In order to curb some of these problems, natural forest should be conserved and managed. Under the present trend of human population growth and socio-economic situations which have resulted in intense competition for land for subsistence and commercial agriculture as well as for industrial development, protection of the whole natural forests of an area is not feasible. However, some areas could be selected and designated as conservation sites. Biodiversity is one of the useful parameter used for the selection of sites for the purpose of conservation (Goldsmith 1987). Biodiversity includes species diversity, genetic diversity and ecosystem diversity. Species diversity is the most obvious and frequently used measure of biodiversity. Species diversity in tropical forests, however, is not fully understood and this necessitates their immediate documentation.

The vascular plant floras of Ethiopia, Uganda and Kenya are relatively well known due to the publications of the Flora of Tropical East Africa and Flora of Ethiopia and Eritrea. Documentation of the cryptogamic flora of these countries is at its infancy stage. Lichens in general and foliicolous lichens in particular are among the least studied (or unstudied) organisms in these countries as well as in tropical Africa.

In order to include foliicolous lichens in the forest conservation program and to use them, as component of biodiversity, in the selection of forest sites for the purpose of conservation, their diversity and distribution should be documented. Since the monographic work of Santesson (1952), there has been an increasing attention on the systematics of foliicolous lichens. However, very little is known about their ecology and the impact of forest disturbance on their diversity, especially in the forests of tropical

Africa. In this study, comparison of the diversity of foliicolous lichens along disturbance gradient from Budongo (comparatively least disturbed) to Kakamega (comparatively medium disturbance) and Godere (comparatively more disturbed) is presented with the following objectives.

- To describe the species composition of the foliicolous lichens of the three forests
- To compare the α- and β-diversity of foliicolous lichens of the three forests
- To compare the similarity in foliicolous lichen species composition of the three forests
- To analyse the foliicolous lichen species diversity along disturbance gradient
- To identify foliicolous lichen species that could be used as bioindicator of forest types
- To analyse the biographical distribution of the foliicolous lichens of the study area.

6.2 Study area

A detailed description of Godere, Budongo and Kakamega forests are presented in Chapters 3, 4 and 5. The three forests selected for the study of the diversity of foliicolous lichens share several topographic, and physiognomic and climatic characters (Table 6.1). They are situated on flat terrains with gentle slope, at medium altitudes and in similar climatic conditions. Godere and Kakamega forests are composed of a mixture of afromontane and Guineo-Congolian floral elements as well as transitional species. Budongo Forest is a Guineo-Congolian rainforest. Most of the canopy species in both forests are deciduous. Climatically, the three forests are located in high rainfall areas of the respective countries.

Due to the different socio-economic conditions where the three forests are found, the management regime, degree of anthropogenic disturbance and the land use are substantially different. Forest management in Budongo and Kakamega is much better than in Godere where no forest management plan is in place. Due to different management and exploitation history, the three forests are now found in a different disturbance conditions.

Among the three forests, Budongo is the least disturbed with undisturbed primary and disturbed secondary forests located in close proximity. Timber has been selectively extracted from the forest since 1910. In 1957 clear-cutting was promoted and enrichment planting of mahoganies (*Khaya* and *Entandrophragma*) and *Maesopsis* was established in plantations (Paterson 1991). In addition, arboricide treatment was applied to remove trees which did not have commercial value.

Kakamega Forest has a long history of exploitation (Mitchell 2004) and at present forests of different physiognomic, successional and disturbance levels are found. Most of the forests in Kakamega are middle-age secondary which are managed by the Kenya Wildlife Service or the Forest Department. Forests of early seral stages with high level of disturbance and indigenous and exotic plantations are also the features of Kakamega

Forest. Undisturbed primary forest is absent in Kakamega, though some forests areas received greater protection and experienced little disturbance.

Godere is the most disturbed among the three. The major disturbance in the forest is selective cutting by timber industries, shifting cultivation by the indigenous people, commercial coffee plantation by state and private enterprises and semi-forest coffee management by the indigenous people and settlers. Therefore, the forest in Godere is secondary with different level of anthropogenic disturbances. While closed forest are absent in Godere, most of the remaining natural forests are semi-open, so maintained for the growth of *Coffea arabica* under the system of semi-coffee forest management. Under such system, competing trees, shrubs and lianas are removed (Senbetta & Denich 2006) while shade species are maintained.

Table 6.1 Some climatic and physiognomic characters of Godere, Budongo and Kakamega forests

	Godere	Budongo	Kakamega
Altitude (m a.s.l.)	1000-1500	950-1200	1460-1765
Mean annual rain fall (mm)	>1500	1200-1800	1343-2638
Mean annual temperature (^{0}C)	15-25	17-29	10.6-27.7
Forest type	Transitional rainforest (Friis 1992)	Semi-deciduous tropical rainforest (Reynolds 2005)	Dry perpipheral semi-evergreen Guineo-Congolian transitional rainforest (Althof 2005)
Floral elements	Afromontane, Guineo-Congolian, Transitional	Guineo-Congolian	Afromontane, Guineo-Congolian, Transitional
Major disturbance history (type)	Selective logging, shifting cultivation, semi-forest coffee management, commercial coffee plantation	Selective logging, silvicultural treatment	Logging (clear felling & selective), exotic tree plantation

6.3 Methodology

The methodology followed for foliicolous lichen collection and identification is presented in Chapter 2. In order to make comparison of α- and β-diversity of the three forests simple, only taxa identified to species and subspecific level were considered. Exception to this is *Opegrapha* sp. since it occurs in the three forests and all the specimens are expected to belong to the same species. Alpha diversity of foliicolous lichens is analysed from the observed species richness, species accumulation curves, non-parametric species richness estimators (Colwell 2006) and Shannon-Wiener diversity and evenness indices (Magurran 1988). Beta diversity is computed with Whittaker index (Whittaker 1960) and Sørenson's index of similarity (Sørenson 1948). The frequency occurrences of species in the samples of Godere, Budongo and Kakamega forests were analysed based on a six-scale frequency classes (see section 2.3.1). Statistical analyses were done in order to look for significant differences in α-diversity using Statigraphics version 5 software (Statistical Graphics Corporation).

Ordination of the forest sites and species of the three forests was made using Principal Component Analysis (PCA) using the software CANOCO (ter Braak & Šmilauer 2002). PCA is selected for ordination since the initial correspondence analysis provided a gradient length of less than 3 indicating a linear response of species distribution. In the PCA ordination centering by species was selected.

The PCA biplot is used to identify characteristic foliicolous lichen species that can be used as indicator of forest types of different disturbance regimes. Species that have high fidelity to a particular forest type with high frequency of occurrence were then used as indicators of that forest type (disturbance regime). Only species which occurred on all or most of the forest sites of a particular disturbance regime are selected as indicator species. Dufrene and Legendre (1997) called these species as symmetrical indicators whose presence contributes to the habitat specificity.

In order to establish the biogeographical distribution of the typically and facultatively foliicolous lichen species of Ethiopia, Uganda and Kenya, data from the present study as well as additional data for Kenya (Lücking and Kalb 2002) and Uganda (Feuerer 2007) were utilized. Information on the distribution types of the foliicolous lichens were obtained from Lücking *et al.* (2000), Lücking & Colin (2004), and the observation of the present study. The biogeographical distribution of foliicolous lichens is analysed based on the lichenogeographical regions of Lücking (2003). The similarity in foliicolous lichens of Godere, Budongo and Kakamega forests and Taï National Park in Ivory Coast is determined using Sørensen similarity index (Sørensen 1948).

6.4 Results

6.4.1 α-diversity

6.4.1.1 Family, generic and species richness

A total of 16 families of foliicolous lichen were recorded from the three forests (Fig. 6.1). All of these families were represented in Kakamega while only 15 families were recorded from Godere and Budongo. The family Monoblastiaceae was not represented in Budongo and Microthyriaceae was not represented in Godere.

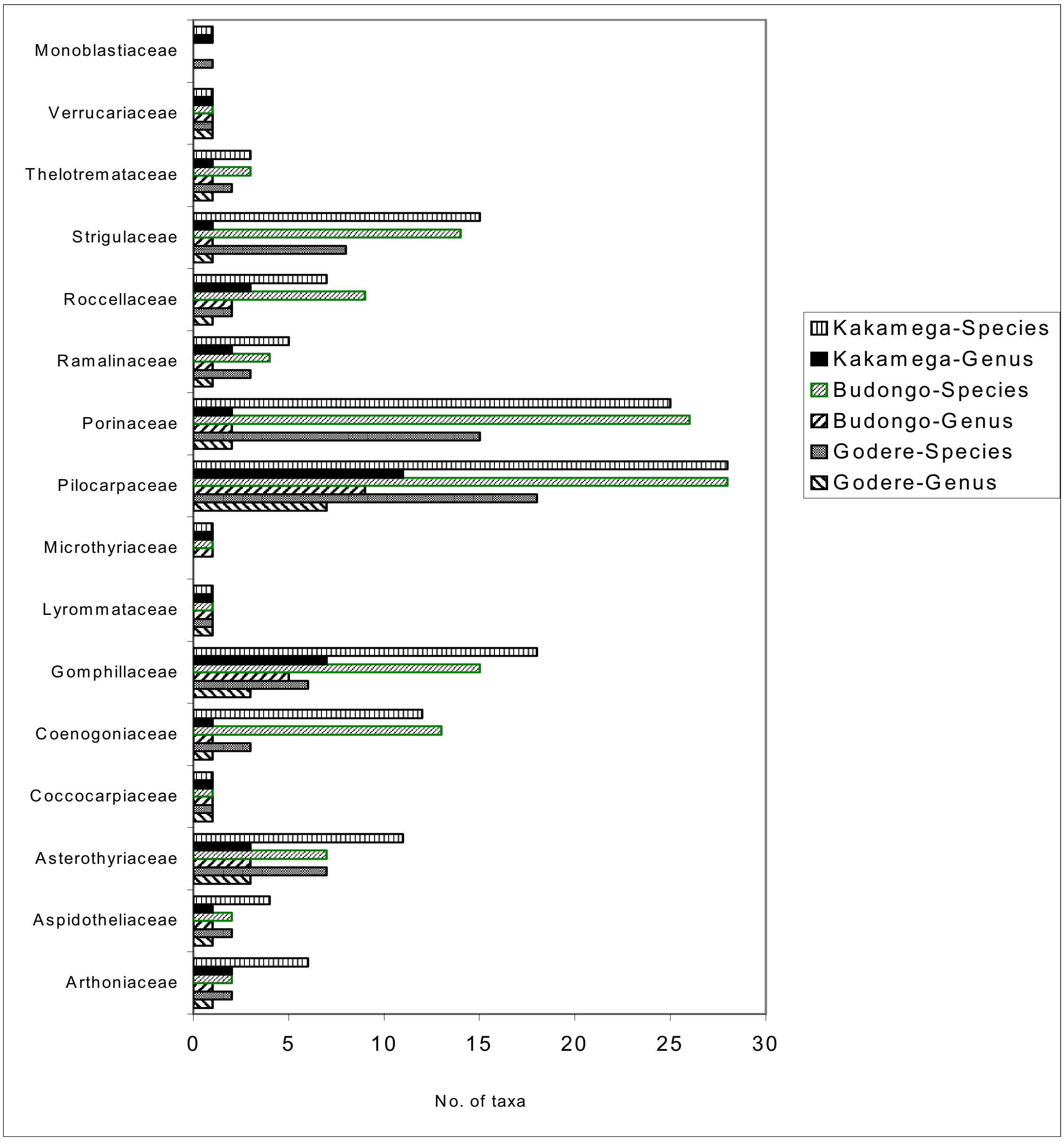


Fig. 6.1 Number of genera and species per family in Godere, Budongo and Kakamega forests.

Forty-one genera were recorded from the three forests. Generic diversity is highest in Kakamega (39 genera), the genera *Caprettia* and *Eugeniella* being absent. Thirty-three genera were recorded from Budongo, the genera *Aderkomyces, Badimia, Caprettia, Enterographa, Eremothecella, Gyalideopsis, Lasioloma,* and *Musaespora* being absent. Godere ranks the least in generic diversity (27 genera). The genera *Aderkomyces, Aulaxina, Badimia, Bapalmuia, Eugeniella, Enterographa, Eremothecella, Gyalideopsis, Lasioloma, Lichenopeltella* (lichenicolous fungi), *Loflammia, Mazosia*, *Musaespora,* and *Tricharia* were not recorded from Godere.

In terms of species diversity, Kakamega and Budongo forests have higher number of foliicolous lichen species diversity than Godere. The observed number of species from Godere is 70, 125 from Budongo and 137 from Kakamega.

The mean number of species per sample in Godere Forest is 9.8, 10.7 in Budongo and 11.1 in Kakamega (Fig. 6.2). Kruskal-Wallis one way ANOVA was performed to see if there is significant difference among the three medians. The result indicated absence of significant difference (Chi square = 4.08, p-value = 0.1298) at 95% confidence level.

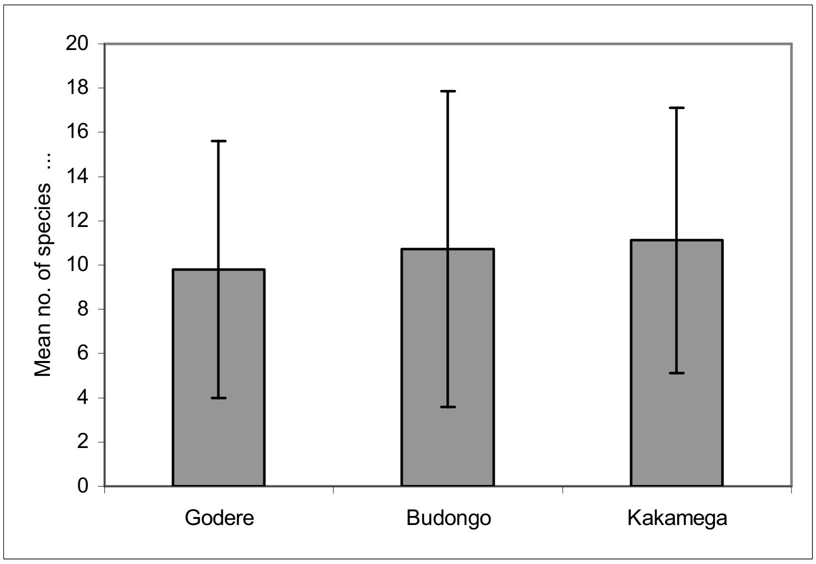


Fig. 6.2 Mean (±SD) number of species per sample in Godere, Budongo and Kakamega forests

The estimated number of species for Godere, Budongo and Kakamega by the non-parametric species richness estimators is presented in Table 6.2. The second order and first order Jackknife estimators respectively predicted the highest richness for both forests and the Michaelis-Menten Means (MMMeans) predicted the lowest species richness. The difference between the highest and the lowest estimates is 13.3 species for Godere, 18.9 species for Budongo and 37.3 species for Kakamega. The Michaelis-Menten Means estimator was not found to be a good estimator for Kakamega as its estimate (135.6 species) is below the observed number of species (138). According to these estimators more than 80% of the foliicolous lichen species predicted were collected from Godere, Budongo and Kakamega forests.

For Godere the species accumulation curves (not shown) of MMMeans and Jack 2 estimators seemed to approach an asymptote, the curves for the others either did not approach an asymptote or did not stabilize. For Budongo, the species accumulation curves of Jack 2 and MMMeans estimators approached a horizontal asymptote. The curves for the other estimators did not approach an asymptote. Therefore, for Godere and Budongo the estimates of MMMeans could be considered as the lower limit of species richness and the Jack 2 estimates as the upper limit. For Kakamega the curves for Jack 1 and Chao 2 estimators seem to approach an asymptote. Accordingly the estimate of Chao 2 could be considered as the lower limit of species richness and that of Jack 1 as the upper limit.

Table 6.2 Species richness estimates and other summary values for foliicolous lichen species in Godere, Budongo and Kakamega forests

	Godere	Budongo	Kakamega
No. of samples	64	194	304
No. of individuals	626	2068	3380
S_{obs}	71	126	138
MMMeans	75.6	128.1	135.6
Chao 2	78.95 ± 5.5	135.5 ± 5.8	159±11.6
Jackknife 1	85.8 ±4.4	144.9±4.4	169.9±6.1
Jackknife 2	88.9	146.97	172.9
ICE	82.6	138.8	156.4
Bootstrap	78.6	135.6	148.6
Collection degree (%)	80-94	86-98	80-102

6.4.1.2 Shannon diversity

Table 6.3 presents the Shannon diversity and evenness indices for the foliicolous lichen species of Godere, Budongo and Kakamega forests. ANOVA followed by Fischer’s least significant difference (LSD) *post hoc* test indicated significant difference (F-value = 69.04, $p<0.05$) in Shannon diversity between Godere and Budongo as well as Godere and Kakamega. There is no significant difference between Budongo and Kakamega. Diversity of foliicolous lichens, as measured by Shannon index, is therefore significantly higher in Budongo and Kakamega than in Godere. The Shannon evenness is similar in Godere and Budongo but is slightly lower in Kakamega.

Table 6.3 Shannon diversity and evenness of foliicolous lichens in Godere, Budongo and Kakamega forests.

	Godere	Budongo	Kakamega
Shannon diversity index (H’)	3.66	4.14	4.09
Shannon evenness index (J’)	0.86	0.86	0.83

6.4.2 Beta diversity

Beta diversity of foliicolous lichens, expressed as the number of species observed divided by the mean number of species, is high in Kakamega and Budongo and low in Godere (Table 6.4). As this index of β-diversity is a measure of the species turnover or the degree of change in species composition, species turnover is high in Kakamega and Budongo and low in Godere.

Table 6.4 Total β-diversity in Godere, Budongo and Kakamega forests

	Total species number (a)	Mean number of species per sample (b)	β-diversity (a/b)
Godere	71	9.8	7.2
Budongo	126	10.7	11.8
Kakamega	138	11.1	12.4

The similarity in species composition, measured by Sørensen similarity index, shows high foliicolous lichens similarity between Budongo and Kakamega than between these forests and Godere (Table 6.5).

Table 6.5 Sørensen similarity index values for Godere, Budongo and Kakamega

	Godere	Budongo
Godere	-	
Budongo	0.59	-
Kakamega	0.61	0.77

6.4.3 Species frequency

In Godere, Budongo and Kakamega forests rare species constituted 62%, 74.6% and 77.5% of the total species respectively (Fig. 6.3). Occasional species constituted the next highest proportion. The species which fall in the other frequency classes constituted very small proportion.

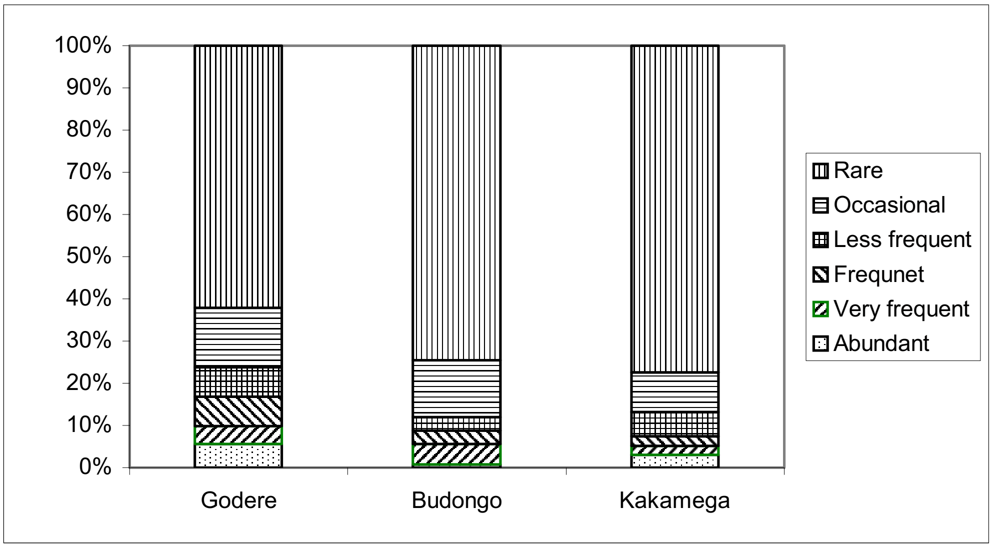


Fig. 6.3 Proportion (%) of species in the various frequency classes in Godere, Budongo and Kakamega forests

In Godere, *Porina epiphylla, P. nitidula, P. subpallescens,* and *P. rubentior* were the dominant species. *Strigula phyllogena, Bacidina apiahica,* and *Calopadia puiggarii* were the very frequent species. Species classified as frequent were *Calopadia fusca, Gyalectidium filicinum, Porina cupreola* var. *cupreola, P. leptosperma,* and *Strigula smaragdula*. *Fellhanera paradoxa, Gyalidea epiphylla, Calenia monospora, Lyromma nectandrae*, and *Trichothelium africanum* constituted the less frequent class. The species classified as occasional were *Aspidothelium fugiens, Brasilicia foliicola, Byssolecania hymenocarpa, Coccocarpia stellata, Fellhanera bouteillei, Gyalectidium imperfectum, Strigula nemathora var. hypothelia, Strigula nitidula, Trichothelium pauciseptatum* and *Trichothelium minutum* The remaining 44 species were rare.

In Budongo Forest, only *Porina epiphylla* fall into the dominant frequency class. Species classified as very frequent were *Porina nitidula, P. radiata, P. rubentior, Strigula phyllogena, S. smaragdula,* and *Coenogonium dilucidum*. The frequent species were *Mazosia rotula, M. melanopthalma, Strigula nemathora* var. *hypothelia* and *S. nitidula*. *Porina sphaerocephala, P. alba*, *P. semicarpi* and *Strigula microspora* constituted the less frequent frequency class. *Byssolecania deplanata, Bacidina apiahica, Brasilicia foliicola, Byssolecania hymenocarpa, Echinoplaca pellicula, Fellhanera submicrommata, Gyalectidium filicinum, Lyromma nectandrae, Porina conica, Porina cupreola* var.

cupreola, P. epiphylloides, P. kamerunensis, P. leptosperma, P. rubescens, Sporopodium leprieurii, Strigula multipunctata, and *S. obducta* were the species classified as occasionals. The remaining species were classified as rare.

In Kakamega Forest *Porina nitidula, P. epiphylla, P. rubetior,* and *P. cupreola* var. *cupreola* were the dominant species. The very frequent species were *Strigula phyllogena, S. amaragdula* and *Porina subpallescens. Gyalectidium filicinum, Strigula nitidula* and *Byssoloma leucoblepharum* were the species classified as frequent. Species classified as less frequent were *Coenogonium geralense, C. subluteum, Lyromma nectandrae, Calopadia puiggarii, Calenia monospora, Strigula macrocarpa,* and *Trichothelium pauciseptatum. Bacidina apiahica, Chroodiscus verrucosus, Coenogonium lisowskii, Coenogonium pocsii, C. siquirrense, Fellhanera bouteillei, Gyalectidium caucasicum, Mazosia melanopthalma, Porina epiphylloides, P. rubescens, Strigula microspora, S. nemathora* var. *hypothelia and S. obducta* were the species classified as occasional. The remaining species were rare.

6.4.4 Ordination

Principal component analysis (PCA) biplot of the species by forest sites data matrix of Godere, Budongo and Kakamega forests is presented in Fig. 6.4. The first four axes of the PCA ordination explain 50.6% of the total variation in the species data. The first and second axes of PCA ordination explain 21.7% and 13.8% of the total variation respectively; therefore most of the variation in species composition is explained by the first axis. In the PCA biplot species are represented by arrows and forest sites by dots. The direction of the arrow indicates the direction in which the abundance of a species increases most rapidly. The length of the arrows indicates the rate of change in abundance in that direction. A long arrow indicates gradual rate of change in abundance, while a short arrow represents very rapid change.

The distribution of the forest sites in the PCA biplot shows a clear pattern, with the primary, swamp, old secondary and young secondary forests of Budongo showing a strong positive correlation with the first axis but negative correlation with the second axis. The forest sites of Isiukhu, Yala, Ikuywa, and Salazar are positively correlated with both the first and the second axes but the correlation with the second axis is stronger. The forest site of Buyangu is slightly positively correlated with both axes while Kisere is slightly negatively correlated with the first axis and positively correlated with the second axis. Isecheno, Bukhaywa, Busambuli and Colobus forest sites of Kakamega are negatively correlated with the first axis and positively with the second axis. The forest sites of Dushi, Bishan Waka, Kaimosi, Malava, Ghostisland and Camp site are negatively correlated both with both the first and the second axes. The distribution of the study sites along the first PCA axis seems to depend on the level of forest disturbance. Therefore, forest sites with a strong positive correlation with the first PCA axis are undisturbed or slightly disturbed, while forest site negatively correlated with the first axis are more disturbed.

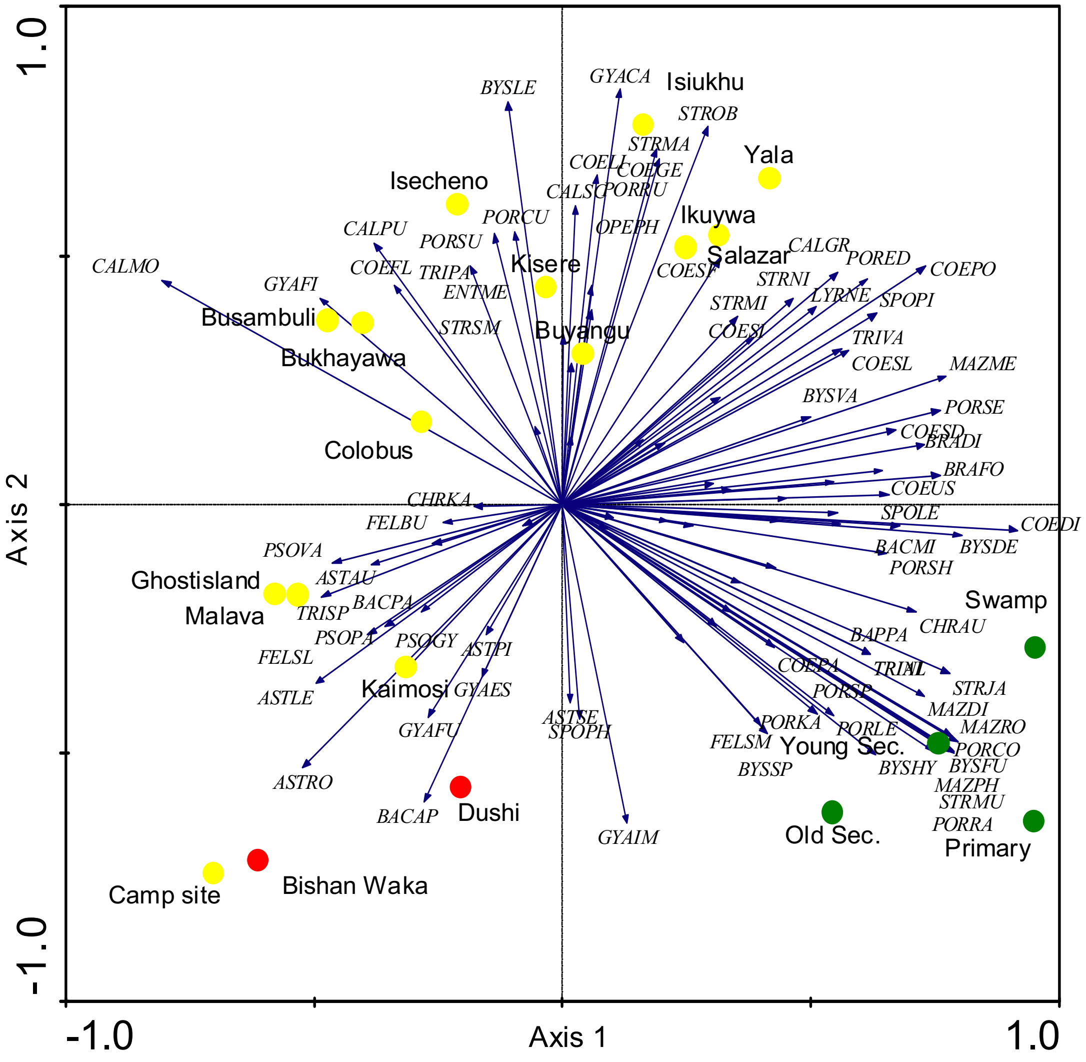


Fig. 6.4 PCA biplot of species and forest sites.. For species acronym see Appendix 4. For the purpose of clarity some of the species are omitted.

6.4.5 Foliicolous lichens as indicator of disturbance

Indicator species of forest types (disturbance regime) are determined from the distribution of species along the first axis of PCA biplot (Fig. 6.4). Species with a strong positive correlation with the first PCA axis are characteristic of undisturbed closed forest. Species with a strong negative correlation with the first axis are characteristic of a heavily disturbed forest site. The frequency of a species in the various forest types is also consulted in order to select indicator species. Only species restricted to a particular forest type with high frequency are considered as indicator of that forest type. Based on the distribution of the species and forest sites on the PCA biplot, the following species are selected as indicator of three forest types with different disturbance regime.

1. **Undisturbed/slightly disturbed closed forest**. Forests of this type have closed canopy with infrequent canopy openings. The primary, swamp, old secondary and young

secondary forests of Budongo belong to this group. The predominant microsite in such forest types is shady understorey and species of such microsite are more abundant than the other species (Table 6.6). Light gap species constitute a very small proportion and canopy species are either absent or very rare. Indicator species for this group are *Porina sphaerocephala, Porina conica, Porina radiata*, and *Mazosia rotula*. These species are mostly confined to the primary or old growth forests and have not been recorded from the middle-aged and young secondary forests.

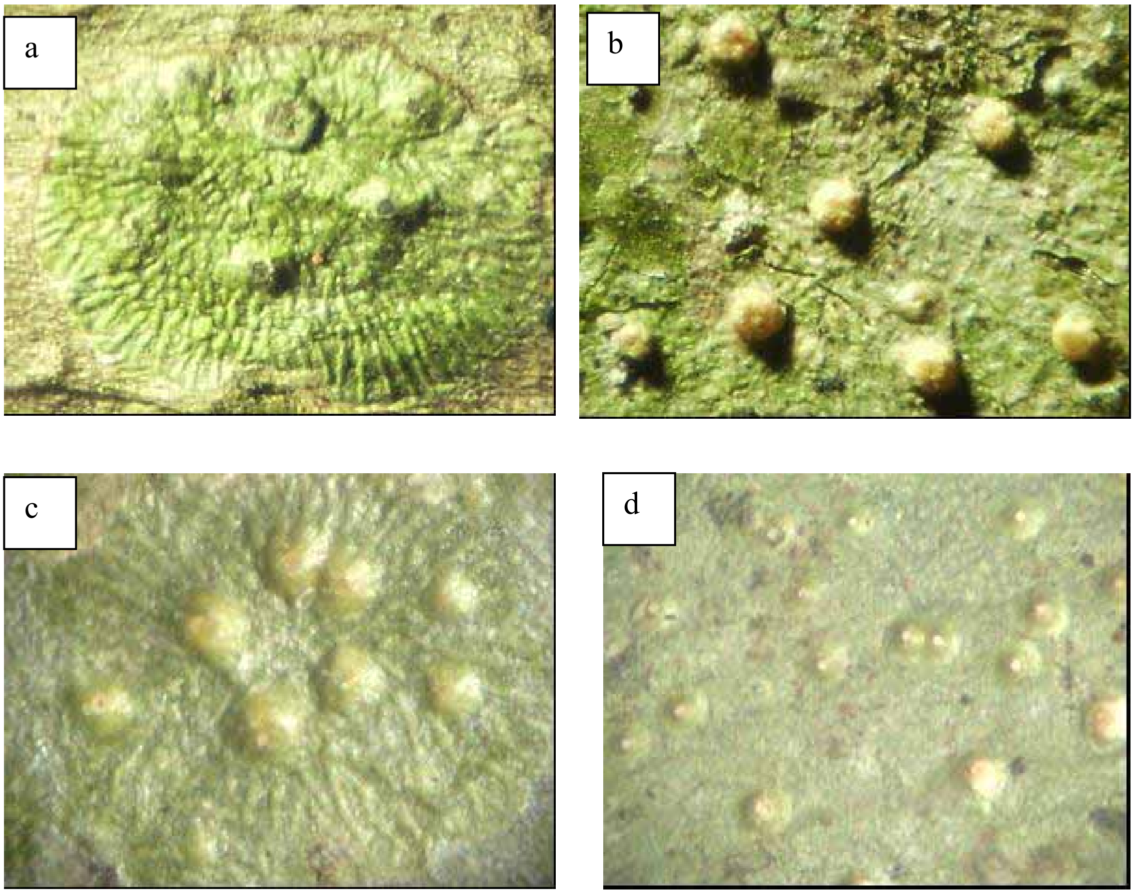


Fig. 6.5 Indicator species for undisturbed closed forest, (a) *Mazosia rotula*, (b) *Porina sphaerocephala,* (c) *Porina radiata,* (d) *Porina conica*

Foliicolous lichens associated with this forest type include *Mazosia phyllospora, M. dispersa, Strigula janeriensis, S. multipunctata, Bysoloma fumosonigricans, B. hymenocarpa, Chroodiscus australiensis, Porina leptosperma, P. kameruensis, P. sphaerocephaloides, Fellhanera submicrommata, Byssoloma subpolychromum,* and *Bapalmuia palmularis.*

2. **Closed forest with moderate disturbance.** This is the largest forest type where most of the forest sites of the study area belong. The forest canopy in this group is largely closed, however irregular openings could be seen here and there. Yala, Ikuywa, Salazar, Buyangu,

Isiukhu, Isecheno, Colobus and Kisere forest sites belong to this category. Forests under this group have most of the species distributed both in the shady understorey and light gap microsites and very few species in the canopy microsite (Table 6.5). Indicator species for this group are *Coenogonium geralense, Coenogonium siquirrense, Coenogonium pocsii,* and *Byssoloma leucoblepharum.*

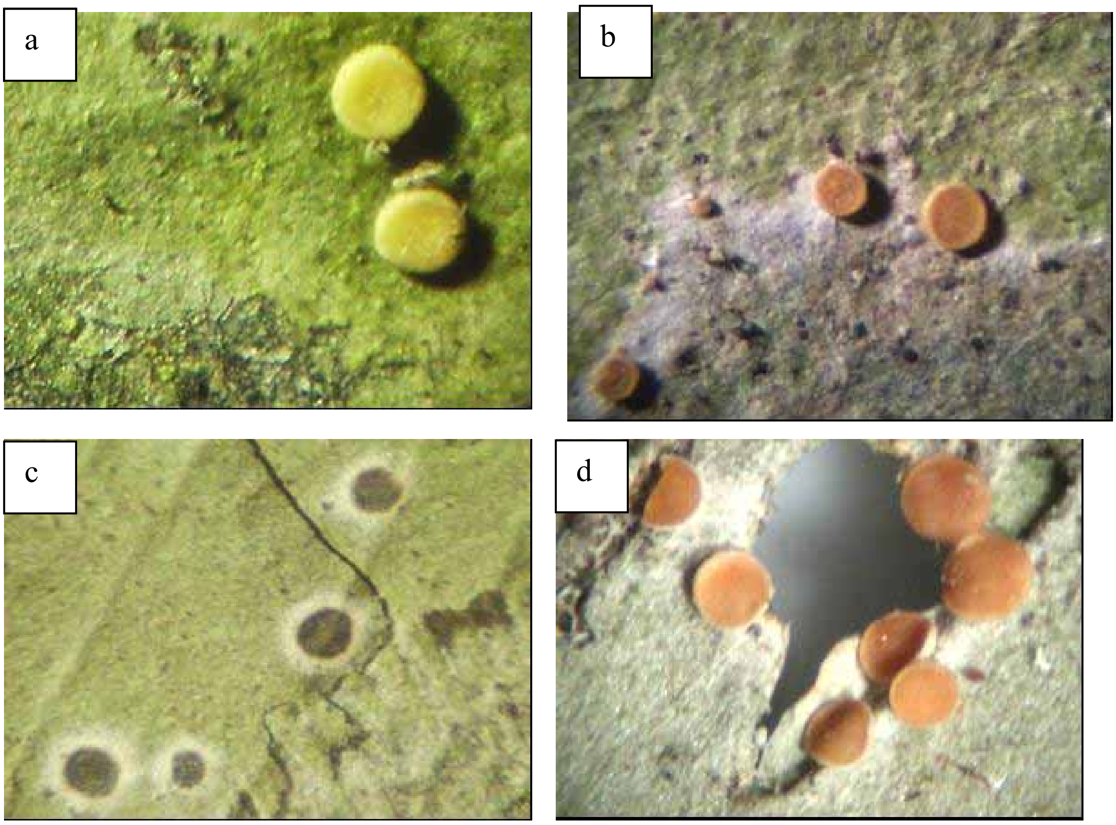


Fig. 6.6 Indicator species for closed forest with moderate disturbance, (a) *Coenogonium geralense*, (b) *C. pocsii*, (c) *Byssoloma leucoblepharum,* (d) *C. siquirrense.*

Foliicolous lichens associated with this forest type include *Coenogonium subfallaciosum, C. subluteum, C. usambarense, C. pocsii, Brasilicia foliicola, B. dimerelloides, Tricharia vainioi, Mazosia melanopthalna, Porina semicarpi, Porina epiphylloides, Byssolecania variabilis* and *Sporopodium pilocarpoides*.

3. **Disturbed semi-open forest**. The forests grouped under this type have semi-open canopy which allows light to reach the inside of the forest. Bukhaywa, Busambuli, Ghostisland, Malava, Kaimosi, Dushi, Bishan Waka and Camp site forests belong to this category. The foliicolous species composition is largely made up of more of light gap species than shady understorey species. In the Camp site forest which is more open than the other forest sites in this group, the proportion of light gap species is very high (70%) and more canopy specialists are recorded in the understorey (Table 6.6). Indicator species for the semi-open canopy forest group are *Asterothyrium rotuliforme, Psorotheciopsis gyalideoides*, *P. varieseptata, Calenia aspidota* and *Gyalectidium imperfectum*. Species

associated with this forest type include *Fellhanera bouteillei, Asterothyrium aulaxinoides, Fellhanera sublecanorina,* and *Calenia monospora.*

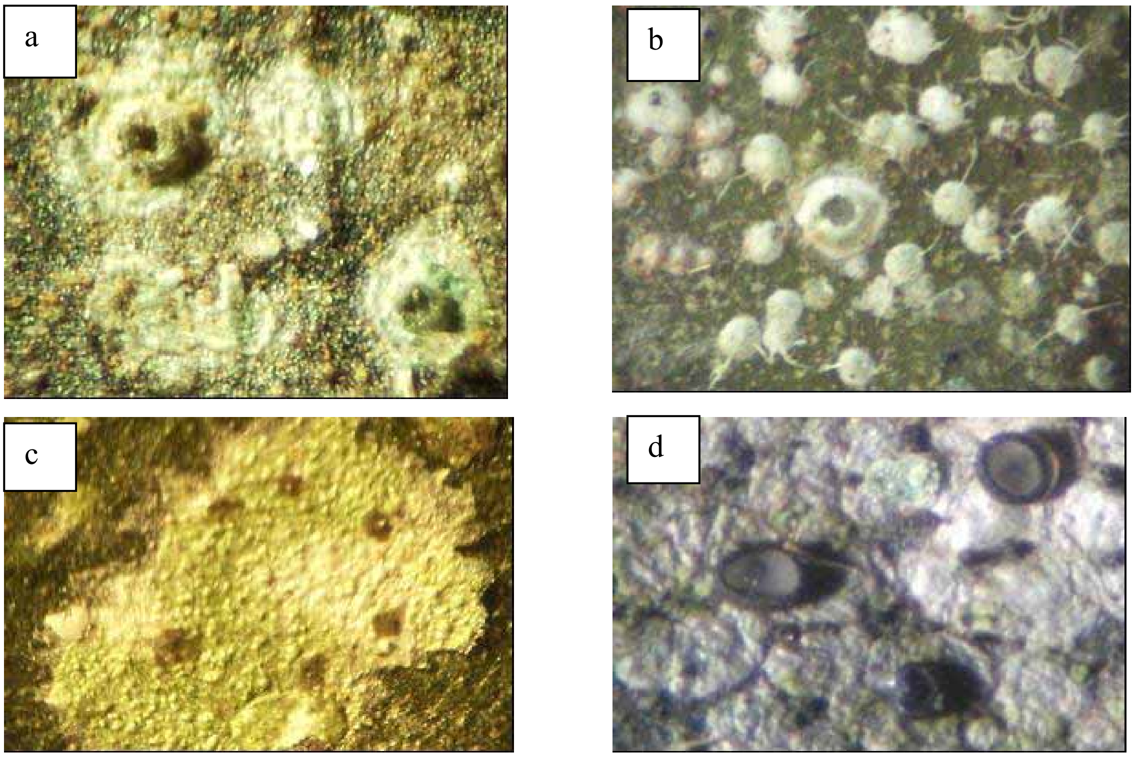


Fig. 6.7 Indicators species for open forest, (a) *Asterothyrium rotuliforme*, (b) *Calenia aspidota*, (c) *Gyalectidium imperfectum*, (d) *Psorotheciopsis gyalideoides*

Table 6.6.Proportion (%) of foliicolous lichen species of the forest sites of Godere, Budongo and Kakamega in the forest microsites

	Shady understorey	Transition to light gap	Light gap	Transition to canopy	Outer canopy
Old secondary	38.6	26.3	29.8	5.3	-
Isecheno	37	26.1	21.7	13	2.2
Primary	34.2	31.6	26.3	6.6	1.3
Kisere	32.3	24.6	27.7	10.8	3.1
Swamp	31.3	31.5	26.1	8.7	2.2
Ikuywa	31.1	23	32.8	9.8	3.3
Colobus	31.1	24.4	33.3	6.7	4.4
Yala	30.8	26.2	29	10.8	3.1
Young secondary	28	30.1	30.1	11.8	-
Dushi	26.7	21.7	35	13.3	3.3
Buyangu	24.7	31.5	27.4	13.7	2.7
Kaimosi	24.4	22	36.6	12.2	4.9
Isikuhu	24.3	27	31.1	16.2	1.4

Table 6.6 contd.

	Shady understorey	Transition to light gap	Light gap	Transition to canopy	Outer canopy
Salazar	23.8	33.3	31.7	9.5	1.6
Ghostislanid	22.6	19.4	38.7	9.7	9.7
Bukhaywa	22.2	24.4	35.6	13.3	4.4
Bishan Waka	19.4	13.9	44.4	13.9	8.3
Busambuli	18.9	18.9	30.2	22.6	7.5
Malava	17.1	19.5	41.5	14.6	7.3
Camp site	7.4	3.7	37	25.9	25.9

6.4.6 Biogeographic affinity of the foliicolous lichens of the study area

Lücking (2003) distinguished 6 lichenogeographical regions for foliicolous lichens. These are (1) Neotropics, (2) African Paleotropics, (3) Eastern Paleotropics, (4) Valdivian region, (5) Tethyan region, and (6) Neozealandic-Tasmanian region. About 57% of the foliicolous lichen species of Ethiopia, Uganda and Kenya were pantropical being distributed in the three tropical regions (Latin America, Africa and Southeast Asia) (Fig. 6.8). The African paleotropical species constituted 18.6% of the total species. Seventeen per cent of the species had their distribution in the African Paleotropics and the Neotropics, and are thus called Western Gondwana. Paleotropical species have their distribution range in the African Paleotropics and the Eastern Paleotropics and they constituted 7.2% of the whole species. About 1% of the species were cosmopolitan with distribution in the tropical regions as well as in the extra tropical regions and 1 species had distribution range in the African Paleotropics and Tethyan region.

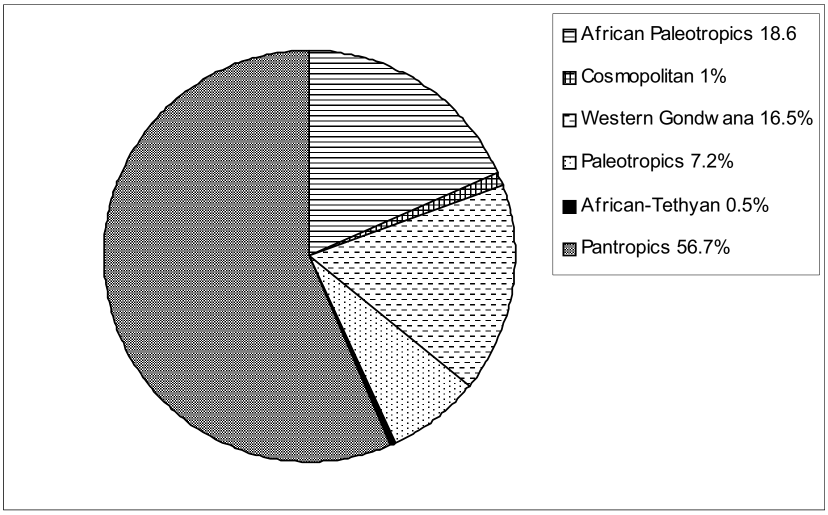


Fig. 6.8 Proportion of world distribution types of currently known foliicolous lichens of Ethiopia, Uganda and Kenya

Thirteen species which had a recorded distribution outside Africa have been recorded from Godere, Budongo and Kakamega forests for the first time and are thus new records for Africa. These are *Aspidothelium geminiparum, Asterothyrium aulaxinoides, Calenia triseptata, Coenogonium barbatum, Coenogonium pannosum, Coenogonium siquirrense, Eugeniella wettsteinii, Fellhanera aurantiaca, Porina rubescens, Strigula microspora,* and *Trichothelium africanum.* All of these species were previously recorded from the Neotropics only. *Aspidothelium scutelicarpum* was previously recorded from the Amphipacific region (Neotropics and Eastern Paleotropics) and *Coenogonium flavum* which was recorded from the Neotropics and Neozealandic-Tasmanian region are new records for Africa.

In order to see if there is similarity in the foliicolous lichens of the study area with other rainforests in Africa, the lowland tropical rainforest of Taï National Park in Ivory Coast was considered (Lücking *et al*. 1998). Taï National Park, located in southwestern Ivory Coast (Cote d'Ivoire) at altitudes 80-396 m, is the largest undisturbed tropical rainforest in West Africa. Comparison of the 97 foliicolous lichen species reported from this forest (Lücking *et al.* 1998) with our study area provided 50 shared species and a Sørensen similarity index of 0.39. This low level of similarity can be partly ascribed to the difference in disturbance conditions. While the forests of our study area are found under different anthropogenic disturbance conditions, the forest in Taï National Park is largely an undisturbed primary rainforest (Santesson & Lücking 1999). The list of foliicolous lichen species of Taï National Park did not contain species typical of open habitats.

6.5 Discussion

6.5.1 Foliicolous lichens diversity in Ethiopia, Uganda and Kenya

Lichens in general and foliicolous lichens in particular were overlooked both in Ethiopia, Uganda and Kenya. The 70 species of foliicolous lichens and lichenicolous fungi new to Ethiopia, 108 species new to Uganda and 77 species new to Kenya recorded in this study from a single forest in each country is a clear indication that high diversity of lichens could be expected in these countries. The number of new species recorded from the three forests is considerably high. It is worthmentioning that most of the new species were recorded from forest sites affected by disturbance. The major reason for the under collection of lichens in Africa is lack of expertise. Many African botanists prefer working on vascular plants to cryptogams. Lack of reference material is also a bottleneck for research in lichens. There is only one book (Swinscow and Krog 1988) available as a reference material for the macrolichens of East African (Ethiopia, Uganda, Kenya and Tanzania). For foliicolous lichens, however, no compiled reference material has ever been prepared for Africa. Santesson (1952) and the various publications after him are the only sources of information. There is therefore much work and challenge ahead before the lichen flora of tropical Africa is fully revealed.

Comparison of the foliicolous lichens recorded in the present study with earlier reports from the Neotropics, Southeast Asia and East and West Africa is made. Diversity of foliicolous lichens is high in the neotropical rainforests. The Central American rainforest, for example, harbours 390 species of foliicolous lichens (Cáceres *et al*. 2000). At site level, high foliicolous lichen diversity is found at ''La Selva'', a lowland rainforest in Costa Rica, with 280 species of foliicolous lichens and 18 species of lichenicolous fungi (Lücking 1999g), at ''Jatun Satcha, a lowland rainforest in Ecuador, with 232 species of foliicolous lichens (Lücking 1999d) and at the Botarrama trail, a premontane rainforest in Costa Rica, with 217 species of typically foliicolous lichens (Lücking 1999f). From Guyana, Lücking (1998b) reported 233 species of foliicolous lichens and 18 species of lichenicolous fungi. From the Atlantic rainforest of Brazil, Cáceres *et al*. (2000) reported 191 species of foliicolous lichens and 19 lichenocolous fungi on foliicolous lichens.

For Southeast Asia Papong *et al*. (2006) reported 8 species of foliicolous lichens from Nepal, 53 species from Sri Lanka , 60 species from China, 70 species from Vietnam, 83 species from Japan, 90 species from India, 106 species from Thailand, 120 species from Indonesia, 120 species from Malaysia, 191 species from Papua New Guinea, and 224 species from Philippines. In the continental Australia, 202 species of foliicolous lichens have been reported (Lücking *et al*. 2001). The numbers of foliicolous lichens recorded from Kakamega and Budongo forests are higher than the number of species reported from most of these tropical countries. The number of foliicolous lichens recorded from Godere is higher than the number reported at a country level for Nepal, Sri Lanka, China and Vietnam.

Comparison with reported species number from forest sites in Africa shows higher species diversity in Budongo and Kakamega and comparable or low diversity in Godere. Pócs (1978) reported 75 species from lowland and submontane rainforests in Tanzania and Lücking *et al*. (1998) reported 98 species from a lowland rainforest of Taï National Park in Ivory Coast.

Several studies have documented high foliicolous lichen diversity in undisturbed primary forests compared to disturbed secondary forests (Lücking 1998b, Sipman 1991). Our results show high foliicolous lichen diversity in primary forest and in secondary forests with relatively little disturbance. Although the large part of Kakamega is secondary forest and is more disturbed than Budongo, at forest level high foliicolous lichen species were recorded from the former than the latter. In Budongo Forest, 100 species were recorded from the two primary forest sites and 118 species from the secondary forest sites. In Kakamega Forest comparable numbers of foliicolous lichens were recorded from the secondary forest sites of Yala (67 species), Buyangu (74 species) and Isiukhu (77 species) and the near-primary forest site of Kisere (66 species). In the more disturbed secondary forest sites of Kakamega (e.g. Malava, Kaimosi, Camp site) and in Godere Forest, foliicolous lichen diversity is substantially reduced.

Since high diversity is recorded in forests with relatively low level of disturbance, our observation is in line with the Intermediate Disturbance Hypothesis (Connell 1978). The diversity of an area is influenced by the type, frequency and intensity of disturbance (Petraitis *et al*. 1989). Since the diversity and composition of foliicolous lichens is dependent on the available microsite habitats in a forest, any human impact that results in loss of habitat and significant change in the microclimatic environment will inevitably affect the diversity of foliicolous lichens. Clear-cutting and forest conversion to agricultural land use system, for example, result in total or partial removal of the understorey and light gap microsites resulting in a significant reduction of diversity. The effect on foliicolous lichen diversity of local forest exploitation for example by pit-sawing or fuelwood collection might be minimal. The impoverishment of foliicolous lichens in Godere Forest is primarily due to the conversion of a natural forest to a semi-forest coffee land use system. When understorey shrubs and lianas are removed under such system, foliicolous lichens are also removed along with. Besides, the number of available phorophyte individuals and species are limited, further diminishing the diversity of foliicolous lichens. For maintaining foliicolous lichens diversity, semi-coffee forest land use system is, however, much better than shifting cultivation and conversion to permanent agriculture. Selective logging or pitsawing, on the other hand, could enhance high foliicolous lichen diversity if the intensity and frequency is very limited. These types of human activity have taken place in the secondary forests of Budongo and the middle-age and old secondary forests of Kakamega; nevertheless, foliicolous lichens diversity in these forest types is still high. In contrast where the impact of disturbance was higher (e.g. Malava, Camp site, Kaimosi forests of Kakamega and Godere Forest), the diversity of foliicolous lichens is considerable reduced.

Tropical lowland and lower montane rainforests are most suitable habitats for foliicolous lichens (Lücking 2001). Under natural conditions, high foliicolous lichens diversity is expected from Godere, Budongo and Kakamega forests. The results from our studies confirmed high diversity in Budongo and Kakamega forests which is even higher than the diversity recorded for some countries in Southeast Asia.

6.5.2 Indicator species

Lichens have been found to be sensitive to anthropogenic disturbance and are useful indicators of ecological change (Nimis *et al*. 2002). The use of lichens as bioindicator lies in their poiklohydrous physiological conditions and symbiotic nature. Metabolic processes such as photosynthesis, nitrogen fixation, mineral accumulation, and growth rate in lichens vary in response to seasonal and environmental changes (Galloway 1992, Renhorn *et al*. 1997). Any environmental change that damages either the fungal or the algal partner results in a breakdown of the symbiosis and ultimately to the death of the lichen (Nimis & Purvis 2002)

Several studies (Wolseley and Aguirre-Hudson 1991, Wolseley and Aguirre-Hudson 1997, Mistry 1998, Wolseley 2002, Holz 2003, Nöske 2004, Saipunkaew *et al.* 2005, Plata *et al.* 2007) have demonstrated the potential of lichens as indicators of environmental changes in tropical areas. Furthermore, foliicolous lichens have been shown to have a high potential as bioindicators of altitudinal zonation (Pocs 1977, Lücking 1995b, Herrera-Campos *et al.* 2004, Alejandrina *et al*. 2007), microclimate (Lücking 1994), seasonality (Sérusiaux & De Sloover 1986, Lücking 1995b), anthropogenic disturbances (Lücking 1995a, Lücking 1997d), biodiversity (Lücking 1995b) and biogeographic affinity (Lücking & Kalb 2001). Lücking (2000) discussed the characters that make foliicolous lichens useful as bioindicator. Their relationship to the living leaf is reduced, their dependence on atmospheric factors are high, they have an accelerated life cycle and respond rapidly to environmental changes, there are taxonomically better known and they are particularly useful for ex-situ evaluation, since they are easily collected in large quantities and quickly processed for investigation and documentation.

The distribution of foliicolous lichens within a given forest is largely dependent on microsites (Lücking 1997d). The structure of a forest affects the distribution of foliicolous lichens through its influence on the moisture and light regime in the microsite. In a tropical lowland forest three microsites and two transitions are recognized (Lücking 1997d). These are shady understorey, transition to light gap, light gap, transition to outer canopy and outer canopy. Corresponding to these microsite habitats, foliicolous lichens form three well-defined associations.

In the forest sites of our study area foliicolous lichens belonging to the genera *Arthonia* (Arthoniaceae)*, Bapalmuia, Brasilicia, Byssolecania, Fellhanera* (Pilocarpaceae), *Coenogonium* (Coenogoniaceae), *Enterographa, Mazosia* (Roccellaceae)*, Porina, Trichothelium* (Porinaceae) and *Strigula phyllogena,* and *S. obducta* (Strigulaceae) belong to the shady understorey microsites. Except the family Pilocarpaceae which has Chlorococcaceae photobiont, all the other families have Trentepohliaceae photobiont.

Foliicolous lichen species belonging to the genera *Calenia, Gyalectidium, Echinoplaca* (Gomphillaceae), *Strigula smaragdula, S. nemathora, S. antillarum* (Strigulaceae), *Calopadia, Tapellaria, Loflammia,* and *Lasioloma* (Pilocarpaceae) dominate the light gap microsite. These genera, except *Strigula*, have Chlorococcaceae photobiont. The outer canopy microsite is dominated by the genera *Asterothyrium* and *Psorotheciopsis* (Asterothyriaceae) with Chlorococcaceae photobiont. Our results are in consistence with the observation of Lücking (1995c, 1999e) who recorded foliicolous lichen species of the family Arthoniaceae, Opegraphaceae (=Roccellaceae), Trichotheliaceae (=Porinaceae) and Pilocarpaceae (pycnidia bearing members) in the shady understorey, and Gomphillaceae and Ectolechiaceae (=campylidia bearing members of Pilocarpaceae) in the light gap.

The difference in foliicolous lichens composition in the various microsites is due to light regime (Lücking 1999e). Foliicolous lichens exhibit ecomorphological adaptations to the light regime. Foliicolous lichens in the shady understorey have thin thalli with smooth surface (e.g. species of *Arthonia, Bapalmuia, Brasilicia, Trichothelium, Mazosia phyllosema, Porina epiphylla, P. rufula, P. rubescens*) or are provided with small verrucae (e.g. *Porina sphaerocephala, P. sphaerocephaloides, P. mazosoides, P. radiata, Mazosia rotula*).

Foliicolous lichens in the light gap and outer canopy microsites have dispersed and white thalli (e.g. species of *Calopadia*, *Lasioloma arachnoideum*, *Loflammia epiphylla*) black apothecia (e.g. species of *Tapellaria*) and the phtobiont is *Trebouxia* (Chlorococcaceae). The white thallus reflects light reaching the surface of the thallus thereby reducing excessive loss of evaporation. In addition the thalli of foliicolous lichens in the outer canopy have cortex made from dead cells e.g. species of *Asterothyrium* and *Psorotheciopsis*).

The use of foliicolous lichens as indicator of forest disturbance lies in their compositional differentiation in the different forest microsites. In undisturbed forest, the canopy is closed and the amount of light intensity reaching the understorey vegetation is very small and the moisture content is high. Under such condition, foliicolous lichens adapted to the low light intensity become abundant, the proportion of light gap species is very small and the proportion of canopy species is negligible. In the Primary and Swamp forest of Budongo, for example, more than 60% of the species belong to the shady understorey and the transition to light gap microsites. The most frequent species in the shady understorey of the undisturbed and moderately disturbed group of forest are *Arthonia lividula, Brasilicia dimerelloides, B. foliicola, Coenogonium pocsii, C. siquirrense, C. subfallaciosum, Mazosia melanopthalma* and *Opegrapha velata* (lichenicolous).

When a disturbance occurs in a forest, for example by selective logging, canopy opening allows high light intensity to reach the understorey and this results in reduced moisture content in the understorey. While shady understorey species find these conditions unfavorable for their development, the conditions become favorable for the growth of light gap species. Under extreme condition of disturbance, where the canopy is widely opened, foliicolous lichens adapted to the outer canopy could grow in the understorey. About 22% of the foliicolous lichen species recorded from the understorey of Camp site forest of Kakamega are canopy specialists. All the foliicolous lichen species recorded from the canopy tree of *Ficus lutea* in Susungiru in Uganda have been recorded in the understorey of Camp site forest.

The degree of forest disturbance can be inferred from the proportional abundance of species in the different light regime of a forest. Occurrence of species of the outer canopy (e.g. *Asterothyrium leucophthalmum, A. monsporum, Calenia monosora, C. aspidota, Psorotheciopsis gyalideoides, Psorotheciopsis patellarioides, Psorotheciopsis varieseptata*) in the understorey is a clear indication of wider canopy opening and thus severe forest disturbance. High proportional abundance of species like *Calopadia puiggarii, Fellhanera bouteillei, Gyalectidium caucasicum, G. microcarpum, Lasioloma arachnoideum,* and *Strigula antillarum* in the understorey is an indication of moderate forest disturbance, for example by selective logging or pitsawing resulting in partial or irregular canopy openings.

6.5.3 Biogeography

Among the three tropical lichenogeographical regions, Africa is poor in foliicolous lichens. Lücking (2003) reported 539 species from the Neotropics, 403 from Eastern Paleotropics and 309 from the African Paleotropics. Meggers *et al*. (1973) compared the epiphytic diversity of tropical Africa and South America and indicated that the low epiphytic diversity in Africa is due to paleoclimatic dry periods. It is not known whether the low number of foliicolous lichen species in Africa is due to paleoclimatic conditions or due to insufficient collection. Since many areas of Africa have not been investigated for their foliicolous lichen flora, appropriate explanation for their diversity should be preceded by a thorough collection of different forest types. The 7 new species recorded from the three forests as well as those collections which are expected to belong to new species and the 13 new records for Africa are clear indicators that the foliicolous lichen flora of tropical Africa is under collected.

Santesson & Lücking (1999) analysed the world distribution pattern of the foliicolous lichen flora of Ivory Coast. They found out that 56.5% of the species had pantropical distribution, 22.4% Western Gondwana, 8.7% African Paleotropical, and 6.8% Paleotropical. Foliicolous lichens are known for their wide distribution and high proportion of pantropical species were recorded from collections made in different areas (Santesson & Lücking 1999, Cáceres *et al*. 2000, Herrere-Campos *et al*. 2004). The proportion of pantropical and paleotropical species in Ivory Coast and in Ethiopia, Uganda and Kenya are similar. However, higher proportion of Western Gondwana species and lower proportion of African Paleotropical species were recorded from Ivory Coast than from the three countries investigated in this study. The new species of foliicolous lichens described from the present study have contributed for the increased proportion of the African paleotropical species of the three countries. The low proportion of Western Gondwana species in our study area as compared to those from Ivory Coast indicates that the foliicolous lichen flora of the Ivory Coast is more similar to the flora of Neotropical rainforests than to the flora of the East African rainforests.

The proportion of species common to the African Paleotropics and the Neotropics is more than twice as much as those shared between the African and Eastern Paleotropics. From the foliicolous lichens collected from Ivory Coast, Santesson & Lücking (1999) reported that the Western Gondwana species were three times more than the paleotropical species, indicating higher affinity of the African foliicolous lichens to the Neotropical counterparts. Lücking *et al.* (1998) proposed further study to determine whether this observed similarity is due to paleogeographical relationships between the tropical Africa and tropical South America or due to long distance dispersal.

6.6 Conclusion

The foliicolous lichen flora of Godere, Budongo and Kakamega forests has been found to be considerably high. The number of species recorded especially from Budogo and Kakamega are substantially higher than the species recorded at a country level for many of the tropical countries in Southeast Asia. The numbers of new species science and new records for Africa discovered in this study are indicative that the foliicolous lichens flora of tropical Africa is insufficiently known. The result of the present study predicts high foliicolous lichen diversity in the tropical forests of Africa should such forests are investigated in detail. Therefore it is recommended that more floristic and ecological study should be done especially in the lowland and submontane rainforests of Africa.

At forest level, high foliicolous lichen diversity has been recorded from Kakamega Forest than from Budongo and Godere. It is assumed that the diversity of forest type with different seral stages and disturbance levels has contributed for the diversity of foliicolous lichens in Kakamega Forest. At site level, the forest sites of Budongo have high foliicolous lichen diversity than the forest sites of Kakamega and Godere. Secondary forests with low level of disturbance have been shown to support similar foliicolous lichen diversity like primary forests. Therefore, for the maintenance of high foliicolous lichen diversity in tropical Africa both primary and old growth secondary forests should be conserved.

Due to differences in light intensity and moisture level the composition of foliicolous lichens in the various microsites has been shown to be different. Forest disturbance affects the structure of a forest which in turn affects the environmental conditions in the microsites. Therefore, by observing the composition of foliicolous lichen flora of a given forest site, it is possible to predict the degree of human disturbance in the forest. In addition, some foliicolous lichens have been found to be restricted to a particular microsite making them useful as bioindicator of anthropogenic forest disturbance. Therefore, the identification of indicator foliicolous lichens could provide a basis for management recommendation in areas of disturbed and fragmented forests in tropical Africa.

Most of the foliicolous lichen flora of the study has pantropical distribution and more similar to the Neotropical flora than the Eastern Paleotropical flora. As a result of the new species discovered in this study, the proportion of the African Paleotropical species has ncreased.

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APPENDICIES

Appendix 1. Foliicolous lichens and lichenicolous fungi from Godere Forest

Species acronym	Species	Family	Growth habit
ARTAT	*Arthonia atropunctata* Vain.	Arthoniaceae	Lichenicolous fungi
ARTLI	*Arthonia lividula* Vain.	Arthoniaceae	Typical foliicolous
ASPFU	*Aspidothelium fugiens* (Müll. Arg.) R. Sant.	Aspidotheliaceae	Typical foliicolous
ASPHI	*Aspidothelium hirustum* sp. nov.	Aspidotheliaceae	Typical foliicolous
ASTLE	*Asterothyrium leucophthalmum* (Müll. Arg.) R. Sant.	Asterothyriaceae	Typical foliicolous
ASTMI	*Asterothyrium microsporum* R. Sant.	Asterothyriaceae	Typical foliicolous
ASTOC	*Asterothyrium octomerum* R. Sant.	Asterothyriaceae	Typical foliicolous
ASTRO	*Asterothyrium rotuliforme* (Müll. Arg.) Sérus.	Asterothyriaceae	Typical foliicolous
BACAP	*Bacidina apiahica* (Müll. Arg.) Vezda	Ramalinaceae	Typical foliicolous
BACMI	*Bacidina mirabilis* (Vezda) Vezda	Ramalinaceae	Typical foliicolous
BACPA	*Bacidina pallidocarnea* (Müll. Arg.) Vezda	Ramalinaceae	Typical foliicolous
BRAFO	*Brasilicia foliicola* (Vezda) Lücking, Kalb & Sérus.	Pilocarpaceae	Typical foliicolous
BYSHY	*Byssolecania hymenocarpa* (Vain.) Kalb, Vezda & Lücking	Pilocarpaceae	Typical foliicolous
BYSCH	*Byssoloma chlorinum* (Vain.) Zahlbr.	Pilocarpaceae	Typical foliicolous
BYSLE	*Byssoloma leucoblepharum* (Nyl.) Vain.	Pilocarpaceae	Typical foliicolous
BYSSU	*Byssoloma subpolychromum* Vezda	Pilocarpaceae	Typical foliicolous
CALMO	*Calenia monospora* Vezda	Gomphillaceae	Typical foliicolous
CALSP	*Calenia* sp.	Gomphillaceae	Typical foliicolous
CALTR	*Calenia triseptata* Zahlbr.	Gomphillaceae	Typical foliicolous
CALFU	*Calopadia fusca* (Müll. Arg.) Vezda	Pilocarpaceae	Typical foliicolous
CALPH	*Calopadia phyllogena* (Müll. Arg.) Vezda	Pilocarpaceae	Typical foliicolous
CALPU	*Calopadia puiggarii* (Müll. Arg.) Vezda	Pilocarpaceae	Typical foliicolous

Species acronym	Species	Family	Growth habit
CAPSP	*Caprettia goderei* sp. nov.	Monoblastiaceae	Typical foliicolous
CHRSP	*Chroodiscus kakamegensis* sp. nov.	Thelotremataceae	Typical foliicolous
CHRVE	*Chroodiscus verrucosus* R. Sant., Lücking & Vezda	Thelotremataceae	Typical foliicolous
COCST	*Coccocarpia stellata* Tuck.	Coccocarpiaceae	Facultative foliicolous
COEDI	*Coenogonium dilucidum* (Kremp.) Kalb & Lücking	Coenogoniaceae	Typical foliicolous
COESU	*Coenogonium subluteum* (Rehm) Kalb & Lücking	Coenogoniaceae	Typical foliicolous
COEUS	*Coenogonium usambarense* (Vezda & Farkas) Lücking & Kalb	Coenogoniaceae	Typical foliicolous
ECHPE	*Echinoplaca pellicula* (Müll. Arg.) R. Sant.	Gomphillaceae	Typical foliicolous
FELAU	*Fellhanera* cf. *aurantiaca* (Vezda) Vezda	Pilocarpaceae	Typical foliicolous
FELBO	*Fellhanera bouteillei* (Desm.) Vezda	Pilocarpaceae	Ubiquotus
FELCF	*Fellhanera* aff. *bouteillei* (Desm.) Vezda	Pilocarpaceae	
FELPA	*Fellhanera paradoxa* (Vezda) Vezda	Pilocarpaceae	Typical foliicolous
FELSF	*Fellhanera subfuscatula* Lücking	Pilocarpaceae	Typical foliicolous
FELSL	*Fellhanera sublecanorina* (Nyl.) Vezda	Pilocarpaceae	Typical foliicolous
FELSM	*Fellhanera submicrommata* (Vezda) Lücking & Kalb	Pilocarpaceae	Typical foliicolous
GYAFI	*Gyalectidium filicinum* Müll. Arg.	Gomphillaceae	Typical foliicolous
GYAFU	*Gyalectidium fuscum* Lücking & Sérus.	Gomphillaceae	Typical foliicolous
GYAIM	*Gyalectidium imperfectum* Vezda	Gomphillaceae	Typical foliicolous
GYAEP	*Gyalidea epiphylla* Vezda	Asterothyriaceae	Typical foliicolous
LYRNE	*Lyromma nectandrae* Bat. & H. Maia	Lyrommataceae	Typical foliicolous
OPESP	*Opegrapha* sp.	Roccellaceae	Lichenicolous fungi
OPEVE	*Opegrapha velata* (Müll. Arg.) Vain.	Roccellaceae	Lichenicolous fungi
PHYPO	*Phylloblastia pocsii* (Farkas & Vezda) Lücking	Verrucariaceae	Typical foliicolous
PORCF	*Porina* cf. *triseptata* (Vezda) Lücking	Porinaceae	Typical foliicolous
PORCU	*Porina cupreola* (Müll. Arg.) F. Schill. var. *cupreola*	Porinaceae	Typical foliicolous
POREP	*Porina epiphylla* (Fée) Fée	Porinaceae	Typical foliicolous
PORLE	*Porina leptosperma* Müll. Arg.	Porinaceae	Typical foliicolous

Species acronym	**Species**	**Family**	**Growth habit**
PORNI	*Porina nitidula* Müll. Arg.	Porinaceae	Typical foliicolous
PORRU	*Porina rubentior* (Stirt.) Müll. Arg.	Porinaceae	Typical foliicolous
PORRB	*Porina rubescens* (Lücking) Hafellner & Kalb	Porinaceae	Typical foliicolous
PORRF	*Porina rufula* (Kremp.) Vain.	Porinaceae	Typical foliicolous
PORSU	*Porina subpallescens* Vezda	Porinaceae	Typical foliicolous
PORTE	*Porina tetramera* (Malme) R. Sant.	Porinaceae	Typical foliicolous
PORTI	*Porina trichothelioides* R. Sant.	Porinaceae	Typical foliicolous
PSOPA	*Psorotheciopsis patellarioides* (Rehm) R. Sant.	Asterothyriaceae	Typical foliicolous
PSOVA	*Psorotheciopsis varieseptata* (Vezda) Henssen & Lücking	Asterothyriaceae	Typical foliicolous
SPOAN	*Sporopodium antonianum* Elix, Lumbsch & Lücking	Pilocarpaceae	Typical foliicolous
SPOLE	*Sporopodium leprieurii* Mont.	Pilocarpaceae	Typical foliicolous
SPOPH	*Sporopodium phyllocharis* (Mont.) Massal.	Pilocarpaceae	Typical foliicolous
SPOSP	*Sporopodium* sp.	Pilocarpaceae	
STRMA	*Strigula macrocarpa* Vain.	Strigulaceae	Typical foliicolous
STRMI	*Strigula microspora* Lücking	Strigulaceae	Typical foliicolous
STRHY	*Strigula nemathora* var. *hypothelia* (Nyl.) R. Sant.	Strigulaceae	Typical foliicolous
STRNE	*Strigula nemathora* Mont.	Strigulaceae	Typical foliicolous
STRNI	*Strigula nitidula* Mont.	Strigulaceae	Typical foliicolous
STRPH	*Strigula phyllogena* (Müll. Arg.) R. C. Harris	Strigulaceae	Typical foliicolous
STRSC	*Strigula schizospora* R. Sant.	Strigulaceae	Typical foliicolous
STRSM	*Strigula smaragdula* Fr.	Strigulaceae	Typical foliicolous
TAPBI	*Tapellaria bilimbioides* R. Sant.	Pilocarpaceae	Typical foliicolous
TRIAF	*Trichothelium africanum* Lücking	Porinaceae	Typical foliicolous
TRIEP	*Trichothelium epiphyllum* Müll. Arg.	Porinaceae	Typical foliicolous
TRISP	*Trichothelium minutum* (Lücking) Lücking	Porinaceae	Typical foliicolous
TRIPA	*Trichothelium pauciseptatum* Vezda	Porinaceae	Typical foliicolous

Appendix 2. Foliicolous lichens and lichenicolous fungi from Budongo Forest

Species acronym	**Species**	**Family**	**Growth habit**
ARTLI	*Arthonia lividula* Vain.	Arthoniaceae	Typical foliicolous
ARTOR	*Arthonia orbygniae* (H. B. P. Upadhyay) Matzer	Arthoniaceae	Typical foliicolous
ASPFU	*Aspidothelium fugiens* (Müll. Arg.) R. Sant.	Aspidotheliaceae	Typical foliicolous
ASPGE	*Aspidothelium geminiparum* (Malme) R. Sant.	Aspidotheliaceae	Typical foliicolous
ASTMI	*Asterothyrium microsporum* R. Sant.	Asterothyriaceae	Typical foliicolous
ASTMO	*Asterothyrium monosporum* Müll. Arg.	Asterothyriaceae	Typical foliicolous
ASTPI	*Asterothyrium pittieri* Müll. Arg.	Asterothyriaceae	Typical foliicolous
ASTRO	*Asterothyrium rotuliforme* (Müll. Arg.) Sérus.	Asterothyriaceae	Typical foliicolous
ASTSE	*Asterothyrium septemseptatum* ssp. africanum Lücking & Kalb	Asterothyriaceae	Typical foliicolous
AULMI	*Aulaxina microphana* (Vain.) R. Sant.	Gomphillaceae	Typical foliicolous
BACAP	*Bacidina apiahica* (Müll. Arg.) Vezda	Ramalinaceae	Typical foliicolous
BACMI	*Bacidina mirabilis* (Vezda) Vezda	Ramalinaceae	Typical foliicolous
BACPA	*Bacidina pallidocarnea* (Müll. Arg.) Vezda	Ramalinaceae	Typical foliicolous
BACSI	*Bacidina simplex* Farkas & Vezda	Ramalinaceae	Typical foliicolous
MAPIV	*Bapalmuia ivoriensis* R. Sant. & Lücking	Pilocarpaceae	Typical foliicolous
MAPPA	*Bapalmuia palmularis* (Müll. Arg.) Sérus.	Pilocarpaceae	Typical foliicolous
BIASP	*Biatora* sp.	Bacidiaceae	Facultative foliicolous
BRADI	*Brasilicia dimerelloides* (Vezda) Lücking, Kalb & Sérus.	Pilocarpaceae	Typical foliicolous
BRAFO	*Brasilicia foliicola* (Vezda) Lücking, Kalb & Sérus.	Pilocarpaceae	Typical foliicolous
BYSDE	*Byssolecania deplanata* (Müll. Arg.) R. Sant.	Pilocarpaceae	Typical foliicolous
BYSFU	*Byssolecania fumosonigricans* (Müll. Arg.) R. Sant.	Pilocarpaceae	Typical foliicolous
BYSHY	*Byssolecania hymenocarpa* (Vain.) Kalb, Vezda & Lücking	Pilocarpaceae	Typical foliicolous
BYSVA	*Byssolecania variabilis* (Vain.) Kalb, Vezda & Lücking	Pilocarpaceae	Typical foliicolous

Species acronym	Species	Family	Growth habit
BYSCH	*Byssoloma chlorinum* (Vain.) Zahlbr.	Pilocarpaceae	Typical foliicolous
BYSLE	*Byssoloma leucoblepharum* (Nyl.) Vain.	Pilocarpaceae	Typical foliicolous
BYSSD	*Byssoloma subdiscordans* (Nyl.) P. James	Pilocarpaceae	Typical foliicolous
BYSSP	*Byssoloma subpolychromum* Vezda	Pilocarpaceae	Typical foliicolous
CALAS	*Calenia aspidota* (Vain.) Vezda	Gomphillaceae	Typical foliicolous
CALBU	*Calenia bullatinoides* Lücking	Gomphillaceae	Typical foliicolous
CALDE	*Calenia depressa* Müll. Arg.	Gomphillaceae	Typical foliicolous
CALGR	*Calenia graphidea* Vain.	Gomphillaceae	Typical foliicolous
CALSP	*Calenia* sp.	Gomphillaceae	Typical foliicolous
CALFU	*Calopadia fusca* (Müll. Arg.) Vezda	Pilocarpaceae	Typical foliicolous
CALPU	*Calopadia puiggarii* (Müll. Arg.) Vezda	Pilocarpaceae	Typical foliicolous
CHRAU	*Chroodiscus australiensis* Vezda & Lumbsch	Thelotremataceae	Typical foliicolous
CHRKA	*Chroodiscus kakamegensis* sp. nov.	Thelotremataceae	Typical foliicolous
CHRVE	*Chroodiscus verrucosus* R. Sant., Lücking & Vezda	Thelotremataceae	Typical foliicolous
COCST	*Coccocarpia stellata* Tuck.	Coccocarpiaceae	Facultative foliicolous
COEBA	*Coenogonium barbatum* Lücking, Aptroot & Umaña	Coenogoniaceae	Typical foliicolous
COEDI	*Coenogonium dilucidum* (Kremp.) Kalb & Lücking	Coenogoniaceae	Typical foliicolous
COEFA	*Coenogonium fallaciosum* (Müll. Arg.) Kalb & Lücking	Coenogoniaceae	Typical foliicolous
COEGE	*Coenogonium geralense* (P.Henn) Lücking	Coenogoniaceae	Typical foliicolous
COELI	*Coenogonium lisowskii* (Vezda) Lücking	Coenogoniaceae	Typical foliicolous
COEPA	*Coenogonium pannosum* Mull.Arg.	Coenogoniaceae	Typical foliicolous
COEPO	*Coenogonium pocsii* (Vezda & Farkas) Lücking	Coenogoniaceae	Typical foliicolous
COESI	*Coenogonium siquirrense* (Lücking) Lücking	Coenogoniaceae	Typical foliicolous
COESP	*Coenogonium* sp.	Coenogoniaceae	Typical foliicolous
COESD	*Coenogonium subdilucidum* (Vezda) Lücking	Coenogoniaceae	Typical foliicolous

Species acronym	Species	Family	Growth habit
COESF	*Coenogonium subfallaciosum* (Vezda & Farkas) Lücking	Coenogoniaceae	Typical foliicolous
COESL	*Coenogonium subluteum* (Rehm) Kalb & Lücking	Coenogoniaceae	Typical foliicolous
COEUS	*Coenogonium usambarense* (Vezda & Farkas) Lücking & Kalb	Coenogoniaceae	Typical foliicolous
COEZO	*Coenogonium zonatum* (Müll. Arg.) Kalb & Lücking	Coenogoniaceae	Typical foliicolous
ECHDI	*Echinoplaca diffluens* (Müll. Arg.) R. Sant.	Gomphillaceae	Typical foliicolous
ECHPE	*Echinoplaca pellicula* (Müll. Arg.) R. Sant.	Gomphillaceae	Typical foliicolous
EUGWE	*Eugeniella wettsteinii (Müll.Arg.)* Lücking, Sérus. & Kalb	Pilocarpaceae	Typical foliicolous
FELAF	*Fellhanera africana* (Vezda) Lücking	Pilocarpaceae	Typical foliicolous
FELBO	*Fellhanera bouteillei* (Desm.) Vezda	Pilocarpaceae	Ubiquotus
FELPA	*Fellhanera paradoxa* (Vezda) Vezda	Pilocarpaceae	Typical foliicolous
FELRH	*Fellhanera rhaphidophylli* (Rehm) Vezda	Pilocarpaceae	Typical foliicolous
FELSF	*Fellhanera subfuscatula* Lücking	Pilocarpaceae	Typical foliicolous
FELSM	*Fellhanera submicrommata* (Vezda) Lücking & Kalb	Pilocarpaceae	Typical foliicolous
GYACA	*Gyalectidium caucasicum* (Elenk. & Woron.) Vezda	Gomphillaceae	Typical foliicolous
GYAES	*Gyalectidium eskuchei* Sérus.	Gomphillaceae	Typical foliicolous
GYAFI	*Gyalectidium filicinum* Müll. Arg.	Gomphillaceae	Typical foliicolous
GYAFU	*Gyalectidium fuscum* Lücking & Sérus.	Gomphillaceae	Typical foliicolous
GYAIM	*Gyalectidium imperfectum* Vezda	Gomphillaceae	Typical foliicolous
GYAMI	*Gyalectidium microcarpum* (Vezda) Lücking, Sérus. & Vezda	Gomphillaceae	Typical foliicolous
GYAEP	*Gyalidea epiphylla* Vezda	Asterothyriaceae	Typical foliicolous
LICEP	*Lichenopeltella epiphylla* R. Sant.	Microthyriaceae	Lichenicolous fungi
LOFEP	*Loflammia epiphylla* (Fée) Lücking & Vezda	Pilocarpaceae	Typical foliicolous
LYRNE	*Lyromma nectandrae* Bat. & H. Maia	Lyrommataceae	Typical foliicolous
MAZDI	*Mazosia dispersa* (Hedr.) R. Sant.	Roccellaceae	Typical foliicolous
MAZME	*Mazosia melanopthalma* (Müll. Arg.) R. Sant.	Roccellaceae	Typical foliicolous

Species acronym	Species	Family	Growth habit
MAZPA	*Mazosia paupercula* (Müll. Arg.) R. Sant.	Roccellaceae	Typical foliicolous
MAZPH	*Mazosia phyllosema* (Nyl.) Zahlbr.	Roccellaceae	Typical foliicolous
MAZRO	*Mazosia rotula* (Mont.) Massal.	Roccellaceae	Typical foliicolous
OPEEP	*Opegrapha epiporina* Matzer	Roccellaceae	Lichenicolous fungi
OPEMA	*Opegrapha mazosiae* Matzer	Roccellaceae	Lichenicolous fungi
OPEPH	*Opegrapha phylloporinae* Müll. Arg.	Roccellaceae	Lichenicolous fungi
OPESP	*Opegrapha* sp.	Roccellaceae	Lichenicolous fungi
PHYPO	*Phylloblastia pocsii* (Farkas & Vezda) Lücking	Verrucariaceae	Typical foliicolous
PORAL	*Porina alba* (R.Sant.) Lücking	Porinaceae	Typical foliicolous
PORCF	*Porina* cf. *triseptata* (Vezda) Lücking	Porinaceae	Typical foliicolous
PORCO	*Porina conica* R. Sant.	Porinaceae	Typical foliicolous
PORCU	*Porina cupreola* (Müll. Arg.) F. Schill. var. *cupreola*	Porinaceae	Typical foliicolous
POREP	*Porina epiphylla* (Fée) Fée	Porinaceae	Typical foliicolous
POREI	*Porina epiphylloides* Vezda	Porinaceae	Typical foliicolous
PORKA	*Porina kamerunensis* F. Schill.	Porinaceae	Typical foliicolous
PORLE	*Porina leptosperma* Müll. Arg.	Porinaceae	Typical foliicolous
PORLI	*Porina limbulata* (Kremp.) Vain.	Porinaceae	Typical foliicolous
PORMA	*Porina mazosoides* Lücking & *Vezda*	Porinaceae	Typical foliicolous
PORNI	*Porina nitidula* Müll. Arg.	Porinaceae	Typical foliicolous
PORRA	*Porina radiata* Kalb, Lücking & Vezda	Porinaceae	Typical foliicolous
PORRU	*Porina rubentior* (Stirt.) Müll. Arg.	Porinaceae	Typical foliicolous
PORRB	*Porina rubescens* (Lücking) Hafellner & Kalb	Porinaceae	Typical foliicolous
PORRF	*Porina rufula* (Kremp.) Vain.	Porinaceae	Typical foliicolous
PORSE	*Porina semicarpi* Vain.	Porinaceae	Typical foliicolous
PORSR	*Porina sphaerocephala* Vain.	Porinaceae	Typical foliicolous

Species acronym	Species	Family	Growth habit
PORSH	*Porina sphaerocephaloides* Farkas	Porinaceae	Typical foliicolous
PORSP	*Porina subpallescens*Vezda	Porinaceae	Typical foliicolous
PORTE	*Porina tetramera* (Malme) R. Sant.	Porinaceae	Typical foliicolous
PORTR	*Porina trichothelioides* R. Sant.	Porinaceae	Typical foliicolous
PSOPA	*Psorotheciopsis gyalideoides* (Vezda) Henssen & Lücking	Asterothyriaceae	Typical foliicolous
SPOAN	*Sporopodium antonianum* Elix, Lumbsch & Lücking	Pilocarpaceae	Typical foliicolous
SPOLE	*Sporopodium leprieurii* Mont.	Pilocarpaceae	Typical foliicolous
SPOPH	*Sporopodium phyllocharis* (Mont.) Massal.	Pilocarpaceae	Typical foliicolous
SPOPI	*Sporopodium pilocarpoides* (Zahlbr.) Lücking & Kalb	Pilocarpaceae	Typical foliicolous
STRAN	*Strigula antillarum* (Fée) Müll. Arg.	Strigulaceae	Typical foliicolous
STRJA	*Strigula janeriensis* (Müll. Arg.) Lücking	Strigulaceae	Typical foliicolous
STRMA	*Strigula macrocarpa* Vain.	Strigulaceae	Typical foliicolous
STRMC	*Strigula maculata* (Cooke & Massee) R. Sant.	Strigulaceae	Typical foliicolous
STRMI	*Strigula microspora* Lücking	Strigulaceae	Typical foliicolous
STRMU	*Strigula multipunctata* (G. Merr. ex R. Sant.) R. C. Harris	Strigulaceae	Typical foliicolous
STRHY	*Strigula nemathora* var. *hypothelia* (Nyl.) R. Sant.	Strigulaceae	Typical foliicolous
STRNE	*Strigula nemathora* Mont.	Strigulaceae	Typical foliicolous
STRNI	*Strigula nitidula* Mont.	Strigulaceae	Typical foliicolous
STROB	*Strigula obducta* (Müll. Arg.) R. C. Harris	Strigulaceae	Typical foliicolous
STRPH	*Strigula phyllogena* (Müll. Arg.) R. C. Harris	Strigulaceae	Typical foliicolous
STRSC	*Strigula schizospora* R. Sant.	Strigulaceae	Typical foliicolous
STRSM	*Strigula smaragdula* Fr.	Strigulaceae	Typical foliicolous
STRST	*Strigula subtilissima* (Fée) Müll. Arg.	Strigulaceae	Typical foliicolous
TAPMO	*Tapellaria molleri* (Lücking) Lücking	Pilocarpaceae	Typical foliicolous
TAPNI	*Tapellaria nigrata* (Müll. Arg.) R. Sant.	Pilocarpaceae	Typical foliicolous

Species acronym	**Species**	**Family**	**Growth habit**
TRINI	*Tricharia nigriuncinata* sp.nov.	Gomphillaceae	Typical foliicolous
TRIVA	*Tricharia vainioi* R. Sant.	Gomphillaceae	Typical foliicolous
TRIAF	*Trichothelium africanum* Lücking	Porinaceae	Typical foliicolous
TRIAL	*Trichothelium alboatrum* Vain.	Porinaceae	Typical foliicolous
TRIEP	*Trichothelium epiphyllum* Müll. Arg.	Porinaceae	Typical foliicolous
TRISP	*Trichothelium minutum* (Lücking) Lücking	Porinaceae	Typical foliicolous
TRIPA	*Trichothelium pauciseptatum* Vezda	Porinaceae	Typical foliicolous

Appendix 3 Foliicolous lichens and lichenicolous fungi from Kakamega Forest

Species acronym	Species	Family	Growth habit
ADEDI	*Aderkomyces dilatatus* (Vezda) Lücking, Serusiaux & Vezda	Gomphillaceae	Typical foliicolous
ARTAT	*Arthonia atropunctata* Vain.	Arthoniaceae	Lichenicolous fungi
ARTFL	*Arthonia flavoverrucosa* U. Becker & Lücking	Arthoniaceae	Typical foliicolous
ARTFU	*Arthonia fuscocyanea* U. Becker & Lücking	Arthoniaceae	Typical foliicolous
ARTLI	*Arthonia lividula* Vain.	Arthoniaceae	Typical foliicolous
ARTOR	*Arthonia orbygniae* (H. B. P. Upadhyay) Matzer	Arthoniaceae	Typical foliicolous
ASPFU	*Aspidothelium fugiens* (Müll. Arg.) R. Sant.	Aspidotheliaceae	Typical foliicolous
ASPGE	*Aspidothelium geminiparum* (Malme) R. Sant.	Aspidotheliaceae	Typical foliicolous
ASPHI	*Aspidothelium hirustum* sp. nov.	Aspidotheliaceae	Typical foliicolous
ASPSC	*Aspidothelium scutelicarpum* Lücking	Aspidotheliaceae	Typical foliicolous
ASTAU	*Asterothyrium aulaxinoides* Lücking	Asterothyriaceae	Typical foliicolous
ASTLE	*Asterothyrium leucophthalmum* (Müll. Arg.) R. Sant.	Asterothyriaceae	Typical foliicolous
ASTMI	*Asterothyrium microsporum* R. Sant.	Asterothyriaceae	Typical foliicolous
ASTPI	*Asterothyrium pittieri* Müll. Arg.	Asterothyriaceae	Typical foliicolous
ASTRO	*Asterothyrium rotuliforme* (Müll. Arg.) Sérus.	Asterothyriaceae	Typical foliicolous
ASTSE	*Asterothyrium septemseptatum* ssp. africanum Lücking & Kalb	Asterothyriaceae	Typical foliicolous
ASTSP	*Asterothyrium* sp.	Asterothyriaceae	Typical foliicolous
AULEP	*Aulaxina epiphylla* (Zahlbr.) R. Sant.	Gomphillaceae	Typical foliicolous
AULMI	*Aulaxina opegraphina* Fée	Gomphillaceae	Typical foliicolous
AULOP	*Bacidia medialis* (Tuck. ex Nyl.) de Lesd.	Ramalinaceae	Facultative foliicolous
BACAP	*Bacidina apiahica* (Müll. Arg.) Vezda	Ramalinaceae	Typical foliicolous
BACMI	*Bacidina mirabilis* (Vezda) Vezda	Ramalinaceae	Typical foliicolous
BACPA	*Bacidina pallidocarnea* (Müll. Arg.) Vezda	Ramalinaceae	Typical foliicolous
BACSI	*Bacidina simplex* Farkas & Vezda	Ramalinaceae	Typical foliicolous
BADDI	*Badimia dimidiata* (C. Bab. ex Leight.) Vezda	Pilocarpaceae	Typical foliicolous

Species acronym	Species	Family	Growth habit
BAPIV	*Bapalmuia ivoriensis* R. Sant. & Lücking	Pilocarpaceae	Typical foliicolous
BIASP	*Biatora* sp.	Bacidiaceae	Facultative foliicolous
BRADI	*Brasilicia dimerelloides* (Vezda) Lücking, Kalb & Sérus.	Pilocarpaceae	Typical foliicolous
BRAFO	*Brasilicia foliicola* (Vezda) Lücking, Kalb & Sérus.	Pilocarpaceae	Typical foliicolous
BYSDE	*Byssolecania deplanata* (Müll. Arg.) R. Sant.	Pilocarpaceae	Typical foliicolous
BYSHY	*Byssolecania hymenocarpa* (Vain.) Kalb, Vezda & Lücking	Pilocarpaceae	Typical foliicolous
BYSVA	*Byssolecania variabilis* (Vain.) Kalb, Vezda & Lücking	Pilocarpaceae	Typical foliicolous
BYSCH	*Byssoloma chlorinum* (Vain.) Zahlbr.	Pilocarpaceae	Typical foliicolous
BYSLE	*Byssoloma leucoblepharum* (Nyl.) Vain.	Pilocarpaceae	Typical foliicolous
BYSSU	*Byssoloma subdiscordans* (Nyl.) P. James	Pilocarpaceae	Typical foliicolous
CALAS	*Calenia aspidota* (Vain.) Vezda	Gomphillaceae	Typical foliicolous
CALBU	*Calenia bullatinoides* Lücking	Gomphillaceae	Typical foliicolous
CALDE	*Calenia depressa* Müll. Arg.	Gomphillaceae	Typical foliicolous
CALGR	*Calenia graphidea* Vain.	Gomphillaceae	Typical foliicolous
CALMO	*Calenia monospora* Vezda	Gomphillaceae	Typical foliicolous
CALSP	*Calenia* sp.	Gomphillaceae	
CALTH	*Calenia thelotremela* Vain.	Gomphillaceae	Typical foliicolous
CALFU	*Calopadia fusca* (Müll. Arg.) Vezda	Pilocarpaceae	Typical foliicolous
CALPU	*Calopadia puiggarii* (Müll. Arg.) Vezda	Pilocarpaceae	Typical foliicolous
CALSC	*Calopadia subcoerulescens* (Zahlbr.) Vezda	Pilocarpaceae	Typical foliicolous
CHRAU	*Chroodiscus australiensis* Vezda & Lumbsch	Thelotremataceae	Typical foliicolous
CHRKA	*Chroodiscus kakamegensis* sp. nov.	Thelotremataceae	Typical foliicolous
CHRVE	*Chroodiscus verrucosus* R. Sant., Lücking & Vezda	Thelotremataceae	Typical foliicolous
COCST	*Coccocarpia stellata* Tuck.	Coccocarpiaceae	Facultative foliicolous
COEDI	*Coenogonium dilucidum* (Kremp.) Kalb & Lücking	Coenogoniaceae	Typical foliicolous
COEFA	*Coenogonium fallaciosum* (Müll. Arg.) Kalb & Lücking	Coenogoniaceae	Typical foliicolous
COEFL	*Coenogonium flavum* (Malcom & Vezda) Lücking	Coenogoniaceae	Typical foliicolous
COEGE	*Coenogonium geralense* (P.Henn) Lücking	Coenogoniaceae	Typical foliicolous

Species acronym	Species	Family	Growth habit
COELI	*Coenogonium lisowskii* (Vezda) Lücking	Coenogoniaceae	Typical foliicolous
COEPO	*Coenogonium pocsii* (Vezda & Farkas) Lücking	Coenogoniaceae	Typical foliicolous
COESI	*Coenogonium siquirrense* (Lücking) Lücking	Coenogoniaceae	Typical foliicolous
COESP	*Coenogonium* sp.	Coenogoniaceae	Typical foliicolous
COESD	*Coenogonium subdilucidum* (Vezda) Lücking	Coenogoniaceae	Typical foliicolous
COESF	*Coenogonium subfallaciosum* (Vezda & Farkas) Lücking	Coenogoniaceae	Typical foliicolous
COESL	*Coenogonium subluteum* (Rehm) Kalb & Lücking	Coenogoniaceae	Typical foliicolous
COEUS	*Coenogonium usambarense* (Vezda & Farkas) Lücking & Kalb	Coenogoniaceae	Typical foliicolous
COEZO	*Coenogonium zonatum* (Müll. Arg.) Kalb & Lücking	Coenogoniaceae	Typical foliicolous
ECHDI	*Echinoplaca diffluens* (Müll. Arg.) R. Sant.	Gomphillaceae	Typical foliicolous
ECHPE	*Echinoplaca pellicula* (Müll. Arg.) R. Sant.	Gomphillaceae	Typical foliicolous
ENTFE	*Enterographa fellhaneroides* sp.nov.	Roccellaceae	Typical foliicolous
ENTME	*Enterographa meklitiae* sp.nov.	Roccellaceae	Typical foliicolous
ERECA	*Eremothecella calamicola* Syd.	Arthoniaceae	Typical foliicolous
FELBU	*Fellhanera bouteillei* (Desm.) Vezda	Pilocarpaceae	Ubiquotus
FELBU	*Fellhanera* aff. *bouteillei*	Pilocarpaceae	
FELEN	*Fellhanera encephalarti* (Vezda) Vezda	Pilocarpaceae	Typical foliicolous
FELPA	*Fellhanera paradoxa* (Vezda) Vezda	Pilocarpaceae	Typical foliicolous
FELPR	*Fellhanera parvula* (Vezda) Vezda	Pilocarpaceae	Typical foliicolous
FELRH	*Fellhanera rhaphidophylli* (Rehm) Vezda	Pilocarpaceae	Typical foliicolous
FELSF	*Fellhanera subfuscatula* Lücking	Pilocarpaceae	Typical foliicolous
FELSL	*Fellhanera sublecanorina* (Nyl.) Vezda	Pilocarpaceae	Typical foliicolous
FELSM	*Fellhanera submicrommata* (Vezda) Lücking & Kalb	Pilocarpaceae	Typical foliicolous
GYACA	*Gyalectidium caucasicum* (Elenk. & Woron.) Vezda	Gomphillaceae	Typical foliicolous
GYAES	*Gyalectidium eskuchei* Sérus.	Gomphillaceae	Typical foliicolous
GYAFI	*Gyalectidium filicinum* Müll. Arg.	Gomphillaceae	Typical foliicolous
GYAFU	*Gyalectidium fuscum* Lücking & Sérus.	Gomphillaceae	Typical foliicolous

Species acronym	Species	Family	Growth habit
GYAIM	*Gyalectidium imperfectum* Vezda	Gomphillaceae	Typical foliicolous
GYAEP	*Gyalidea epiphylla* Vezda	Asterothyriaceae	Typical foliicolous
GYAPS	*Gyalidea psorotheciopides* sp. nov.	Asterothyriaceae	Typical foliicolous
GYACO	*Gyalideopsis cochlearifer* Lücking & Sérus.	Gomphillaceae	Lichenicolous fungi
LASAR	*Lasioloma arachnoideum* (Kremp.) R. Sant.	Pilocarpaceae	Typical foliicolous
LICEP	*Lichenopeltella epiphylla* R. Sant.	Microthyriaceae	Lichenicolous fungi
LOFEP	*Loflammia epiphylla* (Fée) Lücking & Vezda	Pilocarpaceae	Typical foliicolous
LYRNE	*Lyromma nectandrae* Bat. & H. Maia	Lyrommataceae	Typical foliicolous
MAZME	*Mazosia melanopthalma* (Müll. Arg.) R. Sant.	Roccellaceae	Typical foliicolous
MUSKA	*Musaespora kalbii* Lücking & Sérus.	Monoblastiaceae	Typical foliicolous
OPEEP	*Opegrapha epiporina* Matzer	Roccellaceae	Lichenicolous fungi
OPEPH	*Opegrapha phylloporinae* Müll. Arg.	Roccellaceae	Lichenicolous fungi
OPESP	*Opegrapha* sp.	Roccellaceae	Lichenicolous fungi
OPEVE	*Opegrapha velata* (Müll. Arg.) Vain.	Roccellaceae	Lichenicolous fungi
PHYPO	*Phylloblastia pocsii* (Farkas & Vezda) Lücking	Verrucariaceae	Typical foliicolous
PHYSP	*Phyllospora* sp.	Bacidiaceae	Facultative foliicolous
PORAT	*Porina atrocoerulea* Müll. Arg.	Porinaceae	Typical foliicolous
PORCF	*Porina* cf. *triseptata* (Vezda) Lücking	Porinaceae	Typical foliicolous
PORCU	*Porina cupreola* (Müll. Arg.) F. Schill. var. *cupreola*	Porinaceae	Typical foliicolous
PORDI	*Porina distans* Vezda & Vivant	Porinaceae	Typical foliicolous
POREP	*Porina epiphylla* (Fée) Fée	Porinaceae	Typical foliicolous
PORED	*Porina epiphylloides* Vezda	Porinaceae	Typical foliicolous
PORKA	*Porina kamerunensis* F. Schill.	Porinaceae	Typical foliicolous
PORLE	*Porina leptosperma* Müll. Arg.	Porinaceae	Typical foliicolous
PORLI	*Porina limbulata* (Kremp.) Vain.	Porinaceae	Typical foliicolous
PORLU	*Porina lucida* R. Sant. var. *lucida*	Porinaceae	Typical foliicolous
PORMA	*Porina mazosoides* Lücking & *Vezda*	Porinaceae	Typical foliicolous
PORNI	*Porina nitidula* Müll. Arg.	Porinaceae	Typical foliicolous

Species acronym	Species	Family	Growth habit
PORPA	*Porina pallescens* R. Sant.	Porinaceae	Typical foliicolous
PORRB	*Porina rubentior* (Stirt.) Müll. Arg.	Porinaceae	Typical foliicolous
PORRF	*Porina rubescens* (Lücking) Hafellner & Kalb	Porinaceae	Typical foliicolous
PORRU	*Porina rufula* (Kremp.) Vain.	Porinaceae	Typical foliicolous
PORSE	*Porina semicarpi* Vain.	Porinaceae	Typical foliicolous
PORSH	*Porina sphaerocephaloides* Farkas	Porinaceae	Typical foliicolous
PORSP	*Porina subpallescens*Vezda	Porinaceae	Typical foliicolous
PORTE	*Porina tetramera* (Malme) R. Sant.	Porinaceae	Typical foliicolous
PORTR	*Porina trichothelioides* R. Sant.	Porinaceae	Typical foliicolous
PSOGY	*Psorotheciopsis gyalideoides* (Vezda) Henssen & Lücking	Asterothyriaceae	Typical foliicolous
PSOPA	*Psorotheciopsis patellarioides* (Rehm) R. Sant.	Asterothyriaceae	Typical foliicolous
PSOVA	*Psorotheciopsis varieseptata* (Vezda) Henssen & Lücking	Asterothyriaceae	Typical foliicolous
SPOAN	*Sporopodium antonianum* Elix, Lumbsch & Lücking	Pilocarpaceae	Typical foliicolous
SPOLE	*Sporopodium leprieurii* Mont.	Pilocarpaceae	Typical foliicolous
SPOPI	*Sporopodium pilocarpoides* (Zahlbr.) Lücking & Kalb	Pilocarpaceae	Typical foliicolous
SPOSP	*Sporopodium* sp.	Pilocarpaceae	
STRAN	*Strigula antillarum* (Fée) Müll. Arg.	Strigulaceae	Typical foliicolous
STRCO	*Strigula concreta* (Fée) R. Sant.	Strigulaceae	Typical foliicolous
STRJA	*Strigula janeriensis* (Müll. Arg.) Lücking	Strigulaceae	Typical foliicolous
STRMA	*Strigula macrocarpa* Vain.	Strigulaceae	Typical foliicolous
STRMC	*Strigula maculata* (Cooke & Massee) R. Sant.	Strigulaceae	Typical foliicolous
STRME	*Strigula melanobapha* (Kremp.) R. Sant.	Strigulaceae	Typical foliicolous
STRMI	*Strigula microspora* Lücking	Strigulaceae	Typical foliicolous
STRMU	*Strigula nemathora* var. *hypothelia* (Nyl.) R. Sant.	Strigulaceae	Typical foliicolous
STRNE	*Strigula nemathora* Mont.	Strigulaceae	Typical foliicolous
STRNI	*Strigula nitidula* Mont.	Strigulaceae	Typical foliicolous
STROB	*Strigula obducta* (Müll. Arg.) R. C. Harris	Strigulaceae	Typical foliicolous
STRPH	*Strigula phyllogena* (Müll. Arg.) R. C. Harris	Strigulaceae	Typical foliicolous

Acronym	Species	Family	Growth habit
STRSC	*Strigula schizospora* R. Sant.	Strigulaceae	Typical foliicolous
STRSM	*Strigula smaragdula* Fr.	Strigulaceae	Typical foliicolous
STRST	*Strigula subtilissima* (Fée) Müll. Arg.	Strigulaceae	Typical foliicolous
TAPEP	*Tapellaria epiphylla* (Müll. Arg.) R. Sant.	Pilocarpaceae	Typical foliicolous
TAPNI	*Tapellaria nigrata* (Müll. Arg.) R. Sant.	Pilocarpaceae	Typical foliicolous
TRIVA	*Tricharia vainioi* R. Sant.	Gomphillaceae	Typical foliicolous
TRIAF	*Trichothelium africanum* Lücking	Porinaceae	Typical foliicolous
TRIEP	*Trichothelium epiphyllum* Müll. Arg.	Porinaceae	Typical foliicolous
TRIMI	*Trichothelium minutum* (Lücking) Lücking	Porinaceae	Typical foliicolous
TRIPA	*Trichothelium pauciseptatum* Vezda	Porinaceae	Typical foliicolous

Appendix 4. Distribution of foliicolous lichens in the forest sites of Godere, Budongo and Kakamega.

1 = presence, 0 = absence. * = new to Africa, ** new to science

Species acronym	**Species**	**Bishan Waka**	**Bukhaywa**	**Buyangu**	**Busambuli**	**Camp site**	**Colobus**	**Dushi**	**Ghostislanid**	**Ikuywa**	**Isecheno**	**Isikuhu**	**Kaimosi**	**Kisere**	**Malava**	**Salazar**	**Yala**	**Old secondary**	**Primary**	**Swamp**	**Young secondary**
ADEDI	*Aderkomyces dilatatus*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
ARTAT	*Arthonia atropunctata*	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
ARTFL	*Arthonia flavoverrucosa*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARTFU	*Arthonia fuscocyanea*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARTLI	*Arthonia lividula*	0	0	0	1	0	0	1	0	1	1	1	0	0	1	0	1	1	1	0	1
ARTOR	*Arthonia orbygniae*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0
ASPFU	*Aspidothelium fugiens*	1	0	1	0	0	0	1	0	1	0	1	0	0	0	1	1	0	1	0	1
ASPGE	**Aspidothelium geminiparum*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
ASPHI	**Aspidothelium scutelicarpum*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
ASPSC	***Aspidothelium hirsutum* sp. nov.	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
ASTAU	*Asterothyrium aulaxinoides*	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASTLE	*Asterothyrium leucophthalmum*	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASTMI	*Asterothyrium microsporum*	0	0	0	1	0	0	1	0	0	0	1	0	1	1	1	0	1	1	1	1
ASTMO	*Asterothyrium monosporum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
ASTOC	*Asterothyrium octomerum*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
ASTPI	*Asterothyrium pittieri*	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
ASTRO	*Asterothyrium rotuliforme*	1	0	1	0	1	0	1	1	0	0	0	1	1	1	0	0	0	0	0	1
ASTSE	*Asterothyrium septemseptatum*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
ASTSP	*Asterothyrium* sp.	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AULEP	*Aulaxina epiphylla*	0	0	1	0	1	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0
AULMI	*Aulaxina microphana*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
AULOP	*Aulaxina opegraphina*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
BACAP	*Bacidia medialis*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
BACME	*Bacidina apiahica*	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	1	1
BACMI	*Bacidina mirabilis*	0	0	1	0	0	0	1	0	1	0	0	0	1	0	1	0	1	1	1	0

Species acronym	Species	Bishan Waka	Bukhaywa	Buyangu	Busambuli	Camp site	Colobus	Dushi	Ghostislanid	Ikuywa	Isecheno	Isikuhu	Kaimosi	Kisere	Malava	Salazar	Yala	Old secondary	Primary	Swamp	Young secondary
BACPA	*Bacidina pallidocarnea*	1	1	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0
BACSI	*Bacidina simplex*	0	1	1	0	0	1	0	0	1	1	1	0	1	1	1	0	1	1	0	1
BADDI	*Badimia dimidiata*	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
BAPIV	*Bapalmuia ivoriensis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0
BAPPA	*Bapalmuia palmularis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
BRADI	*Brasilicia dimerelloides*	0	1	1	0	0	0	0	0	1	0	0	0	0	0	1	1	1	1	1	1
BRAFO	*Brasilicia foliicola*	0	0	0	0	0	0	1	0	1	1	1	1	1	0	1	1	1	1	1	1
BYSCH	*Byssolecania deplanata*	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	1	1	1	1
BYSDE	*Byssolecania fumosonigricans*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
BYSFU	*Byssolecania hymenocarpa*	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	1	1	1
BYSHY	*Byssolecania variabilis*	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	1	0	1
BYSLE	*Byssoloma chlorinum*	0	1	0	1	0	1	1	0	1	0	1	0	1	1	0	1	1	1	1	1
BYSSD	*Byssoloma leucoblepharum*	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1
BYSSP	*Byssoloma subdiscordans*	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
BYSVA	*Byssoloma subpolychromum*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1
CALAS	*Calenia aspidota*	0	0	1	1	1	0	0	1	1	1	1	1	0	0	1	1	0	0	1	1
CALBU	*Calenia bullatinoides*	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1
CALDE	*Calenia depressa*	0	1	1	1	1	0	0	0	1	0	1	0	0	0	1	1	0	1	1	1
CALGR	*Calenia graphidea*	0	0	1	1	0	0	0	0	1	0	1	0	1	0	1	1	0	1	1	1
CALMO	*Calenia monospora*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
CALTH	*Calenia thelotremela*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
CALTR	**Calenia triseptata*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
CALFU	*Calopadia fusca*	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
CALPH	*Calopadia phyllogena*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
CALPU	*Calopadia puiggarii*	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
CALSC	*Calopadia subcoerulescens*	0	0	0	1	0	0	0	0	1	1	1	1	0	0	1	1	0	0	0	0
CAPGO	***Caprettia goderei* sp. nov.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
CHEVE	*Chroodiscus australiensis*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1
CHRAU	***Chroodiscus kakamegensis* sp. nov.	0	0	1	0	0	0	1	1	0	1	0	1	1	1	1	0	0	1	0	0
CHRKA	*Chroodiscus verrucosus*	1	0	1	1	1	0	1	1	1	1	1	0	1	1	1	1	0	1	1	1

Species acronym	**Species**	**Bishan Waka**	**Bukhaywa**	**Buyangu**	**Busambuli**	**Camp site**	**Colobus**	**Dushi**	**Ghostislanid**	**Ikuywa**	**Isecheno**	**Isikuhu**	**Kaimosi**	**Kisere**	**Malava**	**Salazar**	**Yala**	**Old secondary**	**Primary**	**Swamp**	**Young secondary**
COCST	*Coccocarpia stellata*	1	0	0	1	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	1
COEBA	**Coenogonium barbatum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
COEDI	*Coenogonium dilucidum*	0	0	1	0	0	0	1	0	1	0	1	0	1	0	1	1	1	1	1	1
COEFA	*Coenogonium fallaciosum*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0
COEFL	**Coenogonium flavum*	0	1	0	1	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0
COEGE	*Coenogonium geralense*	0	1	1	1	0	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1
COELI	*Coenogonium lisowskii*	0	1	0	1	0	1	0	0	1	1	1	0	1	1	1	1	0	0	1	1
COEPA	**Coenogonium pannosum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
COEPO	*Coenogonium pocsii*	0	0	1	0	0	1	0	0	1	1	1	0	1	0	1	1	1	1	1	1
COESI	**Coenogonium siquirrense*	0	0	0	0	0	1	0	0	1	1	0	1	1	0	1	1	1	0	1	1
COESD	*Coenogonium subdilucidum*	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	1	0	1	1	1
COESF	*Coenogonium subfallaciosum*	0	0	1	0	0	0	0	1	0	1	1	0	1	0	1	1	0	0	1	1
COESL	*Coenogonium subluteum*	0	0	1	1	0	1	1	0	1	0	1	1	1	0	1	1	1	1	1	1
COEUS	*Coenogonium usambarense*	0	0	1	0	0	0	1	0	1	0	0	1	1	0	1	1	1	1	1	1
COEZO	*Coenogonium zonatum*	0	0	1	0	0	1	0	1	0	0	0	1	1	0	1	1	1	0	1	1
ECHDI	*Echinoplaca diffluens*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1
ECHPE	*Echinoplaca pellicula*	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	1	1	1
ENTFE	***Enterographa fellhaneroides* sp.nov.	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
ENTME	***Enterographa meklitiae* sp.nov.	0	0	0	1	0	1	0	0	1	1	0	0	1	0	0	0	0	0	0	0
ERECA	*Eremothecella calamicola*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
EUGWE	*Eugeniella wettsteinii*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
FELAF	*Fellhanera africana*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
FELAU	*Fellhanera aurantiaca*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
FELBU	*Fellhanera bouteillei*	1	1	1	1	1	0	1	0	1	0	1	1	1	1	0	1	0	1	0	1
FELEN	*Fellhanera encephalarti*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
FELPA	*Fellhanera paradoxa*	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	1
FELPR	*Fellhanera parvula*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FELRH	*Fellhanera rhaphidophylli*	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0
FELSF	*Fellhanera subfuscatula*	0	0	1	1	0	0	1	0	0	0	1	0	1	0	1	1	0	0	1	1
FELSL	*Fellhanera sublecanorina*	1	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0

Species acronym	Species	Bishan Waka	Bukhaywa	Buyangu	Busambuli	Camp site	Colobus	Dushi	Ghostislanid	Ikuywa	Isecheno	Isikuhu	Kaimosi	Kisere	Malava	Salazar	Yala	Old secondary	Primary	Swamp	Young secondary
FELSM	*Fellhanera submicrommata*	0	0	0	1	0	0	1	0	0	0	0	1	1	0	0	0	1	1	1	1
GYACA	*Gyalectidium caucasicum*	0	1	1	1	0	0	0	0	1	1	1	0	1	0	1	1	0	0	1	0
GYAES	*Gyalectidium eskuchei*	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
GYAFI	*Gyalectidium filicinum*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
GYAFU	*Gyalectidium fuscum*	1	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
GYAIM	*Gyalectidium imperfectum*	1	0	0	0	1	0	1	0	1	0	1	1	0	1	0	0	1	1	1	1
GYAMI	*Gyalectidium microcarpum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
GYAEP	*Gyalidea epiphylla*	1	1	0	0	0	1	1	0	0	1	1	0	1	0	0	1	0	1	1	1
GYAPS	***Gyalidea psorothecioides* sp. nov.	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
GYACO	*Gyalideopsis cochlearifer*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
LASAR	*Lasioloma arachnoideum*	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
LICEP	*Lichenopeltella epiphylla*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0
LOFEP	*Loflammia epiphylla*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
LYRNE	*Lyromma nectandrae*	0	1	1	0	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
MAZDI	*Mazosia dispersa*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
MAZME	*Mazosia melanopthalma*	0	1	1	0	0	1	0	0	1	0	1	0	1	0	1	1	1	1	1	1
MAZPA	*Mazosia paupercula*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
MAZPH	*Mazosia phyllosema*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
MAZRO	*Mazosia rotula*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
MUSKA	*Musaespora kalbii*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OPEEP	*Opegrapha epiporina*	0	1	1	0	0	0	0	0	0	0	1	1	0	0	1	0	1	0	1	1
OPEMA	*Opegrapha mazosiae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
OPEPH	*Opegrapha phylloporinae*	0	1	1	1	0	1	0	0	1	1	1	1	1	1	0	1	1	0	1	1
OPESP	*Opegrapha* sp.	0	1	0	1	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	1
OPEVE	*Opegrapha velata*	0	1	0	1	0	1	1	0	0	0	1	1	1	0	0	0	0	0	0	0
PHYPO	*Phylloblastia pocsii*	1	1	0	0	0	1	0	0	0	1	0	0	1	0	1	0	0	0	0	0
PORAL	*Porina alba*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
PORAT	*Porina atrocoerulea*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
PORCF	*Porina* cf. *triseptata*	1	1	0	0	0	0	1	0	0	0	0	0	1	1	1	1	0	1	0	1
PORCO	*Porina conica*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1

Species acronym	Species	Bishan Waka	Bukhaywa	Buyangu	Busambuli	Camp site	Colobus	Dushi	Ghostislanid	Ikuywa	Isecheno	Isikuhu	Kaimosi	Kisere	Malava	Salazar	Yala	Old secondary	Primary	Swamp	Young secondary
PORCU	*Porina cupreola* var. *cupreola*	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
PORDI	*Porina distans*	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
PORED	*Porina epiphylla*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
POREP	*Porina epiphylloides*	0	0	1	1	0	0	0	0	0	1	1	0	1	0	1	1	0	1	1	1
PORKA	*Porina kamerunensis*	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	1
PORLE	*Porina leptosperma*	1	0	1	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1	1	1
PORLI	*Porina limbulata*	0	0	1	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	1
PORLU	*Porina lucida* var. *lucida*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PORMA	*Porina mazosoides*	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0
PORNI	*Porina nitidula*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PORPA	*Porina pallescens*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
PORRA	*Porina radiata*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
PORRB	*Porina rubentior*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PORRF	*Porina rubescens*	0	0	0	0	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
PORRU	*Porina rufula*	0	0	1	0	0	0	1	0	0	1	0	1	0	1	1	0	1	1	1	0
PORSE	*Porina semicarpi*	0	0	1	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	1	1
PORSH	*Porina sphaerocephala*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
PORSP	*Porina sphaerocephaloides*	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1
PORSU	*Porina subpallescens*	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
PORTE	*Porina tetramera*	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	1
PORTR	*Porina trichothelioides*	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	1
PSOGY	*Psorotheciopsis gyalideoides*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PSOPA	*Psorotheciopsis patellarioides*	1	1	0	0	1	1	0	1	1	0	0	0	1	1	0	0	0	0	1	1
PSOVA	*Psorotheciopsis varieseptata*	0	0	1	1	1	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0
SPOAN	*Sporopodium antonianum*	0	0	1	0	0	0	1	0	1	0	0	1	0	0	1	1	0	1	1	1
SPOLE	*Sporopodium leprieurii*	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	1	0	1	1	1
SPOPH	*Sporopodium phyllocharis*	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
SPOPI	*Sporopodium pilocarpoides*	0	0	1	0	0	0	0	0	1	0	1	0	0	0	1	1	0	1	1	0
STRAN	*Strigula antillarum*	0	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1
STRCO	*Strigula concreta*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0

Species acronym	Species	Bishan Waka	Bukhaywa	Buyangu	Busambuli	Camp site	Colobus	Dushi	Ghostislanid	Ikuywa	Isecheno	Isikuhu	Kaimosi	Kisere	Malava	Salazar	Yala	Old secondary	Primary	Swamp	Young secondary
STRHY	*Strigula janeriensis*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1
STRJA	*Strigula macrocarpa*	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
STRMA	*Strigula maculata*	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
STRMC	*Strigula melanobapha*	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
STRME	**Strigula microspora*	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
STRMI	*Strigula multipunctata*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
STRMU	*Strigula nemathora* var. *hypothelia*	1	1	1	1	0	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1
STRNE	*Strigula nemathora* var. *nemathora*	1	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	1	1
STRNI	*Strigula nitidula*	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
STROB	*Strigula obducta*	0	1	1	1	0	1	0	0	1	1	1	0	1	1	1	1	1	1	1	0
STRPH	*Strigula phyllogena*	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
STRSC	*Strigula schizospora*	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
STRSM	*Strigula smaragdula*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
STRST	*Strigula subtilissima*	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1	1	1	1	1
TAPBI	*Tapellaria bilimbioides*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
TAPEP	*Tapellaria epiphylla*	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
TAPMO	*Tapellaria molleri*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
TAPNI	*Tapellaria nigrata*	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
TRINI	***Tricharia nigriuncinata* sp.nov.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
TRIVA	*Tricharia vainioi*	0	0	1	1	0	0	0	0	1	0	1	1	0	0	1	1	0	1	1	1
TRIAF	**Trichothelium africanum*	1	0	1	1	0	1	1	1	1	0	1	1	0	0	0	0	1	1	1	1
TRIAL	*Trichothelium alboatrum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
TRIEP	*Trichothelium epiphyllum*	1	1	1	0	0	1	1	0	0	0	1	0	0	0	0	0	1	1	1	1
TRISP	**Trichothelium minutum*	1	1	1	1	1	0	1	1	1	0	0	0	0	1	0	0	0	0	0	1
TRIPA	*Trichothelium pauciseptatum*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

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