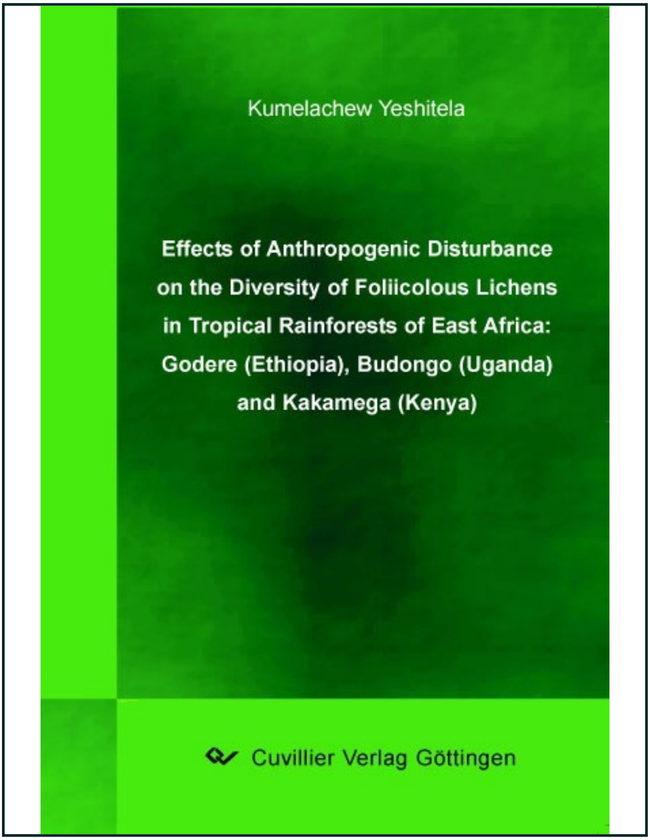
Kumelachew Yeshitela (Autor)

Effects of nithropogenic disturbance on the diversity of foliicolous lichens in tropical rainforests of East Africa: Godere (Ethiopia), Budongo (Uganda) and Kakamega (Kenya)



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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).

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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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