ABSTRACT

MUNISHI K. T. PANTALEO. The Eastern Arc Mountain Forests of Tanzania: Their Role in Biodiversity, Water Resource Conservation, and Net Contribution to Atmospheric Carbon. (Under the direction of Theodore H. Shear)

Mountain forests play major ecological and environmental roles. This study evaluated the roles of the Eastern Arc Mountain forests of Tanzania in conservation of biodiversity, water resources, and net contribution to atmospheric carbon. The major objectives were three-fold: (1) the classification and description of plant community composition, diversity patterns, and their environmental correlates, (2) assessment of biomass and carbon pool in the phytomass and soils, (3) assessment of rainfall interception throughfall, stemflow, streamflow, and their correlation with rainfall.

Data on vegetation, topography, soils, and hydrology were collected from the Usambara and Uluguru ranges. Using cluster analyses, Non-metric Multidimensional Scaling (NMS) ordination, and indicator species analyses, five different plant communities were identified on each range. These communities were associated with two topographic and fourteen edaphic factors. Elevation was the strongest correlate of community composition in individual ranges, followed by several edaphic factors. Landform index and soil sodium concentration [Na] play major roles in separating plant communities between different mountain ranges. The proportions of rare species were high raising a conservation concern as to whether this is evidence of species' declines or a biological characteristic. The forests have tremendous capacity for C storage both in the phytomass (517 ± 17 t ha^{-1} in the Usambaras and 384 ± 10 t ha^{-1} in the Ulugurus), and in the soil (420 ± 100 t ha^{-1} in the Usambaras and 290 ± 53 t ha^{-1} in the Ulugurus). Phytomass C was higher in mid elevation communities while high elevation communities had higher soil carbon, and total carbon. Rainfall interception was 23% in the Usambaras and 20% in the Ulugurus. Throughfall was more than 76% in both forests and stemflow was less than 2%. Streamflow was best modeled using three or more months running mean rainfall. The results suggest that plant community patterns in the Eastern Arc are associated with a complex of topographic and edaphic factors. This complex of factors is an important consideration in restoration and conservation programs. Attention to rare species is especially important. The forests have

substantial capacity for carbon emission mitigation. The slow response in streamflow to rainfall events shows the efficiency of the forests to store water, mitigate storm water impacts by reducing runoff, delaying onset of peak flows, and ensuring constant water supplies.

THE EASTERN ARC MOUNTAIN FORESTS OF TANZANIA:

Their Role in Biodiversity, Water Resource Conservation, and Net Contribution to Atmospheric Carbon.

By

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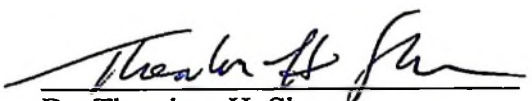

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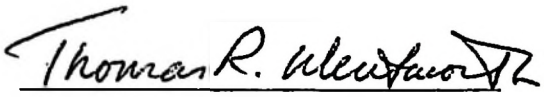

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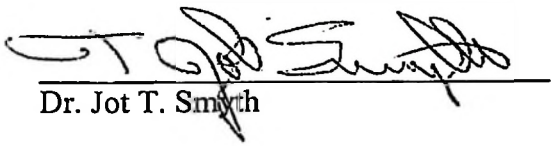

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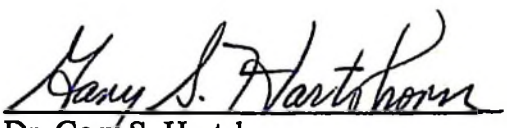

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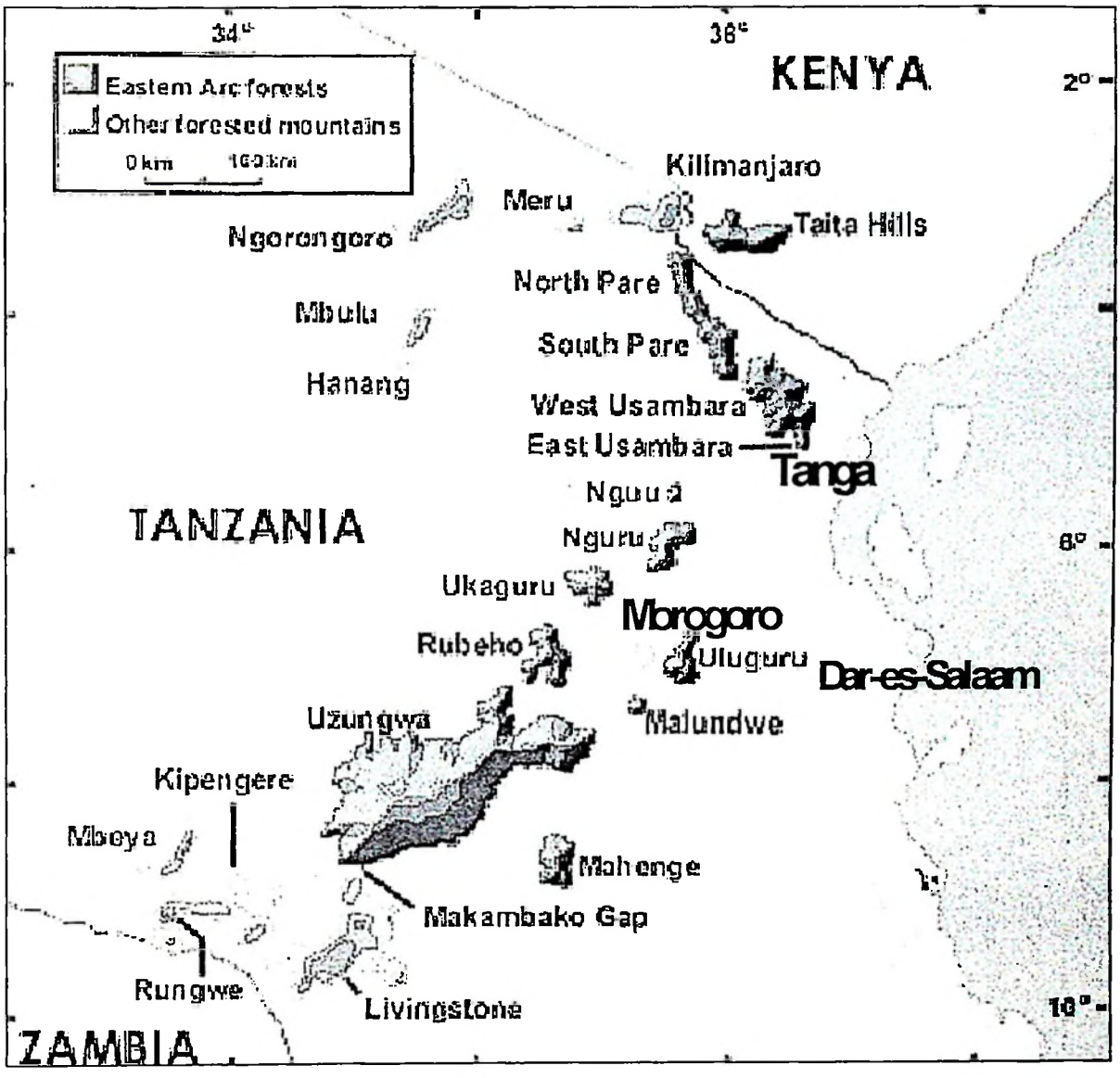

A map of Tanzania showing the most important Eastern Arc Mountains with rain forests (Source: The Forest Health Project, Eastern Arc Mountain Forests, 1999)

for my Mother (Bernadetha, Nkasumaili Makiwali) ..... for everything ..... she is the source of all my achievements!!

for my family Ruwa, Grace, Boney .....
their patience was all my strength!!

BIOGRAPHY

Munishi Pantaleo received his Diploma in Forestry from the Forestry Training Institute (FTI) Arusha, Tanzania in 1981, his undergraduate degree in Forestry from the Sokoine University of Agriculture (SUA) Morogoro, Tanzania in 1990, and his Masters degree in Environmental Management and Forestry from Duke University, North Carolina, USA in 1994. He has worked with the Mbeya Regional Directorate and Mbozi District Council, both in Southern Tanzania, for seven years as a District Forest Officer (DFO), performing duties related to administration and technical advice on district forestry projects, conservation activities, and extension services. Since 1991, he has been working with the Sokoine University of Agriculture Morogoro Tanzania, where he taught and conducted research in forest ecology, watershed management and climatology. He expects to continue with the same career. Munishi is married with two children.

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CHAPTER ONE: INTRODUCTION

The rain forests of Tanzania occupy small areas mostly confined to isolated mountains. This report presents the results of studies conducted to quantify several of the ecosystem services provided by the Eastern Arc Mountain Forests of Tanzania. The primary aims of this project were: (a) the classification and description of the vegetation types (plant associations or communities) based on floristic composition, examination of the relationships between plant communities and environmental factors, and evaluation of plant diversity patterns of two afromontane rain forests of the Eastern Arc Mountains, (b) assessment of the biomass and carbon pools of the two forests, and (c) description and evaluation of precipitation throughfall, stemflow, canopy interception, and streamflow in the two forests. These evaluations can give important information for future input to predictive modeling such as spatial plant community dynamics, carbon dynamics and hydrologic models for such ecosystems, with broader applications to forestry and environmental conservation in similar areas elsewhere in the tropics. This information is also a basis for the management and conservation of the high biodiversity values, catchment values and other environmental, ecological, and social services of these forests.

The Eastern Arc Mountains is a chain of crystalline mountains near the Indian Ocean coast from southern Tanzania to southern Kenya (8° 51' S 34° 49' E to 3° 2' S 38° 20' E). This chain consists of several mountain ranges separated by low lands. The mountains originated by block faulting dating back to the Karoo period, approximately 300 million years ago (Griffiths, 1993; Lovett, 1996). The most important Eastern Arc Mountains in Tanzania with rain forests include South Pare, West Usambara, East Usambara, Nguu, Nguru, Ukaguru, Uluguru, Rubeho, Malundwe, Uzungwa, Mahenge, comprising an area of about 5011 km^2, out of which > 1560 km^2 are closed mature forests with intact epiphyte-rich canopies (TFCG, 1999). This study focused on Mazumbai and Kisimagonja forest reserves (Mazumbai) in the West Usambaras and Uluguru North Forest Reserve in the Ulugurus.

The Eastern Arc Mountains are recognized for their unique and diverse biota and hydrologically important forest vegetation (Lundgren, 1979; Lovett, 1988b; MLNT, 1989; Bruen, 1989; Iversen, 1991; Munishi and Temu, 1992; Bjondalein, 1992; Lovett, 1993; Howell, 1993b; Rodgers and Homewood, 1993; Stuart *et al.*, 1993). The flora of these mountains is much richer in terms of number of endemics and number of species than

equivalent areas of forests outside them from the Horn of Africa to the Cape, and are one of the 24 top biodiversity hot spots in the world (Pomeroy, 1993; Fjeldså, *et al.*, 1998; TFCG. 1999; Mittermeier, *et al.*, 1999; Mittermeier, 2000). Their forests are a big carbon reservoir. important in mitigating emissions of carbon dioxide (CO_2), a greenhouse gas used by plants during photosynthesis and implicated in global warming. Moist forests on these mountains occur from 150m to 3000m elevation, covering extensive areas of their wetter eastern. southern, and northern sides, though lowland forests are relatively rare today due to human impacts.

Although these forests have been given high research priority for their ecological environmental and social services (MLNRT, 1989) relatively little has been done to quantify such roles. Tanzania is developing strategies for biodiversity conservation, greenhouse gas mitigation, and water resource management. Realistic strategies require quantitative information on the extent and present condition of the resources. Among the major foci of the strategies are the Eastern Arc Mountains.

Classification and assessment of vegetation patterns are important tools for land management and conservation strategies. Most studies of plants and plant communities in the Tanzanian natural forests have concentrated on general vegetation surveys and botanical collections. Quantitative studies of factors that influence plant community structure. composition, and distribution at the community and/or association level or objective classification of the vegetation into community types are still inadequate.

The national greenhouse gas inventory of sources and sinks qualitatively identified land use changes and forestry as the most important sources and sinks of anthropogenic greenhouse gasses (CEEST, 1994; Omujuni, 1994). However, there are no quantitative data to show which of the changes create net sources or net sinks. There are a limited number of studies that have quantified the potential of natural forest ecosystems in Tanzania to mitigate greenhouse gas emissions (Munishi *et al.*, 2000). Quantification of sources and sinks of anthropogenic greenhouse gases will enable the development of realistic mitigation options for greenhouse gas emissions and can be a basis for carbon emission offset trading and conservation credits in Tanzania. Such credits have been effective in raising funds for conservation in other countries (Daniel, 1995; Ronald, 1997; Casey, 1997; Brown, 1999).

It is widely believed in Tanzania that montane forests secure a continuous supply of water. In other words, forests mean water. This is contrary to many studies of the influence of forests on water yield (Hibert, 1967; Bosch, 1979, 1982; Bosch & Hewlett, 1982) that show increased water yield with forest removal. However, the knowledge of the internal hydrologic processes in tropical catchment forests is still inadequate at present to fully explain the divergence. Therefore, detailed process analysis to understand the contribution of the forest in the hydrology of a catchment in tropical environments is important to justify the management of the forest resources as water catchments. These three issues, *i.e.*, plant communities and species diversity patterns, potentials for mitigating carbon emissions, and catchment values of the Eastern Arc forests are addressed in this report.

Chapter three gives the classification and description of plant communities, diversity patterns, and associated environmental gradients for two afromontane rain forests of the Eastern Arc Mountains of Tanzania. Classification and description are based on a combination of agglomerative hierarchical cluster analysis, non metric multidimensional scaling ordination, and indicator species analysis using species importance values.

Chapter four examines the biomass and carbon pools of trees and soils in the two forests using tree dimensions (dbh, height), wood density, and soil carbon analyses. The implications of carbon storage in these forests on net atmospheric carbon are discussed.

Chapter five presents a description and quantification of rainfall, throughfall, stemflow, canopy interception and streamflow in the two forests. Models are developed relating rainfall with throughfall, stemflow, and streamflow.

CHAPTER TWO: LITERATURE REVIEW

Environmental gradients in plant community patterns and diversity

The abundance, distribution, and diversity of vegetation are strongly influenced by the qualities of the physical landscape with plant species responding uniquely to the opportunities and constraints arising from physical and chemical characteristics of the landscape (Boughey 1955; Stehli *et al.*, 1969; Holdridge, *et al.*, 1971; Janzen *et al.*, 1976; Wentworth, 1982; Gentry, 1982, 1988a; van Steenes, 1984; Gradstein & Poc's, 1989; Tryon 1989; McNab, 1990; Friis, 1992; Friis and Lowesson, 1993; Edward, 1994; Rosenzweig, 1995; Lovett, 1996; Lieberman, *et al.*, 1996; Webb and Peart, 2000). Such responses are especially more pronounced on mountain ecosystems, where there are abrupt changes in altitude, slope, moisture gradients, hydrology, aspect, temperature, and rainfall (Holdridge, *et al.*, 1971; Hetts, 1994, Lovett, 1996; Lieberman, *et al.*, 1996). These abrupt changes in site conditions are accompanied by changes in the physical and chemical nature of the soil, nutrient dynamics, and the micro-climate. Such variations greatly influence patterns in plant communities and their diversity (McArthur, 1964; Rosenzweig and Wanakur, 1969; Holdridge, *et al.*, 1971; Sousa 1979; Wentworth, 1982; Petraitis *et al.*, 1989; Rosenzweig, 1995; Lieberman, *et al.*, 1996).

Ashton (1964), Austin *et al.*, (1972) and Greig-Smith (1979) found relationships between forest composition and soil at scales of plots as small as 0.08 ha in Brunei. Baillie and Ashton (1983) found that the occurrences of some of the most frequent species in a Dipterocarp forest in Borneo were more closely correlated with reserve cationic soil nutrients than with exchangeable nutrients. Baillie *et al.*, (1987) correlated species distribution with soil [Mg] in Sarawak. Hall (1977) found forest types on ferralitic soils were different from those on ferrisols in Nigeria. Linder (1989) found an influence of substrate type on patterns of herb communities in the East Usambara forests. Further information on influence of edaphic factors on plant communities can be found in Wentworth (1981, 1982), Whitaker and Niering (1968), Bowman and Minchin (1987), Gentry (1982, 1988), Ehrenfeld *et al.*, (1997), Bledsoe and Shear, (2000).

Several studies have suggested the existence of vegetation zones or belts on mountain ecosystems with elevation related discontinuities in floristic composition or structure (Hedberg, 1951; Boughey, 1955; White 1983a; van Steenes, 1984; Friis, 1992; Friis and

Laweson, 1993; Lovett 1996), although other studies have indicated elevational variations in vegetation to be continuous (Chapman and White, 1970; Holdridge, *et al.*, Hamilton, 1975; Hamilton *et al.,* 1989; Lovett, 1996; Lieberman, *et al.*, 1996). Species diversity is thought to decline with elevation and is related to productivity (Gentry, 1982, 1988a, 1989; Wright *et al.,* 1993). Empirical data have shown the relationship between species diversity and productivity to be monomodal (convex or hump shaped) (Rosenzweig, 1992; Rosenzweig and Abramsky, 1993). Other studies have shown ecosystem productivity to be influenced by species diversity, whereby increasing species diversity is related to increasing ecosystem productivity (Kirchner, 1977; Abramsky, 1978; Silvertown, 1980; Abramsky and Rosenzweig, 1984; Tilman, 1987; Owen, 1988; Goldberg and Miller, 1990; Latham and Ricklefs, 1993; Rosenzweig and Abramsky, 1993; Tilman and Downing, 1994; Naeem *et al.,* 1994; Tilman *et al.*, 1996; Lovett, 1996).

A variety of methods have been employed in the analysis of vegetation-environmental factor relationships and responses. The techniques are in three broad categories: direct gradient analysis, indirect gradient analysis, and classification (Orloci *et al.*, 1979; Gauch, 1982; Jongman *et al.*, 1987). Recently, indirect techniques have been more widely used in part because of their capability to analyze a number of species simultaneously either with or without explicit environmental data (Edward, 1994).

Terrestrial vegetation and greenhouse gas emission mitigation

General circulation models and other studies predict a continuous increase in atmospheric concentration of CO_2 and other greenhouse gases (Washington and Mitchell, 1984; Manabe and Wetherald 1987; Schlesinger and Zhao, 1989; Schneider, 1990; IPCC, 1990; Mendelson and Rosenberg, 1994; Flavin and Tunali, 1996). The long term ecological consequences of the change in the chemical composition of the atmosphere are not fully understood, though a possible shift in climate patterns and global warming has been predicted (Kolchugina *et al.,* 1995; Lal *et al.,* 1995).

The fate of at least 10% or more of the CO_2 added to the atmosphere by burning fossil fuels is unaccounted for, and the missing C problem observed in the 1970's is still unresolved (Broecker *et al.,* 1979; Quay *et al.,* 1992; Botkin *et al.*, 1993; Lugo, 1993;

Brown, 1997; Carl *et al.*, 1997; O'Ktinga'ti *et al.*, 1998; Cushman *et al.*, 2000). This missing C may be taken up biologically in the ocean and in forest ecosystems (Botkin and Simpson, 1990; Mendelson and Rosenberg, 1994; Brown, 1997). There is controversy today as to whether terrestrial ecosystems are releasing carbon to the atmosphere or withdrawing it and accumulating it in vegetation and soils. (Woodwell *et al.*, 1978; Bolin *et al.*, 1979; Broecker *et al.*, 1979; Houghton *et al.*, 1983; Moore and Bolin, 1987; Houghton *et al.*, 1987; Melilo *et al.*, 1988; Speth, 1989; Tans *et al.*, 1990; Kauppi *et al.*, 1992; Quay, 1992; Houghton, 1995).

It is widely known that terrestrial ecosystems in general play a major role in the global C budget and fluxes. Depending on the land use system, different ecosystems can be important sources or sinks for carbon (Post *et al.*, 1990; Tans *et al.*, 1990; Johnson, 1992; Jackson IV, R. B. 1992; Brown *et al.*, 1993; Dixon *et al.*, 1994a; CEEST, 1994; Houghton, 1995; Lal *et al.*, 1995; Dixon, 1996; Brown, 1997, 1999). Land use changes and forest management activities have historically been and are currently net sources of C (as CO_2 gas) to the atmosphere (Brown *et al.*, 1996). On the other hand, there is potential for land use and forestry activities to mitigate C emission by emission avoidance or conserving the existing C pools on the land (*e.g.*, slowing down deforestation or improved forest harvesting), C sequestration or expanding C storage in forest ecosystems by increasing the area and/or carbon density of forests (*e.g.*, in plantations, agroforests, natural regeneration, soil management) (Speth, 1989, Johnson, 1992; Dixon *et al.*, 1994b; Kolchugina *et al.*, 1995; Lal *et al.* 1995; Winjum *et al.*, 1997; Brown, Dixon, 1996; Brown, 1997, 1999), increasing storage in durable wood products, and substituting sustainably grown wood for energy intensive and cement-based products (*e.g.*, biofuels, construction materials) (Brown *et al.*, 1996; Brown, 1999).

With the increasing concern about the rise in atmospheric CO_2 concentration, and its implications on global climate, the role of terrestrial vegetation, especially tropical forest management has received greater attention as a means of mitigating C emissions to the atmosphere. Inventorying and monitoring existing C pools in these ecosystems has therefore become of prime importance for understanding the global C budget and the fate of the CO_2 added to the atmosphere by fossil fuels. Biomass density of forests represents the potential

amount of carbon that can be added to the atmosphere as CO_2 when the forest is cleared, as well as the CO_2 that can be removed by regrowing trees (Brown, 1997).

Decisions by policy-makers regarding management and use of forests and trees require accurate and precise information on the states, patterns and rates of change of the resources. These decisions require reliable estimates of forest biomass and its change over the long term for all countries. Biomass estimates for forests of tropical countries are needed because globally they are undergoing the greatest rates of change and reliable estimates are few. Their biomass and carbon contents are generally high, which influence their role in the global C cycle (Brown *et al.*, 1996)

Three methods are possible to determine the rate of biomass and carbon change (Boden *et al.* 1990, Botkin *et al.* 1993): (i) global monitoring of forest biomass so that net changes are observed directly over time; (ii) global monitoring of leaf biomass in forests and a method to estimate net annual photosynthesis, and; (iii) an indirect method of examining the annual oscillations in carbon dioxide concentrations. For the first two methods, the soil carbon pools should be included. Due to inadequate data for each of the above methods and variations in carbon storage by different species, forest types, and forest soils, field measurements for estimation of biomass and total carbon storage for specific forest ecosystems are essential and can significantly improve our understanding about the missing C problem.

Forest vegetation and the water cycle

The variety of climatic and vegetation types of the tropical zone results in a variety of distinct and complex hydrological regimes (Oyebande, 1988). The hydrology of rain forests is complex although most studies have only dealt with the overall water balance without consideration of the internal hydrologic processes. Principally in preparation of the water balance of a catchment, the water should be followed from when the precipitation is received on the forest canopy to the point where it reaches the major stream leading out of the forest. It is widely known that internal catchment processes such as interception, evapotranspiration, through fall, stemflow, infiltration, surface runoff, and ground water movement, determine the nature of water movement through a forest to streams (Jackson,

1971, 1975, 1980; Lundgren and Lundgren, 1979; Lal and Russel, 1981; Bruen, 1989). Many studies have only looked at the most easily accessible data, *i.e.*, input as precipitation (from rain gauges) and the output as discharge through a point on the catchment (Lal and Russel, 1981; Oyebande, 1988; Jackson, 1989; Bjondalein, 1992).

The forest is characterized by three elements which account for the observed distinctive paths taken by water movement in the forest (Oyebande, 1988). These elements include: (i) the foliage above the ground surface forming a number of layers that compose the total thickness of the protective canopy, (ii) the accumulation of dead and decaying plant remains on the ground surface constituting the forest floor, and (iii) the forest soils including the living and dead roots and subsurface stems that permeate the soil. The obstacles presented by forest vegetation to the free fall of rain water are likely to cause changes in the quantity, rate, and time of water delivery to the ground (Anderson, 1976; Miller, 1977; Reifsnyder, 1988; Oyebande, 1988)

In most tropical regions precipitation is the major input of water into a catchment. Fog condensation and horizontal precipitation may contribute considerable amounts of water input in many mountain forest ecosystems and coastal environments (Neggel, 1956; Bayton, 1968; Azevedo & Morgan, 1974; Shiklomanov and Krestovsky, 1988). This kind of precipitation has often not been included in standard meteorological observations and may greatly underestimate the water input to a forest ecosystem, especially in montane cloud forests (Bayton, 1969; Juvik and Ekern, 1978; Ekern, 1964; Bayton, 1969; Juvik & Ekern 1978; Poc's, 1980; Shiklamanov and Kestovsky, 1988; Cavelier and Goldstein; 1989 Bruijnzeel, 1990; Munishi *et al.*, in prep).

Interception is precipitation caught on the forest canopy and returned to the atmosphere by evaporation. (Oyebande, 1988; Bruen, 1989). The intercepted water can be taken as part of the forest's ability to recycle precipitation. Although interception is not a major factor in most hydrologic calculations, it has great significance because it is one of the ways in which altering the vegetation cover affects the water balance of an area.

The amount of interception depends on the ability of the forest to collect and retain rainfall (interception capacity), storm size and intensity, evaporation rate, vegetation type & density and canopy height, form, and age (Dunne and Leopold, 1978; Shiklamanov and

Kestovsky, 1988). Interception loss is higher for light than heavy storms (Oyebane, 1988) and can be 10%-20% of the total rainfall (Soper and Lull, 1967; Jackson, 1971; Tejwani *et al.*, 1975; Lockwood, 1976; Gupta, 1980; Lawson *et al.*, 1981; Lu and Tang, 1995; Asdak *et al.*, 1998; Xiao *et al.*, 1998). Other studies have shown interception to be more than 20% of the incident rainfall, 42% for a stand of *Kunzea ericoides* in New Zealand (Rowe, 1999), 36% for an urban forest of broad leaf evergreens (Xiao *et al.*, 1998), and 65-75% for bamboo stands of different species (Saengkoovong *et al.*, 1999).

Precipitation that is not intercepted reaches the forest floor in either of two major processes/pathways: throughfall, falling through and from the leaves/forest canopy to the ground surface; and stemflow, trickling along twigs, surface of branches and finally down to the ground surface via the main trunk. Although litter may intercept some of the water, most of it infiltrates in the soil and is the net precipitation for a forest ecosystem (Helvey & Patric, 1965; Oyebande, 1988; Bruijnzeel, 1990). This means that the rainfall intercepted by the forest can be derived from measurements of incident (gross) rainfall and net precipitation (throughfall plus stemflow).

Precipitation, interception, evaporation, throughfall, transpiration, and stemflow are the major aboveground component processes of the hydrologic cycle that may influence the hydrology of a forest catchment and determine the value of a forest ecosystem's ability to conserve and regulate water. The processes can be measured by several methods (Ekern, 1964; Eaton *et al.*, 1973; Vogelmann, 1973; Lovett *et al.*, 1982; Bruck *et al.*, 1989; Cavelier and Goldstein, 1989; Bruijnzeel, 1990; Knops *et al.*, 1996).

The high spatial and sometimes temporal heterogeneity of tropical forest canopies and complex nature of processes involved as water moves through the canopy require elaborate sampling designs rarely used (Jackson, 1975; Lloyd & Marques-Filho, 1988). Suggestions have been that a large number of ordinary rain gauges placed along a transect line then randomly relocated gives more accurate estimation of throughfall than fixed gauges. A few investigators in tropical forests have used gauge relocation (Vis, 1986; Llyoyd & Marques-Filho, 1988; Hutjes *et al.*, 1990), but could not get much deviation in throughfall from that determined by fixed gauge studies. Other workers have approached the problem of heterogeneity by increasing the sampling surface through use of metal plates

(Bruijnzeel, 1990), elongated gutters (Clements and Colon, 1975), or plastic sheets (Calder *et al.*, 1986b). Reigner (1964) argues that since distribution of throughfall is very location specific, and troughs form continuous sampling transect, they should be effective in overcoming site variations. Oksendahl (1990) used gauges, troughs, and plastic sheets when studying cloud water interception in Morogoro, Tanzania. Cavalier and Goldstein (1989) used plastic sheets in the study of cloud water interception in Venezuela. Bruijnzeel, (1990) argues that large collecting areas are no guarantee for good estimates. Uebel (1997) suggested methodological aspects such as possible damages to equipment by falling tree branches and wild animals may be good reasons for refraining from using plastic sheets.

Stemflow measurements should also take into account the large spatial variability of tropical forests. Stemflow is usually measured volumetrically and the amounts are converted to millimeters of rain (water) through division by the projected crown area. However, given the difficulties in estimating crown area in tropical rain forests, it is advisable to sample every tree within a sufficiently large plot and divide the total stemflow volume by the plot area to obtain an area weighted average (Helvey and Patric, 1965; Bruijnzeel, 1990).

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CHAPTER THREE: COMPOSITIONAL GRADIENTS, PLANT COMMUNITIES, AND SPECIES DIVERSITY PATTERNS IN TWO AFROMONTANE RAIN FORESTS - EASTERN ARC MOUNTAINS OF TANZANIA

ABSTRACT

This study classified plant communities and examined the environmental correlates of community composition in afromontane rain forests on two mountain ranges of the Eastern Arc Mountains of Tanzania. Using agglomerative cluster analysis, indicator species analysis, and non metric multidimensional scaling (NMS) ordination, based on importance values of tree species, five distinct plant communities were identified in each of the forests. The communities corresponded closely to variations in topography and soil physical and chemical properties. The different communities occurred on clay soils in lower elevations and on sandy-clay to sandy-clay-loam soils in higher elevations. Two topographic and fourteen edaphic factors were significant correlates of plant community composition. Elevation was the strongest correlate of community composition on individual mountain ranges followed by percent clay and soil pH. Land-form index and soil sodium concentration [Na] were the major factors in separating plant communities between different mountain ranges. Species richness was negatively correlated with elevation and aluminum concentration [Al] and positively correlated with basic cations and cation exchange capacity. The results suggest that plant community patterns are influenced by a complex of local heterogeneity in topographic and edaphic factors. Analysis of species distribution shows the proportions of rare species are high, raising a concern as to whether this is an evidence of species' declines. The complex of factors affecting plant distribution is an important consideration in restoration and conservation programs. Close attention to species with rare distribution is specifically important.

Key words: Cluster analysis, Eastern Arc Mountains, Endemic species, Non-metric multidimensional scaling, Ordination, Rare species, Species diversity.

INTRODUCTION

The rain forests of Tanzania occupy small areas mostly confined to isolated mountains. More than half of these forests are found in the crystalline Eastern Arc Mountains, that extend from southern Tanzania to southern Kenya. Most of these are under intense deforestation pressure with the remaining forests gazetted as reserves managed as catchment forests for rainwater capture. In contrast, most lowlands are either dry or have been deforested for agriculture. Therefore, there are no alternatives to catchment forests for capturing water (Kalaghe *et al.*, 1988; Nsolomo and Chamshama, 1990; Bjondalein, 1992; Munishi and Temu, 1992; Rodgers, 1993).

The Eastern Arc Mountain forests are recognized for their unique and diverse biota, with floristically rich forest vegetation that ranges from lowland rain forests to elfin montane forests (Rodgers and Homewood, 1982; MLNRT, 1988; Steiner, 1990; Iversen, 1991; Bjondalein 1992; Lovett, 1993; TFCG, 1999; Mittermeier *et al.*, 1999; Mittermeier, 2000). The level of endemism of the 2,100 known species of vascular plants has been estimated at 25-39%. Some six families have high endemism ranging from 31% for Orchidaceae to 73% for Gesneriaceae, and more than 10 genera are considered endemic or near-endemic (Lovett, 1988b, 1989; Mittremeier, *et al.*, 1999).

Classification and assessment of vegetation patterns and species associations are important tools for land management, restoration, and conservation (Munishi, 1996). The deforested mountain areas in the Eastern Arc are losing agricultural productivity with time, and are likely to be abandoned because of insufficient crop yield sometime in the future. The knowledge of plant community dynamics and species associations as influenced by varying environmental factors will be important as these abandoned (degraded) lands become available for forest restoration.

Past assessments of variations in plant communities and species associations in the Eastern Arc Mountains have mainly been based on variations in elevation and climate (Hall, 1980; Lovett, 1990, 1996; Poc's *et al.*, 1990). Such assessments probably assumed elevation to be a surrogate of other possible environmental factors that affect plant distribution. However, Lovett (1990) also argued that temperature, soil, and precipitation likely influence vegetation distribution in the Eastern Arc mountains in addition to elevation. Poc's (1974,

1976b) observed that rainfall distribution alone was not sufficient to explain the diversity of vegetation types in the Ulugurus. Since mountain rain forest environments are very variable for plant growth (Hetts, 1994), species diversity patterns and plant community associations in mountain areas may be associated with a complex of both topographic and edaphic factors. This study classified plant communities and examined the environmental correlates of community composition in two afromontane rain forests of the Eastern Arc Mountains of Tanzania.

OBJECTIVES

The primary objectives of this study were:

1. the classification and description of the vegetation types (plant associations or communities) based on floristic composition
2. examination of relationships between plant communities and environmental factors, and
3. evaluation of plant diversity and distribution patterns.

MATERIALS AND METHODS

Study Sites

The Eastern Arc Mountains are a chain of crystalline mountains near the Indian Ocean coast from southern Tanzania to southern Kenya (8° 51' S 34° 49' E to 3° 2' S 38° 20' E). This chain is several mountain ranges separated by lowlands that originated by block faulting dating back to the Karoo period, approximately 300 million years ago (Griffiths, 1993; Lovett, 1996). These mountains support some of the most luxuriant montane and sub-montane rain forests of eastern and central Africa. The most important Eastern Arc Mountains in Tanzania with rain forests include South Pare, West Usambara, East Usambara, Nguu, Nguru, Ukaguru, Uluguru, Rubeho, Malundwe, Uzungwa, and Mahenge. The foci of this study were the Mazumbai and Kisimagonja Forest Reserves in the West Usambaras and the Uluguru north Forest Reserve in the Ulugurus.

The West Usambara range is in the northern part of the mountains (4° 25'S – 5° 07' S and 38° 10'E – 38° 35' E). The geology is composed of late Pre-Cambrian rocks of the

Usagara System, metamorphic rocks of gneiss type with two main highland soil types; the Humic Ferrisols in the drier areas and Humic Ferralitic soils in the more humid and wet areas (Hall, 1980; Tosi *et al.*, 1982). The climate is oceanic with bimodal rainfall partly determined by their proximity to the Indian Ocean and the equator. Rainfall peaks in April and November with a mean annual rainfall maximum of 2,000 mm in the wettest areas, falling to less than 600 mm in the drier areas. Moist forests cover extensive areas of the wetter eastern, southern, and northern sides of the mountains (van der Willingan and Lovett, 1979; Lovett, 1996).The Mazumbai Forest Reserves are among those areas with the highest rainfall in the West Usambaras. The monthly rainfall averages > 50 mm and the mean annual rainfall is 1,300 mm (Redhead 1979; Hall, 1980; Tosi *et al.*, 82; Munishi, pers. obs.). The elevation ranges from 1,300 to 1,910 m. The vegetation consists of lower montane, sub-montane, and montane evergreen rain forests (Redhead, 1981; Hall, 1990).

The Uluguru range (7°02'S - 7° 16'S and 38° 0'E - 38° 12'E) is in the central part of the Eastern Arc Mountains. The Uluguru bedrock is made up of Precambrian metamorphic rocks dominated by hornblende-pyroxine granulites with injections of granite and gneiss (Rapp *et al.*, 1972). The climate is oceanic with bimodal rainfall, peaking in April and November. Annual rainfall is 2,900 - 4,000 mm on the windward slopes and 1,200 - 3,100 mm on the leeward slopes. The eastern windward slopes have over 100 mm of rainfall every month (Lovett and Poc's, 1993). The elevation ranges from 1,600 to 2,300 m and the vegetation consists of submontane, montane rain forests, and elfin forests.

Data Collection

One hundred 0.02 ha (20 m x 10 m) plots were established in each of the two ranges. The plots were established along parallel lines whose starting points were subjectively chosen to cover as much variation as possible from valley bottoms to ridge tops. Plots were laid with their long axis perpendicular to the slope. The differences in elevation between adjacent plots along survey lines varied from 5 m – 80 m. The following were collected at each plot: diameter at breast height (dbh, 1.4 m) of all trees ≥ 6 cm (for buttressed trees, diameters were measured above the buttress); occurrence of all other plant species (trees < 6 cm dbh, shrubs, and herbs); elevation, slope, aspect, McNab's Landform index (LFI), and

terrain shape index (TSI) (McNab, 1989, 1993). Species were identified in both the local and botanical names. Botanical names were confirmed at the Lushoto Silvicultural Station Herbarium in Tanzania. Basal area estimates were based on both a prism sweep from the plot center and computations from tree diameters.

Soil samples were collected at 0-15 cm and 15-30 cm depths at three equidistant points along the plot center line. The samples from each point in a plot were mixed to form one sample for each depth. The samples were ground and passed through a 2 mm sieve. Concentrations of Ca, Mg, K, Na, Cu, Al, and Zn ([Ca], [Mg], [K], [Na], [Cu], [Al], [Zn]), were analyzed by inductively coupled plasma-atomic emission spectrometry using a Varian Liberty Series 2 ICP analyzer. Ammonia was determined spectrophotometrically with the Lachat QuickChem 8000 System Autoanalyzer (Ranger and Diamond, Lachat Instruments, 1994), method 31-107-06-1. Cation exchange capacity (CEC) was determined using the method of Zelazny *et al.,* (1996). The effective cation exchange capacity (ECEC) was the sum of [Ca], [Mg], [K], [Na], and [Al].Total basic cation concentrations (CAT) were the sum of [Ca], [Mg], [K], and [Na]. Percent cation saturation was the ratio of cation concentration to the ECEC. Percent base saturation (%BS) was determined as the ratio of total basic cation concentration to the CEC. Percent carbon and nitrogen were determined using a CHN elemental analyzer, model NC2100, CE Instruments. Soil texture was determined by the hydrometer method (Hillel, 1980b; Sheldrick and Wang, 1993). Soil pH was measured electrometrically using 10 g of soil sample diluted by de-ionised water in a ratio of 1:2. Due to their close proximity, the data from the Mazumbai and the Kisimagonja Reserves were combined to form one West Usambara Forest description (see table 1 for the range of soil properties in the different forests).

Data Analyses

Species importance values (IV) for each plot were computed for each species as the average of the relative basal area and relative density. Species richness was computed as the total number of species in each plot. The index of dominance was computed as $C = \sum(n_i/N)^2$ where n_i = importance value of a species, N = total importance value of all species (Ambasht, 1988; Misra, 1989). Simpson's and Shannon's Diversity Indices were computed

as $C = 1 - \sum(p)^2$ and $H = -\sum(p*\ln(p))$, respectively, where p = species relative basal area (Barbour *et al.*, 1987; McGarigal and Marks, 1995). Aspect was transformed as $A' = \cos(A_{max} - A) + 1$ where A' = transformed aspect, A = the direction of the prevailing slope measured in azimuth degrees clockwise from the north, A_{max} = the azimuth to be assigned the highest numerical value on the transform scale = 45 (Beers *et al.*, 1966).

The plots from the two ranges were separately classified by agglomerative hierarchical cluster analyses of the IVs (Orloci, 1967; Gauch, 1982; Greig-Smith, 1983), using Sorensen's distance measure and a group linkage method with flexible β of –0.4. The plots were ordinated by Non-metric Multidimensional Scaling (NMS) using the PC-ORD version 4.0 software (McCune and Mefford, 1999). The data were first run using Detrended Correspondence Analysis (DCA) to get a starting configuration (the graph file from the DCA), then NMS was run using Sorensen's distance measure (McCune and Mefford, 1999). The number of axes were set to two, with a hundred iterations, fifty runs with real data (after Monte Carlo test, and stability criteria of 0.005). Varimax rotation was adopted to preserve the perpendicularity of the coordinate system and maximize the loading of individual variables on the dimensions of the reduced ordination space (McCune and Mefford, 1999). The topographic and edaphic variables were correlated with plant community composition in the NMS ordination. Indicator species analysis was performed using the method of Dufrene and Legendre (1997) contained in the PC-ORD version 4.0 software.

For the analysis of similarities between forest types on the two ranges, the plots from the Usambaras and Ulugurus were combined in one ordination consisting of 200 plots irrespective of differences in elevation. To compare forests at similar elevations in the Uluguru and Usambara ranges, all plots with overlapping elevations (42 in the Usambaras and 68 in the Ulugurus) were combined and ordinated separately filtering out effects due to differences in elevation.

Community types in each range were determined from the agglomerative classifications, ordinations, and indicator species analysis. Community types were named following procedures of the Nature Conservancy (Anderson, *et al.*, 1998) where the name of the dominant and diagnostic species are used as the foundation of the association name. Here the first three to four dominant member species with the highest percent IV, constancy,

and significant indicator values (p = 0.05) (Dufrene and Legendre, 1997) were used to name the association, and member species for a given association would not have a higher constancy in another community than that in its faithful association(s) (Kershaw and Looney, 1985; Barbour *et al.*, 1987). Paired t-tests were used to determine differences in environmental factors between communities. Species were defined as rare if they occurred in only 1-2% of the plots; those with medium distribution occurred in 3%-30% of the plots; those occurring in more than 30% of the plots were considered widely distributed.

RESULTS

Forest Characteristics

The numbers of tree species, vascular plant species, and families were higher in the Ulugurus than in the Usambaras (Table 2). This may be attributed to the wider elevation range sampled in the Ulugurus (1120 m vs. 550 m in the Usambaras), or climatic differences; the Ulugurus are wetter than the Usambaras (higher mean annual rainfall). The plots in the Usambaras generally had bigger trees, which accounts for the higher basal area and lower stem density found there (Table 2). Twelve species in the Usambaras and seventeen species in the Ulugurus accounted for 78-79% of the basal area of the plots (Table 3). *Ocotea usambarensis, Syzygium guineense, Parinari exelsa,* and *Newtonia buchanani* are common dominants of both ranges. The basal area from prism sweep was much lower than that estimated from tree diameters. This may be attributed the subjective sampling employed whereby plot establishment was biased towards sites that were considered to be more fully stocked and/or probably with large trees. The high density figures in this study may be attributed to the adoption of smaller minimum breast height diameter of 6 cm, as well as the bias that may be introduced by subjective sampling.

Gradients in Plant Community Classification and Description in the Usambaras

By examining the dendrograms, ordination diagrams, and significance of the indicator species, five distinct plant communities were characterized in the Usambaras (Figures 1a & 2, Table 4a). These community types were named following procedures of the Nature Conservancy (Anderson, *et al.*, 1998) where the name of the dominant and diagnostic

species are used as the foundation of the association name. The first three to four dominant member species with the highest percent IV, constancy, and significant indicator values ($p = 0.05$) (Dufrene and Legendre, 1997) were used to name the association. Further, member species for a given association would not have a higher constancy in another community than that in its faithful association(s) (Kershaw and Looney, 1985; Barbour *et al.*, 1987).

One topographic and six edaphic factors were associated with plant communities and species distribution (Table 5& 6 & 7). Elevation was the strongest correlate of community composition, followed by percent clay, $\%N_{30}$, $\%C_{15}$, $[Na]_{30}$, percent sand, and percent potassium saturation ($\%[K]SAT_{15}$). Potassium was a strong gradient as a percent cation saturation of the ECEC and not as an individual cation. Plant communities were ordered along the second axis of the ordination, which was positively correlated with elevation, $\%N_{30}$, $\%$ C_{15}, %sand, and $[Na]_{30}$ and negatively correlated with %clay. Axis 1 of the ordination was negatively correlated with $\%[K]SAT_{15}$ (Table 5, Fig. 2). Three communities occurred on clay soils at low elevations and two on sandy-clay-loam soils at higher elevations (Table 4a).

Gradients in Plant Community Classification and Description in the Ulugurus

Like the Usambaras, five distinct plant communities were identified in the Ulugurus (Figures 1b & 2, Table 4b). One topographic factor and six edaphic factors were significant correlates of community composition, elevation being the strongest gradient (Table 5 & 6 & 7). Other correlates of community composition in increasing order were pH_{30}, CAT_{15} $[Ca]_{15}$, percent calcium saturation ($\%[Ca]SAT_{15}$), percent aluminum saturation ($\%$ $[Al]_{15}$ SAT), and $[Mg]_{15}$. Calcium as an individual cation was as strong a gradient as percent calcium saturation of the ECEC. Aluminum was a strong gradient as percent cation saturation of the ECEC but not as individual cation. Plant communities in the Ulugurus were ordered along the first axis, which was negatively correlated with elevation, and $\%$ $[Al]_{15}SAT$, and positively correlated with pH_{30}, CAT_{15}, $[Ca]_{15}$, $[Mg]_{15}$, and $\%$ $[Ca]_{15}$ SAT (Table 5). None of the environmental factors measured was correlated with the second axis in the ordination of the Uluguru plots (Table 5). One community occurred on clay soil at

lower elevations, two on sandy-clay soils at mid elevations, and two on sandy-clay/sandy-clay-loam soils at higher elevations (Table 4b).

Combined Analysis of the Usambara and Uluguru Forests

When all the Usambara and Uluguru plots were combined into one ordination, the two ranges separated out as two different communities ordered along axis 1 of the ordination though some plots from both ranges overlapped (Figure 3a). Axis 1 of this ordination was negatively correlated with elevation, and positively correlated with $[Na]_{30}$ and CEC_{30} (Tables 5, 6 &7). The analysis of the Usambara and Uluguru plots with similar elevations (overlap), separated the two ranges into two completely distinct communities ordered along axis 1of the ordination, without any overlap (Fig. 3b). Axis 1of this ordination was negatively correlated with LFI, and positively correlated with CEC_{30}, $\%N_{30}$, $\%C_{15}$, and $[Na]_{30}$, (Table 5). Axis 2 seems to separate communities responding to a complex of $[K]_{15}$, $[Al]_{15}$, $[Mg]_{30}$, and %BS, (Table 5).

Species Diversity, Richness, and Distribution in the Usambaras

The index of dominance (d) and the Simpson index (C) reflect species dominance in a plant community and has a range of $0 \leq d < 1$. The lower the index value the lower the dominance of a single or few species (Edward, 1996; Ambasht, 1988; Simpson, 1949). The Simpson's diversity index (D) represents the probability that any species encountered at random would be a different species, and its range is $0 \leq D < 1$. Shannon's diversity index represents the amount of "information" per individual (or species in this case). Though it may have no upper limit (Barbour *et al.*, 1987; McGarigal and Marks, 1995), its general range has been put at 1- 4.5 (Pelz and Luebbers, 1998).The higher their values the greater the diversity. For Shannon's Index, values > 2 have been assigned medium to high diversity (Barbour *et al.*, 1987).

The index of dominance in the Usambaras was 0.05. This low value shows that each species contributes to the community relatively evenly (Table 8) (Edward, 1996). Shannon's Diversity Index (2.93) and Simpson's Diversity Index (0.90) were relatively high (Table 7), indicating high species diversity. The percentage of rare species was generally high while

that of wide distribution species was low. The proportions of rare species were higher for the total vascular plants than for tree species alone (Table 7). There was no significant correlation between richness and any of the environmental factors in the Usambara plots (Table 9). Variations in species richness between communities had no any particular pattern (Table 3a & b). Eighteen endemic species were identified in the Usambaras, 72% of which were shared with the Ulugurus, and 17% with other mountain massifs of the Eastern Arc (Table 10).

Species Diversity, Richness, and Distribution in the Ulugurus

The index of dominance in the Ulugurus was 0.04, even lower than in the Usambaras. This shows that no one particular species dominates over the others (Table 8). Shannon's Diversity Index (3.31) and Simpson's Diversity Index (0.93) (Table 8) show high species diversity. The proportions of rare species were higher for the total vascular plants than for tree species alone and that of widely distributed species was even lower (Table 8). Although a wider elevation range was covered in the Ulugurus than in the Usambaras (Table 1), the Ulugurus had the lowest number of widely distributed vascular plants (Table 8), suggesting that species in the Ulugurus have more restricted distributions than in the Usambaras. Species richness was positively correlated with CAT_{15}, CEC, %clay, pH_{30}, $[Mg]_{15}$ and negatively correlated with elevation, %sand and $[Al]_{15}$ (Table 8). Like in the Usambaras, species richness did not vary in any particular pattern between different plant communities (Table 4a & b). Thirty-two endemic species were identified in the Ulugurus, 41% of which were shared with the Usambaras and 28% shared with other mountain massifs of the Eastern Arc (Table 10).

In the combined analysis of the Usambara and Uluguru plots, referred to as "combined analysis" (Table 9), species richness was positively correlated with pH_{15}. The analysis of Usambara and Uluguru plots that had similar elevations, referred to as "overlap analysis" (Table 9), show species richness to be negatively correlated with elevation and $[Al]_{15}$, and positively correlated with pH_{15}.

DISCUSSION

In White's (1983) classification, afromontane rain forests are defined as forests that occur in areas between 1200 m and 2500 m altitude and mean annual rainfall of 1250 mm to 2500 mm. White's transitional forests occur under relatively drier conditions. Lovett (1990) used terminology similar to that of White in the classification of the vegetation of the West Usambara Mountains. Poc's *et al.*, (1990) mossy montane rainforests, montane rain forests, mesic montane rainforests, and submontane rainforests of the Nguru mountains fit into the afromontane and transitional forests of White. Tosi *et al.*, (1992) classified the forest at Mazumbai into two ecological life zones (Holdridge, *et al.*, 1971): Tropical Pre-montane moist forests at 1550m -1600 m, and Tropical Lower montane moist forests above 1600 m.

The different communities identified in this study (Table 4a & b), are more refined forest types of the afromontane and transitional rainforests of White's (1983) classification of the vegetation of Africa, and other classifications of the Eastern Arc vegetation which were general and essentially based on elevation, rainfall, and/or bioclimatic characteristics of the region (Tosi *et al.*, 1982; Poc's *et al.*, 1990; Lovett, 1990). Characteristic species of the afromontane and transitional rainforests of these classifications were similar to those identified in the present study, grouped in one or two general forest types. In the present classification, the species are further refined and grouped into specific associations based on quantitative assessment of species dominance, constancy, and indicator values. Also, the present classification separates communities by soil type, and soil physical and chemical properties (Tables 4a & b, 6, & 7). The *Ocotea usambarensi-Syzygium guineense-Parinari exelsa* and the *Agauria salicifolia-Ocotea usambarensis-Cryptocarya liebertina* forests in the present study may fit into the Tropical Montane moist forests of Tosi *et al.*, (1982). Similarly, the Ulugurus with mean annual rainfall over 2000 mm and altitude of more than 1600 m places the plant communities of this area in the Tropical Pre-montane to Lower Montane wet forests life zone of Holdridge, *et al.* (1971).

The plant communities in this study grow at lower elevations and on different soil types in the Usambaras than in the Ulugurus (Tables 4a & b). Though plant communities differ on the two ranges, several species including *Syzygium guineense, Newtonia buchanani, Ocotea usambarensis* and *Parinary exelsa* are common to both ranges. Several

species occurred either in the Usambaras or in the Ulugurus but not in both (Table 3a & b). Some species such as *Syzygium guineense*, *Parinari exelsa*, *Allanblackia ulugurensis*, *Symphonia globulifera*, *Sorindeia usambarensis* and *Ocotea usambarensis* seem to have wide distributions in the different ranges and are dominants in more than one community. *Syzygium guineense* seems to have a wider ecological range in the Ulugurus as it occurs in more than two communities. *Parinari exelsa* holds the same status in the Usambaras (Table 4a & b)

Generally, elevation was the strongest correlate of community composition in both ranges, followed by a number of edaphic factors that differed from one range to another (Tables 5& 7). Some edaphic factors were strong gradients in the form of cation saturation of the ECEC but not as individual cations. Percent cation saturation of the ECEC for some nutrients has proven a successful index in agronomic studies (Jot Smyth - personal communications). Although plants are most sensitive to nutrient concentrations in solution, generally, the proportions of cations in solution relative to total cations are correlated with the proportion of cations on the exchange complex and can be more robust indicators as to whether "nutrient" reserves or "toxicity" (Al) differ among plant communities (Smyth - personal communications). Clay soils were found at lower elevations than sandy-clay-loam and sandy-clay/sandy-clay loam soils (Table 4a & b). Communities were different from each other in at least one environmental factor as shown by the significance of paired t-tests (Table 7). Other studies have shown species composition to be more closely related to gradients in soil characteristics and topography (Ashton, 1964; Whitaker and Niering, 1968; Austin *et al.*, 1972; Hall, 1977; Greig-Smith, 1979; Wentworth, 1981, 1982; Baillie and Ashton, 1983; Gentry, 1982, 1988a; Baillie *et al.*,1987; Linder, 1989; Bowman and Minchin, 1987; Lovett, 1996; Ehrenfeld *et al.*,1997; Bledsoe and Shear, 2000; Webb and Peart, 2000; Rasmus and Henrik, 2000).

Although the plant communities are distinct from one another, there is substantial species overlap with elevation ranges covered by different communities and species gradation from one community to another (Table 4a & b). Chapman and White (1970), Hamilton (1975), (1989), and Hamilton *et al.*, (1989) suggested a continuous variation in vegetation along an elevation gradient in Afromontane forests. Lovett (1996) could not find

zones of vegetation in the forests of the Eastern Arc mountains using presence -absence data. Lieberman *et al.*, (1996) found no discontinuities in vegetation distribution for a tropical forest in Costa Rica. However, Friis and Lowesson (1993) suggested altitudinal discontinuities in the vegetation of north-eastern Africa.

Basal area distribution and various diversity measures (Table 3 & 8) show relatively low species dominance, an indication of high species diversity as has been shown by other authors (Lovett, 1988b, 1993, 1996; MLNRT, 1989; Irvesen, 1991, Rodgers and Homewood, 1982). The basal area estimated from prism sweep was much lower than that estimated from tree diameters. This may be attributed the subjective sampling employed whereby plot establishment was biased towards sites that were considered to be more fully stocked and/or probably with large trees. The high density figures may also be attributed to the adoption of smaller minimum breast height diameter of 6 cm, as well as the bias that may be introduced by subjective sampling. Both the basal area and stem density figures obtained from tree diameters and tree counts from the plots are almost similar to those from a reconnaissance study done earlier at Mazumbai forest reserve. A reconnaissance done in 1996 using a plot size of 0.04 ha gave an average basal area figure of 153 m^2 ha^{-1} and another one from a bigger plot of 0.1 ha in 1998 gave a figure of 162 m^2 ha^{-1}

The nature of the strength and long time environmental interactions and influence on the floristic composition of the forests can be considered to have allowed species to be broadly associated with the range of their environmental factors. Each of these gradients occupies an appreciable range and any tree species measured may be considered as viable in these forests. The sparse distribution of some species observed in this study may be either a biological characteristic (restricted range), or outlier individuals of populations whose ranges are outside these sites, but may likely an evidence of species declines caused either by a natural phenomena or anthropogenic impacts. Possibilities exist that some wild plant resources may be severely threatened by species selective over-exploitation especially where the species is of specific use by local communities. Hall (1990) observed 15 species (some of which are in this study) that showed very low abundance at Mazumbai forest. Such species should be candidates for future research and immediate conservation.

In the Ulugurus, species richness increased with decreasing elevation, percent sand, [Al], and increasing [Ca], [Mg], CAT, CEC, percent clay, and pH (Table 9). The Usambaras did not show any correlation between richness and any of the environmental factors. The difference may be that the range of environmental factors covered in the Usambaras were not sufficient to cause a change in richness, or the two forests may be different ecosystems all together. The Uluguru plots covered a wider elevation range (1120 m) than the Usambaras (550 m). Also, the Ulugurus have greater prevalence of sharply dissected ridges and valleys, and steeper slopes than the Usambaras which may cause higher heterogeneity in the environment, and greater variations in richness within shorter spans.

The topographic and climatic conditions that favored the isolation of endemics within the Eastern Arc mountains have been discussed elsewhere (Lovett, 1988b, 1989; Poc's, 1989; Poc's *et al.*, 1990; Bjondalein, 1992), with some observers pointing out that endemism in the flora of the Eastern Arc Mountains lies between 25%-30% of the known species of vascular plants. In this study, eighteen (7%) and thirty-two (7%) endemic species were found in the Usambara and Uluguru, respectively, which is below this range. The endemic species found in this study include some species that were earlier believed to be restricted single mountain massifs in the region (Table 10). For example, *Memecylon feruculosum* was earlier believed to be restricted to the Nguru Mountains (Poc's *et al.*, 1990). *Dyschoriste* sp., *Justicia* sp., and *Thunbergia hamata* were earlier listed as Usambara strict endemics (Steiner, 1990). The endemic species found are either strict endemics to individual mountain ranges, or shared endemics between the different mountain massifs. Many of these endemic and sub-endemics belong to polymorphic genera with species restricted to other massifs of the Eastern Arc (*e.g.*, *Impatiens*, *Milletia*, *Polystachya*, *Memecylon*, and *Pavetta*).

The plant community patterns of the Usambaras and the Ulugurus are a result of complex factors arising from local variations in the physical environment, especially soil factors, and cannot be associated only to common origin and oceanic influence (White, 1983; Lovett, 1989; Poc's *et al.*, 1990; Bjondalein, 1992). McNab's (1993) Landform index which was observed to separate plant communities between the Uluguru and Usambara ranges has been shown to be a strong measure of soil depth, moisture, and nutrient redistribution and is an important modifier of the meso-scale environment for plant growth

(Edward, 1994). Latitudinal differences between the two sites are too small to cause a change in species richness (diversity) or plant community associations (Rosenzweig, 1995; Latham and Ricklefs, 1993; Wright *et al.*, 1993; Lovett, 1996).

CONCLUSION

The Usambaras and Ulugurus have different patterns of plant communities and plant species associations determined by complex topographic and edaphic factors. Within a single range, elevation and soil factors (particularly texture, CEC, CAT, [Al], soil pH, % clay, %carbon and %nitrogen) play key roles in plant distribution. LFI plays the most important role in inter-range differences. There are elevation induced changes in species composition, but variations in edaphic factors play key roles in shaping plant community patterns. Species diversity, richness, and endemism are high. On the other hand, the proportions of rare species are also high, raising a concern as to whether it is a bilogical characteristic or an evidence of species' declines. The results suggest that plant community patterns in the Eastern Arc are associated with complex topographic and edaphic factors. This complex of factors is an important consideration in designing restoration and biodiversity conservation programs. Close attention to the species with rare occurrence is especially important.

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Table1. Topography and soil properties in two afromontane rain forests of the Eastern Arc Mountains of Tanzania. Soil samples were taken at 0-15cm and 15-30cm depths

	Usambara			Uluguru		
Feature/Soil Property	mean	minimum	maximum	mean	minimum	maximum
pH_{15}	4.2	3.3	6.5	4.3	3.4	6.4
pH_{30}	4.6	3.7	6.4	4.6	3.8	6.0
C_{15} (%)	13.1	3.8	42.2	8.2	4.7	21.9
C_{30} (%)	8.9	0.1	17.0	6.7	1.9	16.3
N_{15} (%)	0.9	0.3	2.9	0.6	0.3	1.4
N_{30} (%)	0.7	0.2	1.1	0.5	0.1	1.0
Ca_{15} (cmol kg^{-1})	1.4	0.2	8.5	0.6	0.1	2.4
Ca_{30} (cmol kg^{-1})	1.5	0.3	6.2	0.9	0.2	3.9
Mg_{15} (cmol kg^{-1})	0.3	0.1	1.6	0.3	0.1	1.4
Mg_{30} (cml kg^{-1})	0.2	0.02	1.4	0.2	0.03	1.0
K_{15} (cmol kg^{-1})	0.2	0.1	0.5	0.2	0.1	0.6
K_{30} (cmol kg^{-1})	0.1	0.02	0.3	0.2	0.1	0.4
Na_{15} (cmol kg^{-1})	0.2	0.1	0.3	0.2	0.1	0.4
Na_{30} (cmol kg^{-1})	0.3	0.2	0.4	0.2	0.1	0.4
Al_{15} (cmol kg^{-1})	0.9	0.03	2.5	0.7	0.1	2.1
Al_{30} (cmol kg^{-1})	0.7	0.1	2.2	0.6	0.1	1.4
Mn_{15} (cmol kg^{-1})	0.1	0.01	0.4	0.04	0.0	0.3
Mn_{15} (cmol kg^{-1})	0.03	0.0	0.3	0.0	0.0	0.2
Clay (%)	41.6	19.8	71.0	35.8	20.6	63.0
Sand (%)	43.4	10.0	62.0	49.1	24.0	72.0
Silt (%)	15.1	2.6	35.9	15.1	4.7	30.4
PBS_{15} (%)	31.5	5.5	99.2	35.4	11.2	79.0
PBS_{30} (%)	63.8	7.0	99.4	80.6	15.4	98.2
$ECEC_{15}$ (cmol kg^{-1})	2.9	1.1	10.3	2.1	0.7	4.6
$ECEC_{30}$ (cmol kg^{-1})	2.8	1.2	7.8	2.0	0.9	4.9
Elevation (m)	1588	1360	1910	1861	1190	2280

Table 2. Characteristics of two afromontane rain forests in the Eastern Arc Mountains of Tanzania. The reported basal area was estimated from a prism sweep at the plot center. Numbers in parenthesis show basal area estimates from tree diameters

	Usambaras	Ulugurus
Elevation range (m)	1360 – 1910	1160 - 2280
Total # Species (vascular plants)	262	445
# Tree Species	69	90
# Families	81	97
Basal Area (m^2 ha^{-1})	40 ± 8 (104)	30 ± 7 (83)
Density (stems ha^{-1})	988 ± 376	1161 ± 397

Table 3. Basal area contribution (%) by the dominant species in two afromontane rain forests of the Eastern Arc Mountains of Tanzania. Species are ordered with decreasing % contribution to basal area. Only species contributing ≥ 2% of the total basal are shown.

Species	Usambaras	Ulugurus
Ocotea usambarensis	25	18
Syzygium guineense	12	7
Parinari exelsa	8	5
Newtonia buchanani	8	2
Dicranolepis usambarica	4	
Agauria salicifolia	4	
Isoberlinia scheffleri	4	
Sorindeia usambarensis	3	
Drypetes usambarica	3	
Allanblackia stuhlmanii	3	
Pachystela msolo	2	
Aningeria adolf-friederci	2	
Ficalhoa laurifolia		11
Symphonia globulifera		6
Allanblackia ulugurensis		4
Macaranga kilimandscharica		4
Albizia gummifera		3
Strombosia scheffleri		3
Trichocypha ulugurensis		3
Afrocrania volkensii		3
Myrianthus arboreus		2
Chrysophyllum gorungosanum		2
Cassipourea congoensis		2
Polycias fulva		2
Dasylepis leptophylla		2
Total (%)	78	79

Table 4a. Plant communities and species associations in an afromontane rain forest in the Usambaras - Eastern Arc Mountains of Tanzania. Numbers in parentheses show the species indicator values. A community is named by the first three or four member species with the highest percent IV, constancy and significant indicator value. S = species richness for a given community.

Community	Most abundant species	IV (%)	Constancy (%)	Elevation (m) Range	Mean	S	Soil Type
Sorindeia usambarensis - *Parinari exelsa* - *Newtonia buchanani* forest	*Sorindeia usambarensis*	23 (41)	93	1360 - 1650	1468[1] 50[2] 50[3]	32	clay
	Parinari exelsa	17 (37)	79				
	Newtonia buchanani	14 (27)	57				
	Allanblackia stuhlmanii	8 (35)	57				
Strombosia scheffleri - *Craibea brevicaudata* - *Pachystela msolo* - *Isoberlinia scheffleri* forest	*Strombosia schefleri*	9 (58)	88	1390 - 1840	1515[1] 72[2] 28[3]	39	clay
	Craibia brevicaudata	9 (46)	48				
	Pachystela msolo	9 (31)	36				
	Isoberlinia scheffleri	9 (30)	40				
	Drypetes usambarica	8 (38)	52				
	Dicranolepis usambarica	8 (23)	36				
	Cola greenwayi	5 (28)	48				
Syzygium guineense - *Sorindeia usambarensis* - *Parinari exelsa* - *Newtonia buchanani* forest	*Syzygium guineense*	37 (77)	100	1415 - 1800	1527[1] 74[2] 26[3]	33	clay
	Sorindeia usambarensis	19 (38)	100				
	Parinari exelsa	9 (18)	68				
	Newtonia buchanani	9 (15)	53				
Ocotea usambarensis - *Syzygium guineense* - *Parinari exelsa* forest	*Ocotea usambarensis*	41 (78)	100	1430 - 1880	1662[1] 54[2] 46[3]	48	sandy-clay-loam
	Syzygium guineense	7 (10)	71				
	Parinari exelsa	7 (37)	68				
Agauria salicifolia - *Ocotea usambarensis* - *Cryptocarya liebertina* forest	*Agauria salicifolia*	20 (77)	79	1570 - 1910	1770[1] 43[2] 57[3]	49	sandy-clay-loam
	Ocotea usambarensis	11 (15)	71				
	Cryptocaria liebertina	7 (42)	50				
	Aphloia theiformis	5 (37)	79				

[1] = mean elevation for plots representing a given community
[2] = % of plots below the mean elevation for a given community.
[3] = % of plots above the mean elevation for a given community.

Table 4b. Plant communities and species association in an afromontane rain forest in the Ulugurus - Eastern Arc Mountains of Tanzania. Numbers in parentheses show the species indicator values. A community is named by the first three or four member species with the highest percent IV, constancy and significant indicator value. S = species richness for a given species

Community	Most abundant species	IV (%)	Constancy (%)	Elevation (m) Range	Mean	S	Soil Type
Myrianthus arborea - *Cussonia spicata* - *Albizia gummifera* - *Afrocrania volkensii* - forest	*Myrianthus arborea*	13 (47)	57	1610 - 1820	1682[1]	41	clay
	Cussonia spicata	12 (92)	50		57[2]		
	Albizia gummifera	11 (40)	43		43[3]		
	Afrocrania volkensii	11 (39)	43				
	Vitex doniana	6 (64)	29				
	Oncoba spinosa	5 (23)	43				
Trichocypha ulugurensnsis - *Strombosia sheffleri* - *Dasylepis integra* forest	*Trichocypha ulugurensis*	12 (50)	74	1610 - 1900	1750[1]	50	sandy
	Strombosia schefferi	11 (45)	61		48[2]		-clay
	Dasylepis integra	11 (33)	74		52[3]		
	Ficalhoa laurifolia	9 (19)	26				
	Newtonia buchanani	6 (24)	26				
Symphonia globulifera - *Cassipourea malosana* - *Syzygium guineense* forest	*Symphonia globulifera*	23 (59)	100	1790 - 2010	1901[1]	37	sandy
	Cassipourea malosana	9 (38)	67		63[2]		-clay
	Syzygium guineense	9 (12)	67		37[3]		
	Chrysophyllum gorungosanum	8 (52)	60				
	Zenkerella schliebenii	7 (53)	80				
	Parinari exelsa	6 (11)	17				
Ocotea usambarensis - *Allanblackia ulugurensis* - *Symphonia globulifera* forest	*Ocotea usambarensis*	25 (77)	88	1700 - 2140	1903[1]	57	sandy
	Allanblackia ulugurensis	7 (25)	63		57[2]		-clay/
	Symphonia globulifera	6 (59)	67		43[3]		sandy
	Syzygium guineense	5 (18)	54				- clay-loam
Syzygium guineense - *Allanblackia ulugurensis* - *Garcinia volkensii* forest	*Syzygium guineense*	13 (31)	71	1190 - 2280	1998[1]	59	sandy
	Allanblackia ulugurensis	9 (24)	58		50[2]		-clay-
	Garcinia volkensii	5 (33)	38		50[3]		loam
	Olea europeae	5 (27)	42				

[1] = mean elevation for plots representing a given community
[2] = % of plots below the mean elevation for a given community.
[3] = % of plots above the mean elevation for a given community.

Table 5. Compositional gradients and their correlation with ordination axes in NMS ordination of tree species using species importance values in two afromontane rain forests of the Eastern Arc Mountains of Tanzania.

Forest	Gradients	Axis 1	Axis 2
USAMBARA	Elevation (m)	-	0.83
	Clay (%)	-	-0.64
	N_{30} (%)	-	0.62
	C_{15} (%)	-	0.59
	$[Na]_{30}$ (cmole kg^{-1})	-	0.52
	Sand (%)	-	0.48
	$[K]SAT_{15}$ (%)	-0.56	-
ULUGURU	Elevation (m)	-0.59	-
	pH_{30}	0.59	-
	CAT_{15} (cmole kg^{-1})	0.55	-
	$[Ca]_{15}$ (cmole kg^{-1})	0.55	-
	$[Mg]_{15}$ (cmole kg^{-1})	0.51	-
	$AlSAT_{15}$ (%)	-0.52	-
	$CaSAT_{15}$ (%)	0.55	-
COMBINED	Elevation (m)	-0.66	-
	$[Na]_{30}$ (cmole kg^{-1})	0.61	-
	CEC_{30}	0.50	-
OVERLAP	LFI	-0.59	-
	CEC_{30}	0.53	-
	$[Na]_{30}$ (cmole kg^{-1})	0.73	-
	C_{15} (%)	0.53	-
	N_{30} (%)	0.59	-
	$[Al]_{15}$ (cmole kg^{-1})	-	-0.31
	$[K]_{15}$ (cmole kg^{-1})	-	0.37
	$\%BS_{15}$ (cmole kg^{-1})	-	0.36
	$[Mg]_{30}$ (cmole kg^{-1})	-	0.32

Table 6. Soil physical and chemical properties associated with plant communities and species distribution patterns in two afromontane rain forests of the Eastern Arc Mountains of Tanzania.

	Forest Type (Plant Communities)*				
Nutrients/Property	**1**	**2**	**3**	**4**	**5**
Usambara:					
N_{30} (%)	0.5 ± 0.2	0.5 ± 0.2	0.6 ± 0.2	0.8 ± 0.1	0.9 ± 0.1
C_{15} (%)	11.6 ± 8.5	7.8 ± 3.9	8.9 ± 3.1	17.9 ± 5.4	17.9 ± 4.9
$[K]_{30}$ (cmol kg^{-1})	0.1 ± 0.05	0.1 ± 0.06	0.2 ± 0.06	0.1 ± 0.03	0.1 ± 0.03
Sand (%)	43.0 ± 6.9	42.0 ± 7.9	35.0 ± 11.2	48.0 ± 6.0	51.0 ± 4.1
Clay (%)	46.0 ± 9.2	46.0 ± 9.1	52.0 ± 10.1	32.0 ± 6.8	31.0 ± 5.3
K_{15} saturation (%)	7.1 ± 2.3	6.7 ± 2.8	10.5 ± 3.8	6.6 ± 1.7	7.3 ± 2.2
Uluguru:					
pH_{30}	5.1 ± 0.5	4.5 ± 0.3	4.6 ± 0.4	4.2 ± 0.3	4.5 ± 0.4
CAT_{15} (cmol kg^{-1})	2.4 ± 0.9	1.4 ± 1.0	0.9 ± 0.6	1.1 ± 0.5	1.3 ± 0.6
$[Ca]_{15}$ (cmol kg^{-1})	1.3 ± 0.6	0.7 ± 0.7	0.4 ± 0.4	0.5 ± 0.4	0.5 ± 0.4
$[Mg]_{15}$ (cmol kg^{-1})	0.6 ± 0.4	0.3 ± 0.3	0.2 ± 0.2	0.2 ± 0.1	0.3 ± 0.2
Ca_{15} saturation (%)	48.0 ±13	29.0 ± 19	19.0 ± 12	22.0 ± 13	24.0 ± 14
Al saturation (%)	2.4 ± 0.9	1.4 ± 1.0	1.0 ± 0.6	1.1 ± 0.5	1.3 ± 0.6

* See table 4a & b

Table 7. Environmental gradient differences (p-values) as determined by paired t-tests between plant communities in two afromontane rain forests of the Eastern Arc Mountains, Tanzania.

USAMBARA

Community*	Elevation (m)	Clay (%)	Sand (%)	N_{30} (%)	C_{15} (%)	$[Na_{30}]$	$[K_{30}]$	K-saturation (%)
1 & 2	0.02				0.09			
1 & 3			0.04			0.01	0.01	0.01
1 & 4	0.01	0.01	0.01	0.01	0.01	0.01		
1 & 5	0.01	0.01	0.01	0.01	0.03			
2 & 3	0.06				0.07		0.05	0.01
2 & 4	0.01	0.01	0.04	0.01	0.01	0.01		
2 & 5	0.01	0.01	0.01	0.01	0.01	0.01		
3 & 4	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3 & 5	0.01	0.01	0.01	0.01	0.01	0.01	0.10	0.01
4 & 5							0.07	

ULUGURU

Community*	Elevation (m)	pH_{30}	$[CAT_{15}]$	$[Ca_{15}]$	$[Mg_{15}]$	Ca-saturation (%)	Al-saturation (%)
1 & 2	0.01	0.01	0.02	0.02	0.01	0.01	0.01
1 & 3	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1 & 4	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1 & 5	0.01	0.01	0.01	0.01	0.08	0.02	0.08
2 & 3	0.01		0.08	0.05		0.04	0.07
2 & 4	0.01	0.05					
2 & 5	0.01						
3 & 4	0.01	0.01					
3 & 5	0.01		0.07		0.05		0.05
4 & 5		0.01	0.10		0.08		0.09

* see tables 4a &b. Communities in chronological order.

Table 8. Species diversity and distribution in two afromontane rain forests of the Eastern Arc Mountains of Tanzania. Computations are based on species basal area and frequency.

Diversity Measure /Species Distribution		**Usambara**	**Uluguru**
Diversity:			
Simpson's Index (C)		0.10	0.06
Simpson's Diversity Index (D=1-C)		0.90	0.93
Index of Dominance (d)		0.05	0.04
Shannon's Diversity Index		2.93	3.31
Distribution:			
Rare	Woody species ≥ 6cm dbh (%)	30	33
	Total vascular plants (%)	49	54
Medium	Woody species ≥ 6cm dbh (%)	57	48
	Total vascular plants (%)	38	40
Wide	Woody species ≥ 6cm dbh (%)	13	11
	Total vascular plants (%)	13	6

Table 9. Correlation (r-values) between species richness and environmental factors in two afromontane rain forests of the Eastern Arc Mountains, Tanzania.

	ULUGURU	USAMBARA	COMBINED	OVERLAP
Elevation	-0.30	-0.07	-0.13	-0.31
CEC	0.35	0.05	-0.03	-0.15
CAT_{15}	0.32	0.10	0.15	0.15
%CLAY	0.32	-0.04	0.11	0.24
%SAND	-0.34	-0.02	-0.17	-0.28
$[Al]_{15}$	-0.36	-0.12	-0.24	-0.34
pH30	0.45	0.19	0.34	
pH_{15}		0.19	0.33	0.41
$[Mg]_{15}$	0.38	0.15		0.28

COMBINED: Plots from the Usambaras and Ulugurus combined in one ordination irrespective of their elevation.

OVERLAP: Plots with similar (overlapping) elevations from the Usambaras and Ulugurus combined in one ordination

Factors that were significant correlates of community composition in the respective ordinations are underlined. ($p = 0.05$).

Table 10. Endemic plant species in two afromontane rainforests of the Eastern Arc Mountains, Tanzania.

Usambara	Uluguru	Shared Uluguru/Usambara
Allanblackia stuhlmanii	*Allanblackia ulugurensis*[2]	*Drypetes usambarica*
Dasylepis leptophylla	*Uvariodendron oligocarpum*	*Cryptocarya liebertina*
Isoberlinia scheffleri	*Lasianthus pendunculatus*[2]	*Dicranolepis usambarica*[2]
Sorindeia usambarensis	*Dasylepis integra*	*Cola greenwayii*
Greenwayodendron suaveolens[1]	*Milletia sacleuxii*	*Leptonychia usambarensis*
	Ouratea scheffleri	*Syzygium guineense*
	Polysphaeria multiflora	subsp. afromontana
	Porterandia penduliflora	*Memecylon feruculosum*[6]
	Alsodeiopsis schumanii	*Pavetta holstii*
	Vitex amaniensis	*Danais xanthorhoea*
	Dyschoriste sp. (*subquadrangularis*?)[3]	*Brachystephanus holstii*
	Rhipidantha chlorantha	*Crossandra tridentata*
	Justicia sp. (nov = Verdcourt 211)1	*Justicia anisophylla*
	Thumbergia hamata[3]	*Mimulopsis kilimandscharica*
	Asystasia sp. (H. of Kew)	
	Justicia inaequalis[4]	
	Phaulopsis sp. (nov = Peter 60631)[4]	
	Impatiens hamata	
	Pavetta lynesii[5]	

1 Earlier listed as occurring only in the east Usambaras (Ruffo *et al.*, 1989)
2 Shared with Nguru Mountains (Poc's *et al.*, 1990)
3 Earlier listed as strict endemics to the Usambaras (Steiner, 1990).
4 Known to be coastal near-endemics (Steiner, 1990)
5 Reaches its northmost distribution in the Ngurus and extends south to Udzungwa, Usagara, Mufindi escarpments, and Mahenge plateau (Poc's *et al.*, 1990)
6 Earlier known to be a narrow endemic restricted to the Ngurus (Poc's *et al.*, 1990)

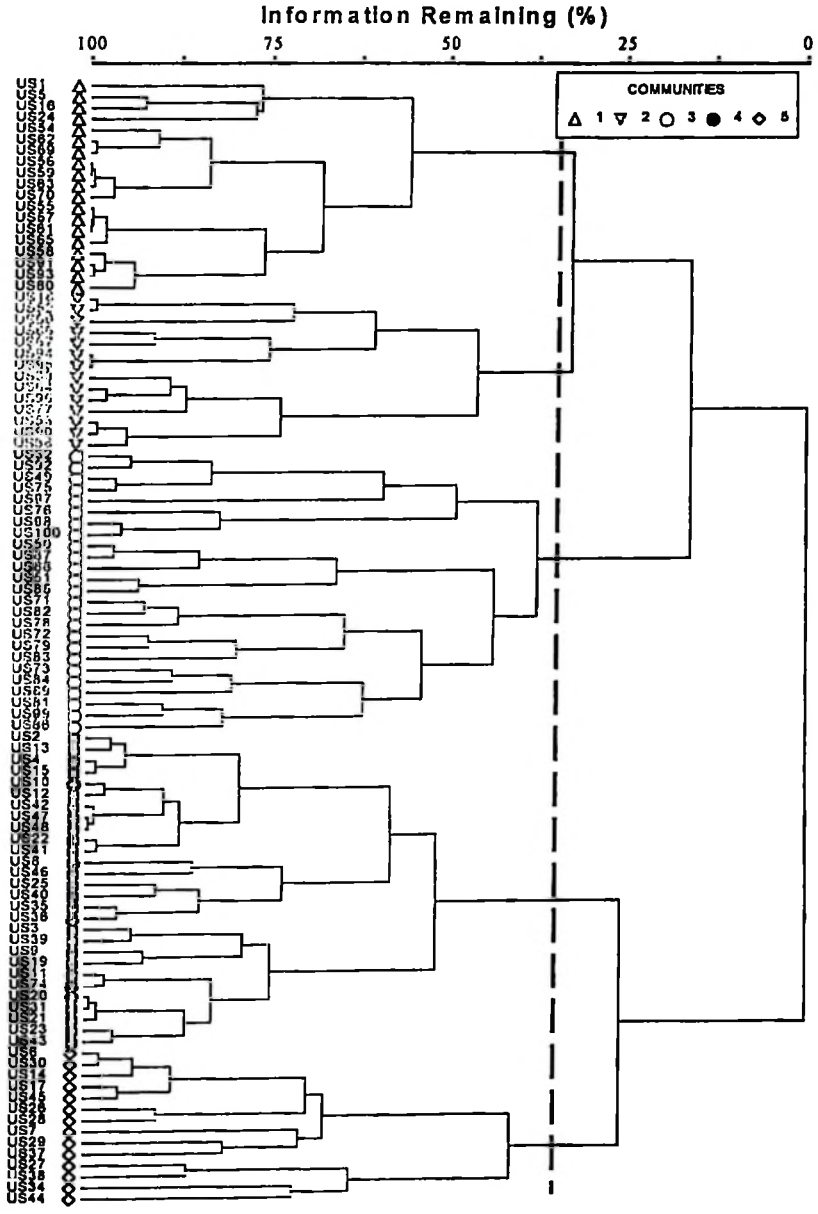

Figure 1a. Community dendrogram of Sorensen distances between plant communities indicating importance value relationships in an afromontane rain forest in the West Usambaras, Eastern Arc Mountains of Tanzania. Using a group linkage method of flexible $\beta = -0.40$, five communities were recognized in this forest. The vertical dashed line represents the cutoff level for community separation.

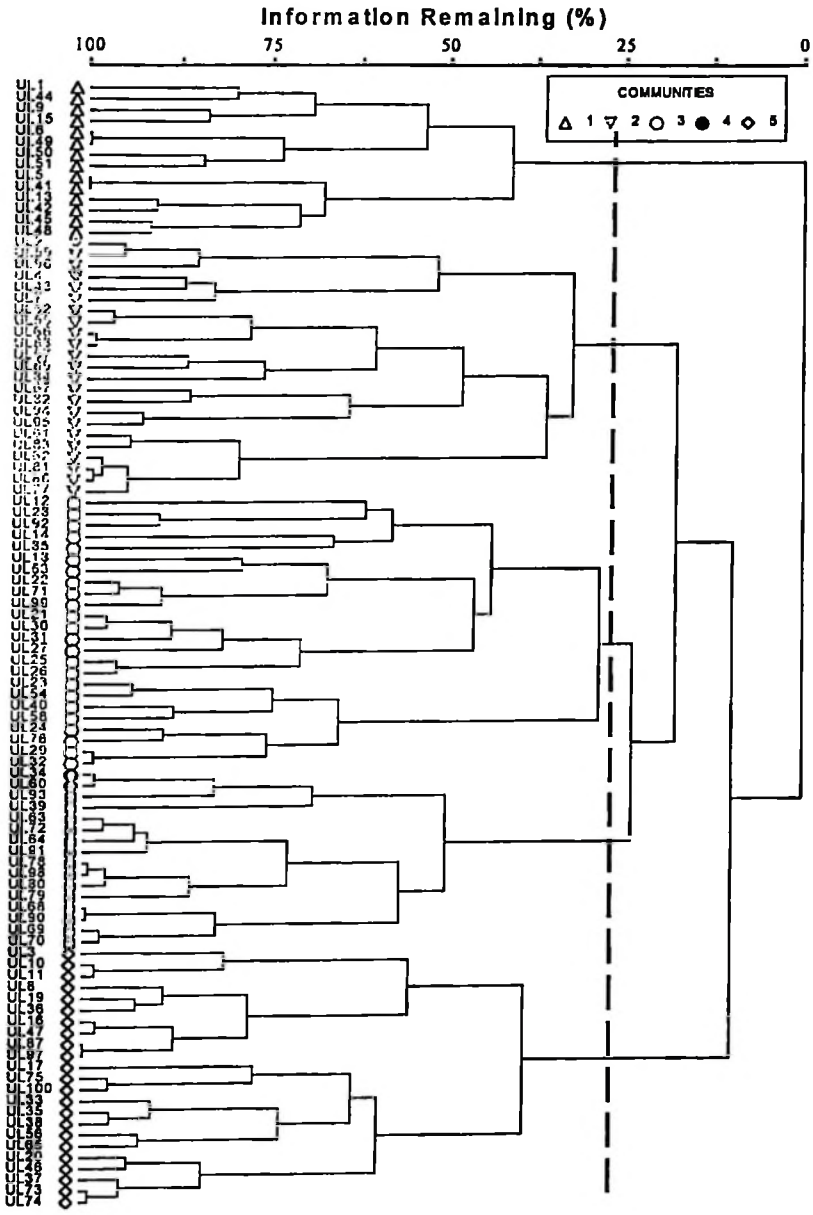

Figure 1b. Community dendrogram of Sorensen distances between plant communities indicating importance value relationships an afromontane rain forest in the Ulugurus, Eastern Arc Mountains of Tanzania. Using a group linkage method of flexible β = -0.40, five communities were recognized in this forest. The vertical dashed line represents the cutoff level for community separation.

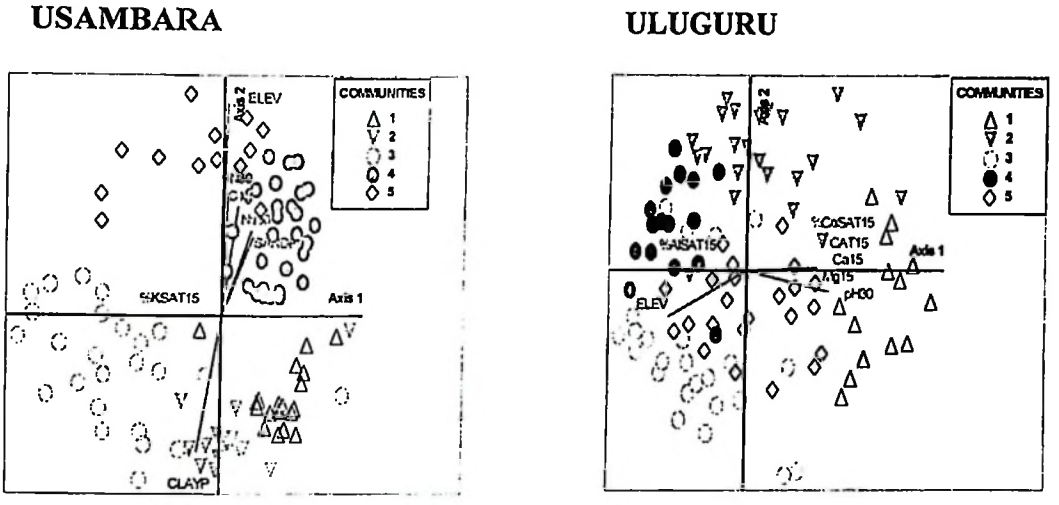

Figure 2. Compositional gradients and plant communities in NMS ordination of 100 vegetation plots in each of two afromontane rain forests, Eastern Arc Mountains of Tanzania. Five communities were recognized in each forest. ELEV = elevation (m), $\%KSAT_{15}$, $\%AlSAT_{15}$, $\%CaSAT_{15}$ = percent K, Al, and Ca saturation at 15 cm depth, CLAYP = % clay, SANDP = % sand, C_{15}, N_{30} = % nitrogen & carbon, Na_{30}, Ca_{15}, Mg_{15} = concentrations of Na, Ca, and Mg, at 15cm and 30cm depth. CAT = total cations. pH_{30} = soil pH 30 cm depth.

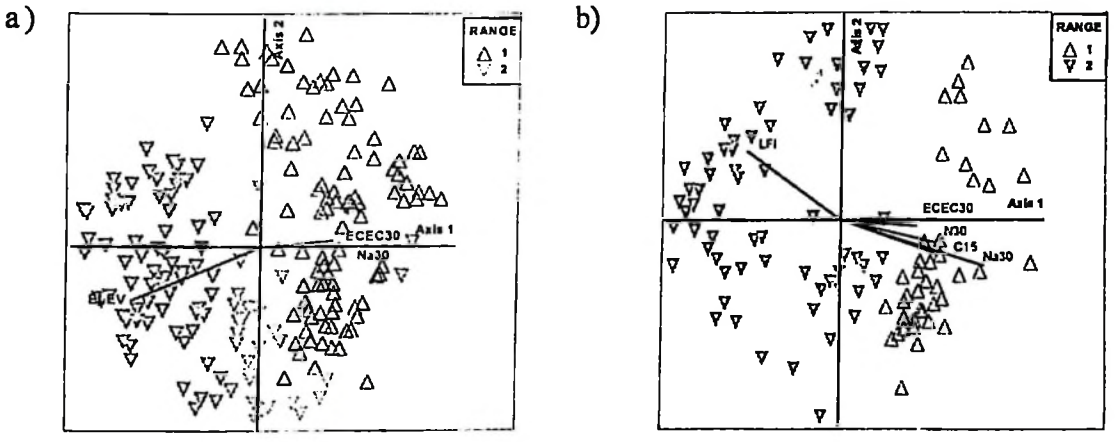

Figure 3. Compositional gradients and vegetation difference between two afromontane rain forests in NMS ordination of vegetation plots, Eastern Arc Mountains. (a) analysis of all elevation ranges (b) analysis of overlapping elevations. Range 1 = Usambara mountains, Range 2 = Uluguru mountains, ELEV = elevation, $ECEC_{30}$ = cation exchange capacity at 30cm depth, Na_{30} = soil [Na] (c-mole kg^{-1}) at 30cm depth, LFI = Landform index. N_{30}, C_{15} = % nitrogen and carbon at 30cm and 15 cm depth. The two ranges separate into two forest types. No overlap plots in (b).

CHAPTER FOUR: CARBON STORAGE OF TWO AFROMONTANE RAIN FORESTS OF THE EASTERN ARC MOUNTAINS OF TANZANIA: THEIR NET CONTRIBUTION TO ATMOSPHERIC CARBON

ABSTRACT

With the increasing concern about the rise in atmospheric carbon dioxide concentration and its implications for global climate, the role of terrestrial vegetation, especially tropical forests, has received attention as a means of mitigating carbon emissions. Inventorying and monitoring of existing carbon pools in these ecosystems has become important for understanding the global carbon budget. Tree dimensions, wood density, and analyses of soil carbon concentration (to 30cm depth) were used to quantify the biomass and carbon pools of two forests of the Eastern Arc Mountains of Tanzania. Carbon density in trees was estimated as the product of wood volume, density, and the proportion of carbon in wood biomass. Soil carbon density was estimated as the product of volume of soil, soil bulk density, and the percent carbon. The tree biomass including roots was 1055 ± 35 t ha^{-1} in the Usambaras and 790 ± 20 t ha^{-1} in the Ulugurus. This aggregates to 517 ± 17 t ha^{-1} carbon in the Usambaras and 384 ± 10 t ha^{-1} in the Ulugurus. The soil organic carbon density was 420 ± 100 t ha^{-1}, in the Usambaras and 290 ± 53 t ha^{-1} in the Ulugurus. Mid altitude communities seem to have higher C storage potential because of higher phytomass carbon. Apart from other environmental values, there is tremendous capacity for carbon storage in these forests to mitigate C emissions, putting their conservation in global context.

Key words: Biomass, Carbon, Eastern Arc Mountains, Rain forests, Plant communities Soil organic carbon.

INTRODUCTION

Understanding the role of terrestrial ecosystems in the global carbon (C) cycle has become increasingly important as policy makers consider options to address the issues associated with global climate change (Brown, 1997; Wayburn, 2000; Wisniewski and Sampson, 1993). With the increasing concern about the rise in atmospheric carbon dioxide (CO_2) concentration and its implications for global climate, the role of tropical forest management in mitigating CO_2 emissions is receiving attention. Determining the amount of changes in vegetation biomass has become important for understanding the global C budget, including the fate of carbon dioxide produced by burning of fossil fuels and forest clearing (Detwiler & Hall, 1988, Brown *et al.*, 1993), and the management of the existing carbon pools on the land for emission mitigation (Brown, 1999).

Biomass and carbon estimates for tropical forests are particularly needed as these forests are undergoing the greatest rates of change worldwide and reliable estimates are few (Brown, 1997). Their biomass and carbon content are high, thus influencing their role in the global C cycle. Tropical forests have the greatest potential for mitigating atmospheric CO_2 emissions through conservation and management (Brown *et al.*, 1996; Munishi *et al.*, 2000). Changes in the cover, use, and management of forests produce sources and sinks of CO_2 that is exchanged with the biosphere. Assessments of the magnitude of these sources and sinks require reliable estimates of the biomass density of forests and change over time (Brown, 1997). About 49%-50% of forest biomass is carbon (Colman & Cote 1968; *quoted* in Haygreen & Bowler 1989; Jackson IV, 1992; Chidumuyo, 1993; Brown, 1997), the potential percentage of CO_2 from forest biomass that can be added to the atmosphere when the forest is cleared for other land-uses. Likewise it is also the percentage of biomass CO_2 that can be removed from the atmosphere by restoring forests or establishing plantations (Brown, 1997).

The national greenhouse gas inventory of sources and sinks in Tanzania (CEEST, 1994) identified land use changes and forest management as the most important sources and sinks of anthropogenic carbon dioxide (CO_2). Mitigation plans for greenhouse gas emissions have to be formulated based on the UN Framework Convention on Climate Change (UNFCCC) of 1992. Options for mitigation include avoiding emissions, conserving the existing C pools on the land (slowing down deforestation or improving forest harvesting),

expanding C storage in forest ecosystems by increasing the area and/or carbon density of forests (*e.g.*, by plantations, agroforests, natural regeneration, soil management) (Dixon *et al.*, 1994b; Dixon, 1996; Brown, 1999), increasing storage in durable wood products, and substituting sustainably grown wood for energy intensive and cement-based products (*e.g.*, biofuels, construction materials) (Brown *et al.*, 1996; Brown, 1999). An analysis of the potential of the major ecosystems to sequester or store carbon will help understand whether the corrective measures taken in land use changes and forest management are likely to create net carbon sources or sinks. Such assessments are also fundamental in quantifying pathways for ecosystem carbon fluxes and sequestration.

Forest ecosystems in Tanzania occupy more than 45% of the land area (MLNRT, 1989) and more than 50% of the moist forests are confined to the Eastern Arc Mountains. These forests have high carbon density and potential for mitigating CO_2 emissions (Munishi *et. al.*, 2000) but their assessment and quantification are still inadequate.

OBJECTIVES

The major objective of this study was to make rapid estimates of the biomass and carbon pools of two afromontane rain forests of the Eastern Arc Mountains of Tanzania using relatively easily measured tree dimensions (DBH and height), wood density, and soil C concentrations.

MATERIALS AND METHODS

Study Site

Data were collected from the west Usambara and Uluguru mountain ranges, that are part of the Eastern Arc Mountains of Tanzania. The West Usambara range is located in the northern part of the Eastern Arc Mountains (4° 25' – 5° 07' S and 38° 10' – 38° 35' E) and cover an area of about 2,200 km^2. The geology of the mountains is late Pre-Cambrian rocks of the Usagara System, metamorphic rocks of gneiss type with two main highland soil types, the Humic Ferrisols in the drier areas and Humic Ferralitic soils in the more humid and wet areas (Hall, 1980). The climate is oceanic with bimodal rainfall partly determined by their proximity to the Indian Ocean and the equator. Rainfall peaks in April and November. The

mean annual rainfall maximum is 2,000 mm in the wettest areas, falling to less than 600 mm in the rain shadow areas. Moist forests occur in a wide elevation range covering extensive areas of the wetter eastern, southern, and northern sides of the mountains (van der Willingan and Lovett, 1979; Lovett, 1996).

In the west Usambaras, data were collected from the Mazumbai Forest Reserve and the adjacent Kisimagonja Forest Reserve (4° 50' S 38° 30' E), within an elevation range of 1,300 to 1,910 m. The monthly rainfall averages > 50 mm and the mean annual rainfall is 1300 mm (Redhead 1979; Hall, 1980; Munishi, pers. obs.). The vegetation consists of lower montane, sub-montane, and montane evergreen rain forests (Redhead, 1981; Hall, 1990).

The Uluguru Mountains (7° 02'S - 7° 16'S and 38° 0'E - 38° 12'E) are located in the central part of the Eastern Arc Mountains. The Uluguru bedrock is Precambrian metamorphic rocks dominated by hornblende-pyroxine granulites with injections of granite and gneiss and minor basic intrusions (Rapp *et al.*, 1972). The climate is oceanic with bimodal rainfall, peaking in April and November. The annual rainfall is 2,900 - 4,000 mm on the eastern windward slopes and 1,200 - 3,100 mm on the western leeward slopes. A pronounced dry season occurs on the western slopes, whereas the eastern slopes have more than 100 mm of rainfall every month. In the Ulugurus, the study site was the Uluguru North Forest Reserve with lower montane, sub-montane, and montane evergreen rain forests (Lovett and Poc's 1993).

Data Collection

One hundred 0.02 ha rectangular plots (20 m x 10 m) were established in each of the Usambara and Uluguru forests. Plots were established on line transects oriented along elevation gradients. Plots were laid with their long axis perpendicular to the direction of slope. The starting points of the lines were subjectively chosen to cover as much variation as possible from valley bottoms to ridge tops. The distances between plots along transects varied depending on elevation difference between plots. The elevation difference between plots ranged from 5 m to 80 m. All trees in each plot with diameter at breast height (dbh) $\geq$ 6 cm were identified and measured for diameter at breast height (dbh). Thirty sample trees of thirty different species, from different parts of the forests were measured for dbh, and total

height using a Suunto hypsometer. Total height was defined as the height to 90% of the crown depth (length) (Phillip, 1994). The trees represented the more common tree species in these forests. One wood core was extracted from each of the sample trees using an increment borer at approximately 1.3 m from the ground. The green weight, length, and diameter of each core were measured. Core diameters were an average of measurements from the two ends and the middle of the cores. The cores were oven dried at 103 ± 2° C for 3 days.

Soil samples were collected from each plot at three points along the center line (5 m, 10 m, and 15 m) and at two different depths, 0-15 cm and 15-30 cm. The three samples from each depth were combined, air dried, and sieved to pass through a 2 mm sieve. Another set of forty soil cores, twenty from each 0 -15 cm and 15 -30 cm depths, were collected from selected areas of each forest using bulk density core samplers and oven dried to constant weight for bulk density determination.

The wood core volumes were computed as the product of their cross-sectional areas and lengths. Wood density was computed as core oven dry weight divided by core volume for each tree species. Soil bulk density was computed as the ratio of the soil oven dry weight to the soil core volume for each sample. Percent soil C was determined using a CHN elemental analyzer, model NC2100, CE Instruments. Due to close proximity, Mazumbai and Kisimagonja Forest Reserves in the west Usambaras were combined as one west Usambara site with 100 plots.

Data Analyses

Tree volumes were computed as the product of the tree basal area and tree height adjusted for taper by the cone formula (Phillip, 1994). The dbh of the 30 sample trees were regressed against tree volume to develop a volume prediction model that was used to compute tree volumes in each of the 100 plots. Aboveground tree biomass was computed as the product of tree volume and the wood density. In computing tree biomasses, either the specific species density, family average, or sample tree average values were used. A biomass expansion factor (BEF) of 29% was used to estimate the biomass of the branches and foliage based on estimates by Hall (1980), and Munishi *et al.*, (2000). Hall (1980) estimated branch

and foliage to represent 30% of the total biomass for a montane rain forest in north eastern Tanzania. Munishi *et al.*,(2000) figured 28% for a montane rain forest in northern Tanzania. An average of the two authors (29%) was used as the biomass expansion factor for branches and foliage in this study. Root biomass was estimated as 22% of the aboveground biomass based on estimates by Brown and Lugo (1992), Malimbwi *et al.*, (1994), and Sanford and Cuevas (1996) for tropical forests. Individual tree biomasses were aggregated to plot biomass and divided by the plot area to obtain biomass density (metric tons ha^{-1}).

A common method of estimating tree biomass is to develop biomass models based on dbh and/or height by felling and weighing sample trees and tree components in the field (Brown *et al.*, 1989; Malimbwi *et al.*, 1994; Munishi *et al.*, 2000). This procedure requires much time and is costly, hence could not be achieved in the present study due to time and cost constraints. Rapid estimates using both field measurements, auxiliary information such as double sampling for sample tree volume prediction, and the biomass expansion factor obtained from studies in similar tropical forests are presented (Hall, 1980; Brown *et al.*, 1989; Sanford and Cuevas 1996; Munishi *et al.*, 2000). This method is expected to give at least first approximations for estimates of carbon storage potential of the forests. The percent soil C for each forest was computed as the average of the 100 plots in each depth.

Tree biomass was converted to C through multiplication by 0.49 (Colman & Cote, 1968; *quoted in* Haygreen & Bowler, 1989; Chidumuyo, 1993; Jackson IV, 1992; Malimbwi *et al.*, 1994; Brown, 1997; Ford-Robertson *et al.*, 2000; Munishi *et al.*, 2000). Soil C density for each forest was computed as the product of volume of soil per unit area (1 ha), bulk density, and the average percent C for each depth. Biomass and carbon storage by different plant communities were also estimated using similar procedure as those used for the whole forests.

RESULTS

Wood Density and Tree Volume

Wood density from the sample trees ranged from 0.24 g cm^{-3} to 0.85 g cm^{-3} with an average of 0.58 g cm^{-3} (Table 1). The average wood density is consistent with wood densities

reported in other studies for tropical Africa (Brown and Lugo, 1992, Brown, 1997; Reyes *et al.*, 1992). The model developed for the determination of tree volume was $V = 194.8803*DBH^{2.3982}$ ($r^2 = 0.99$, $p < 0.0001$) where V = tree volume (cm^3), DBH = breast height diameter in centimetres (Fig 1).

Forest Biomass and Carbon Storage in the Phytomass

The biomass of trees > 6 cm dbh was 1055 ± 35 t ha^{-1} for the Usambaras and 784 ± 20 t ha^{-1} for the Ulugurus. This aggregates to 517 ± 17 t ha^{-1} and 384 ± 10 t ha^{-1} C for the Usambaras and Ulugurus, respectively (Table 2). The Usambara forest has higher basal area, biomass, and C but lower stem density. The higher basal area, biomass and C in the Usambaras may be attributed to the Usambara forest being relatively intact compared to the Ulugurus which have higher rates of human use. The higher stem density in the Ulugurus may be attributed to smaller size trees in the Ulugurus than in the Usambaras.

Ocotea usambarensis (East African Camphor) accounts for the highest percentage of biomass and carbon in both forests (Table 3). Of the 69 tree species in the Usambaras, 11 each contributes more than 2% of the total biomass and C, together accounting for about 80% of the totals. The other 57 species account for the remaining 20% with 51 species each contributing less than 1% of total biomass and carbon. In the Ulugurus, 12 of the 90 tree species each contributed more than 2% of the total biomass/C and accounted for 76% of the totals. The other 78 species account for the remaining 24%, with 68 species each contributing less than 2% of the total biomass/C. Compared to the other species, *Ocotea* is found as a relatively large tree in these old-growth forests. Only three species with high biomass and C ranking are common to both forests: *Ocotea usambarensis*, *Syzygium guineense*, and *Parinari exelsa*.

Soil Organic Carbon

At 418 t ha^{-1}, the soil organic C density in both the 15 and 30 cm depths was 30% higher in the Usambaras than 295 t ha^{-1} in the Ulugurus (Table 3). The C density at the 15 - 30 cm depth was 69% of that at the 0-15 cm depth in the Usambaras and 80% in the Ulugurus. Soil C density was 81% and 75% of the amount contained in tree biomass for the

Usambaras and Ulugurus, respectively. This proportion would be higher if there is a significant amount of C stored below 30 cm.

Carbon Distribution and Storage in Different Plant Communities

Five different plant communities were identified in both the Usambara and Uluguru forests (Chapter 3). The carbon storage potential differed among communities (Table 4). High elevation communities were generally associated with lower carbon in the phytomass but higher soil organic C. Mid-elevation communities had the highest phytomass carbon and lower soil organic carbon. The *Ocotea usambarensis - Syzygium guineense -Parinari exelsa* community in the Usambaras had the highest phytomass carbon density but identical soil carbon density to the *Agauria salicifolia - Ocotea usambarensis - Cryptocarya liebertina* community (Table 4). *Ocotea usambarensis - Syzygium guineense -Parinari exelsa* and *Agauria salicifolia - Ocotea usambarensis - Cryptocarya liebertina* communities had the highest soil and total carbon. This may be associated with the quality of the litter produced by the species that constitute these communities. The higher the quality of litter produced by a given species, the higher the decomposition rate and low accumulation of organic matter. Being high altitude communities, organic matter decomposition rate is likely low, resulting in accumulation of organic matter. Although the *Agauria salicifolia - Ocotea usambarensis - Cryptocarya liebertina* community ranks fourth in phytomass carbon, it is the second in total carbon due to its high soil organic carbon.

In the Ulugurus, the *Trichocypha ulugurensis - Strombosia scheffleri - Dasylepis integra* community had the highest phytomass carbon but lower soil carbon than three other communities (Table 4). On the other hand, the *Ocotea usambarensis - Alanblackia ulugurensis - Symphonia globulifera* community seems to rank high in total carbon due to higher soil carbon.

DISCUSSION

The biomass and C density estimates in this study are identical to earlier estimates for the Mazumbai Forest Reserve (Hall 1980), *e.g.*, 1162 ton ha^{-1} biomass (569.4 t ha^{-1} C), but higher than those of other studies of moist tropical forests (Brown *et al.*, 1991; Brown,

1997), and 60- year rotation plantation-grown *Tectona grandis* (Teak) in Tanzania, *e.g.*, 244 t ha^{-1} C, (O'Kting'ati *et al.*, 1998). The C storage potential is on the higher side of that reported for tropical moist forests. Brown *et al.*, (1991) observed that only about 6% of mature forests in tropical Asia had aboveground biomass estimates > 500 t-ha^{-1} (245 t ha^{-1} C) while more than 61% of the forests had biomasses less than 250 t ha^{-1} (122.5 t ha^{-1} C). The high values of the forests in this study can be attributed to the relatively intact conditions of the forests with little or no anthropogenic (human induced) disturbances. Though used by surrounding communities, the catchment forests are well respected by neighboring local communities for their perceived importance, especially in the maintenance of water supply. This reduces their vulnerability to severe human impacts (Temba, 1996). Forests that have been subjected to human disturbance tend to have lower biomass than their potential (Brown *et al.*, 1991; Brown, 1997). Further, subjective sampling may have biased plot location in areas that are more fully stocked with larger trees than the average which may result into relatively higher aboveground biomass and carbon estimates.

The soil organic C density estimates are different from those given by Tate *et al.*, (1993, quoted in Ford-Robertson *et al.*, 2000) for Australian forests where the soil carbon is estimated to be twice the quantity in vegetation. Also, Munishi *et al.*, (2000) found higher C pools in the soil than in the above ground vegetation for a tropical rainforest in northern Tanzania. The difference is likely that the estimates in the other studies were based on soil analysis down to 100 cm depth as opposed to 30 cm in this study. Although soil organic carbon is normally concentrated in the top 30 cm, there can be substantial amounts down to 200 cm resulting from dead roots, especially in montane forests where roots may grow deeper than 30 cm (Wojick, 1999).

Most forests of the Eastern Arc Mountains are old-growth protected reserves that are relatively undisturbed. Although questioned by Lugo and Brown (1986) and Borchers (1991), a steady state soil C concentration may be assumed for such old growth forests (Jenny, 1980; Johnson *et al.*, 1991). They are likely to have relatively stable soil organic C pools in the form of humic substances with long residence times. Humic substances, that comprise about 65-75% of the organic matter in inorganic soils, are relatively resistant to biological degradation and have a long storage time ranging from decades to centuries

(Schnitzer, 1982; Wojick, 1999). Important characteristics exhibited by all humic fractions are resistance to microbial degradation, formation of stable water-soluble and water insoluble complexes with metal ions and hydrous oxides and interactions with clay minerals. The high % organic matter in these forests (> 6% average) provide physical protection by formation of complexes between organics and mineral particles (i.e., aggregation) which may extend the turnover time for labile soil organic matter (Anderson and Paul, 1984; Borchers, 1991). Kobak and Kondrasheva (1991), estimated a 4,500 yr residence time for both labile and stable C pools (range 3,000 – 6,000 years). If forests are assumed to be in dynamic equilibrium with constant additions of organic matter from leaves and dead wood, their potential to continue storing this constant amount of carbon is high when undisturbed. The forests are also at high altitudes where temperatures are relatively low and organic matter decomposition rates can be low. The difference in phytomass carbon between plant communities may be associated with tree sizes for species that constitute these communities. Differences in soil carbon may be associated with the quality of the litter produced by the species that constitute these communities, as well as elevation ranges in which these communities occur. In high elevation communities, the rate of organic matter decomposition is likely low due to relatively low temperatures, resulting in accumulation of organic matter.

The fate of at least 10% of the carbon dioxide added to the atmosphere by burning fossil fuels is still unaccounted for (Botkin *et al.*, 1993; Cushman *et al.*, 2000; Karl *et al.*, 1997; Lal *et al.*, 1993; O'Kting'ati *et al.*, 1998). This missing carbon might be taken up biologically by terrestrial ecosystems, especially forest vegetation (Botkin and Simpson, 1990; Wisniewski and Sampson, 1993; Dixon *et al.*, 1993; Sampson; 1993; Mendelson and Rosenberg, 1994; Winjum, *et al.*, 1997; Brown, 1996, 1997; Entry and Emmingham, 1998; Wojick, 1999). Ecosystems that can store large amounts of carbon, especially where they can cover relatively extensive areas like the Eastern Arc forests, are likely to be significant for carbon emission mitigation. Being old-growth forests, and possibly in steady-state or dynamic equillibrium, they may not be C sinks or sources. However they continue to be carbon reservoirs that fluctuate as a result of natural perturbations but remaining within distinct bounds. This means that if these forests are conserved, they will retain these high levels of C in perpetuity (see Ford-Robertson *et al.*, 2000). Such C stocks can be used as a

basis for emission offset trading and conservation credits. Such credits have been effective at raising funds for conservation in other countries (Daniel, 1995; Ronald, 1997; Casey, 1997; Brown, 1999).

Conservation and management of the Eastern Arc forests may also mean some permissible harvesting. With lawful harvesting to recover some of their economic values, much of the harvested wood can end up in products with a long life span, increasing carbon storage in durable wood products.

CONCLUSIONS

There is apparently a tremendous reservoir of C in the Eastern Arc Mountain forests and their continued management and conservation has high potential to mitigate carbon emissions. The forests may be considered neither sinks nor sources (steady-state). In this state, they will continue to be a carbon reservoir that will retain the existing high levels of C in perpetuity as long as they are not disturbed. My estimates are first approximations and a preliminary contribution to the assessment of such potential in the Eastern Arc mountain forests. Effort to continue assessment of other forests of the Eastern Arc to improve these estimates are necessary. Apart from other values, C storage potential of these forests puts their conservation in global context, especially as the global community turns to terrestrial vegetation management as a means of mitigating CO_2 emissions. The conservation of these forests has both political and socio-economic challenges. Putting value on non marketable products from these forests for example and ensuring that these values can be translated into tangible benefits to the surrounding local communities is a potential challenge.

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Table 1. Sample trees for biomass and carbon assessment in two afromontane rain forests - Eastern Arc Mountain Forests of Tanzania.

Species Name	Family	Density ($g\ cm^{-3}$)	Dbh (cm)	Height (m)
Polycias fulva (Hierm.) Harms.	Araliaceae	0.24	64.0	33.6
Aningeria adolfi-friedercii (Engl.) Robyns & Gilb.	Apocinaceae	0.43	88.5	51.5
Macaranga kilimandscharica Pax.	Euphorbiaceae	0.45	42.2	24.0
Cussonia spicata Thunb.	Araliaceae	0.49	32.5	27.0
Entandrophragma deiningeri Harms.	Meliaceae	0.49	195.0	60.5
Albizia gumifera (Gmel.) CA. Sm.	Mimosaceae	0.52	37.8	29.0
Pachystela msolo Engl.	Sapotaceae	0.54	62.4	39.0
Craibia brevicaudata (Vatke) Dunn	Papilionaceae	0.55	63.2	30.7
Podocapus usambarensis Pilg.	Podocarpaceae	0.55	30.3	24.0
Sorindeia usambarensis Engl.	Anacardiaceae	0.56	31.0	22.0
Trichocypha ulugurensis Mildbr.	Anacardiaceae	0.56	56.2	34.2
Ficalhoa laurifolia Hiern.	Theaceae	0.57	66.4	33.8
Allanblackia stuhlmanii Engl.	Guttiferae	0.58	87.5	46.5
Caloncoba welwischii (Oliv.) Gilg.	Flacourtiaceae	0.58	17.9	13.5
Syzygium guineense (Willd.) DC	Myritaceae	0.58	90.5	39.0
Teclea amaniensis Engl.	Rutaceae	0.58	27.9	27.5
Newtonia buchanani (Bak.) Gilb & Bout	Mimosaceae	0.59	55.0	34.0
Symphonia globulifera L.f.	Guttiferae	0.59	63.1	39.0
Dicranolepis usambarica Engl.	Annonaceae	0.6	68.8	49.5
Cola greenwayi Bren.	Sterculiaceae	0.62	39.0	30.0
Drypetes usambarica (Pax) Hutch.	Euphorbiaceae	0.62	19.0	19.0
Maytenus accuminatus (l.f) Loes	Celastraceae	0.62	23.6	26.0
Ocotea usambarensis Engl.	Lauraceae	0.63	19.7	37.5
Strombosia scheffleri Engl.	Olacaceae	0.63	24.0	21.0
Dasylepis leptohylla Gilg.	Flacourtiaceae	0.64	13.5	23.5
Cassipourea congoensis DC.	Rhizophoraceae	0.66	45.5	23.2
Parinari excelsa ssp holstii (Engl.) R Grah.	Rosaceae	0.66	79.0	41.5
Aphloia theaeformis (Willd.) Benth.	Flacourtiaceae	0.69	34.0	21.0
Afrocrania volkensii (Harms) Hutch	Connaceae	0.81	52.4	34.0
Isoberlinia scheffleri (Harms.) Greenway	Caesalpiniaceae	0.85	134.5	54.0
	Average	0.58	55.5	32.9

Table 2. Basal area, stem density, biomass, and carbon stocks of two afromontane rain forests - Eastern Arc Mountains of Tanzania. Basal area reported is based on prism sweep. Numbers in parenthesis show basal area estimated from tree diameters.

Parameter	USAMBARA	ULUGURU
Basal Area (m^2 ha^{-1})	40 ± 8 (104)	30 ± 7 (83)
Stem density (stems ha^{-1})	988 ± 376	1161 ± 397
Tree Biomass (t ha^{-1})		
aboveground	872 ± 28	648 ± 16
roots	183 ± 7	142 ±4
total	1064 ± 35	790 ± 20
Tree Carbon (t ha^{-1})		
aboveground	427 ± 14	318 ± 8
roots	90 ± 3	70 ± 2
total	517 ± 17	388 ± 10
Soil Organic Carbon (t ha^{-1})		
0 – 15 cm depth	246 ± 129	164 ± 57
15 – 30 cm depth	172 ± 70	131 ± 48
Total	418 ± 100	295 ± 53

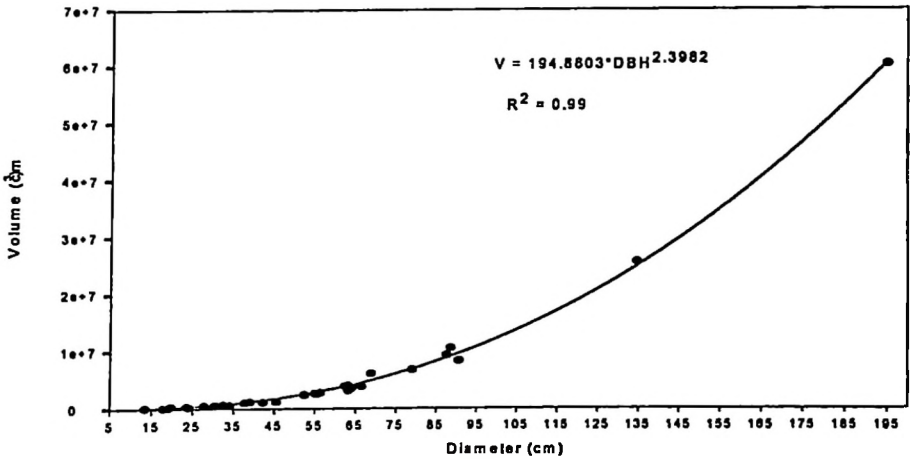

Figure 1. Prediction model for tree volume in two afromontane rain forests of the Eastern Arc Mountains of Tanzania. Model developed from thirty sample trees of thirty different species from the two forests.

Table 3. Biomass and carbon contribution by different species in two afromontane rain forests - Eastern Arc Mountains, Tanzania. Both the local and scientific names are used to name the species. The species are those that contribute each more than 2% of the total forest biomass in each of the forests.

		Usambara			Uluguru		
Local name	**Scientific name**	**Biomass**	**C**		**Biomass**	**C**	
		t/ha	**t/ha**	**%**	**t/ha**	**t/ha**	**%**
Mkulo	*Ocotea usambarensis*	226.9	111	29.4	151.9	74.4	24.9
Mshihwi	*Syzygium guineense*	93.2	45.6	12.4	35.1	17.2	5.7
Mnyasa	*Newtonia buchanani*	59.7	29.2	7.7			
Muula	*Parinari excelsa*	58.5	28.7	7.6	37.9	18.6	6.2
Mpigamagasa	*Isoberlinia scheffleri*	34.3	16.8	4.4			
Msizizi	*Dicranolepis usambarica*	37.9	18.6	4.9			
Mmandai	*Agauria salicifolia*	29.3	14.4	3.8			
Kihambile	*Drypetes usambarica*	22.1	10.9	2.9			
Msambu	*Allanblackia stuhlmanii*	20.6	10.1	2.7			
Msambia	*Pachystela msolo*	17.6	8.7	2.3			
Kuti	*Aningeria adolfi-friederici*	16.9	8.3	2.2			
Msese	*Ficalhoa laurifolia*				92.5	45.3	15.1
Mngobwe	*Symphonia globulifera*				25.8	12.7	4.2
Mkenge	*Albizia gummifera*				21.6	10.6	3.5
Mkani	*Allanblackia ulugurensis*				20.1	9.9	3.3
Msangana	*Strombosia scheffleri*				19.7	9.7	3.2
Mgida	*Macaranga kilimandscharica*				18.2	8.9	2.9
Mpekawake	*Afrocrania volkensii*				13.7	6.7	2.2
Msambwa	*Chrysophyllum gorungosanum*				13.6	6.7	2.2
Mnyagengu	*Trychoscypha ulugurensis*				13.1	6.4	2.1

Table 4. Carbon storage by different plant communities in two afromontane rain forests - Eastern Arc Mountain, Tanzania.

Forest	Community*	Phytomass C (t ha^{-1})	Soil Organic C (t ha^{-1}) 0-15 cm	Soil Organic C (t ha^{-1}) 15-30 cm	Total C (t ha^{-1})	% C	Mean Elevation (m)
Usambara	*Syzygium*	320 ± 155	219 ± 160	141 ± 57	680	9.5 ± 5	1527
	Sorindeia	355 ± 187	147 ± 73	110 ± 59	612	6.8 ± 4	1468
	Strombosia	449 ± 221	168 ± 59	146 ± 59	763	8.2 ± 3	1515
	Ocotea	564 ± 302	338 ± 101	216 ± 47	1118	14.6 ± 4	1662
	Agauria	333 ± 190	338 ± 93	224 ± 42	895	14.9 ± 3	1770
Uluguru	*Myrianthus*	288 ± 173	128 ± 25	92 ± 29	508	5.8 ± 2	1682
	Trichocypha	467 ± 411	139 ± 41	127 ± 46	733	6.9 ± 2	1750
	Syzygium	163 ± 89	166 ± 46	131 ± 39	454	7.7 ± 2	1998
	Symphonia	182 ± 74	164 ± 41	127 ± 24	473	7.6 ± 2	1901
	Ocotea	426 ± 374	206 ± 82	156 ± 61	788	9.4 ± 4	1903

* Communities in order.

Usambara:

. *Syzygium guineense-Sorindeia usambarensis-Parinari exelsa-Newtonia buchanani* forest
. *Sorindeia usambarensis-Parinari exelsa-Newtonia buchanani* forest
. *Strombosia scheffleri-Craibia brevicaudata-Pachystela msolo-Isoberlinia scheffleri* forest
. *Ocotea usambarensis-Syzigium guineense-Parinari exelsa* forest
. *Agauria salicifolia-Ocotea usambarensis-Cryptocarya liebertina* forest

Uluguru

. *Myrianthus arborea-Cussonia spicata-Albizia gumifera-Afrocrania volkensii* forest
. *Trichocypha ulugurensis-Strombosia sheffler-Dasylepis integra* forest
. *Symphonia globulifera-Cassipourea malosana-Syzygium guineense* forest
. *Ocotea usambarensis-Allanblackia stuhlmanii-Symphonia globulifera* forest
. *Syzygium guineense-Allanblackia ulugurensis-Garcinia volkensii* forest

CHAPTER FIVE: RAINFALL INTERCEPTION AND PARTITIONING IN TWO AFROMONTANE RAIN FORESTS OF THE EASTERN ARC MOUNTAINS, TANZANIA: IMPLICATIONS FOR WATER CONSERVATION

ABSTRACT

The aboveground components of the hydrologic cycle of rainforests are important processes that determine the hydrologic behavior and dynamics of these ecosystems. Throughfall, stem flow, canopy interception, and stream flow were measured in two afromontane rain forests in the Eastern Arc Mountains of Tanzania. Measurements were made daily for 50 months in the Ulugurus. In the Usambaras, measurements were made in two different periods; 46 months in 1990-1993 and eight months in 1999. Data were averaged monthly. Throughfall was 76% of the gross rainfall in the Usambaras, 79% in the Ulugurus, and was correlated with gross rainfall ($r^2 = 0.97$ & 0.99). Stem flow was correlated with gross rainfall ($r^2 = 0.86$ & 0.94), and was less than 2% of the gross rainfall. Canopy interception was 23% of rainfall for the Usambaras and 20% for the Ulugurus. Streamflow (stage height) was best modeled using five months running mean rainfall in the Ulugurus ($r^2 = 0.67$) and three to four months in the Usambaras ($r^2 = 0.72$). Despite substantial interception, the effective partitioning of rainfall by the forest canopy delivers more than 75% as net rainfall to the forest floor and provides a reasonable protection against rainfall impact, soil erosion, and storm runoff. The slow response in streamflow to rainfall events shows the efficiency of the forests to mitigate storm water impacts by reducing runoff, delaying the onset of peak flows, and providing flood mitigation. The results are preliminary, and further studies especially on effects of forest harvesting on water yield are pertinent.

Key words: Throughfall, Stemflow, Canopy interception, Streamflow, Rain forest, Eastern Arc Mountains, Net rainfall.

INTRODUCTION

In Tanzania, there is a general view that montane forests secure a continuous supply of water, in other words, forests mean water during the dry season. This is contrary to many studies on the influence of forests on water yield (see Hebert, 1967; Bosch, 1979, 1982; Bosch & Hewlett, 1982; Lal, 1983; Shiklomanov and Krestovsky, 1988). These studies have shown an increase in water yield resulting from reduced evapotranspiration when a forest is cleared. Mountains are of vital importance to the globe as a source of water, typically having higher amounts of precipitation than surrounding lowlands (Price, 2000). Montane forests play an important role in the water cycle, including the capture of atmospheric moisture, storage of water in and beneath canopies, and release to streams (Poc's 1980; Bruen, 1989; Hamilton, 1994; Price, 2000). In semi-arid and arid regions, more than 90 percent of river flow comes from forested mountains (Price, 2000).

To argue for forest conservation for water protection, one should be able to demonstrate the positive effects of a forest on stream flow as it differs from other land uses or non-forested lands. One approach is a paired watershed experiment in which runoff and rainfall are monitored in selected catchments for specific periods around a planned alteration in land use. Alternatively, long term monitoring of a deforested watershed and the effects of forest regrowth on water flow can be used. Estimates of runoff coefficients of forested and non-forested land can be used to assess the effect of the forests on surface runoff generation. High runoff coefficients mean larger amounts of surface runoff and lower base flows (Dune and Leopold, 1978; Bosch & Hewlett, 1982).

The hydrology of a forest ecosystem is complex, and several processes determine the paths of water movement before it reaches streams (Jackson; 1971, 1975; Lundgren and Lundgren, 1979; Lal and Russel, 1981; Jackson, 1989; Bruen 1989; Bjondalein, 1992). These processes include precipitation, interception, throughfall, stemflow, evaporation, and runoff. In most of the tropics, rainfall is the major water input into a catchment. Fog condensation and horizontal precipitation may contribute considerable amounts of water input in mountain forest ecosystems and coastal environments (Ekern, 1964; Bayton, 1969; Juvik & Ekern 1978; Lovett *et al.*, 1982; Shiklamanov and Kestovsky, 1988; Cavelier and Goldstein; 1989 Poc's, 1980; Bruijnzeel, 1990).

Interception is precipitation caught on the forest canopy and returned to the atmosphere by evaporation (Bruijnzeel & Wiersum, 1987; Helvey and Patric, 1965; Bruijnzeel, 1990). The amount of interception depends on the ability of the forest to collect and retain rainfall (interception capacity), storm size and intensity, evaporation rate, vegetation type & density and canopy height, form, and age (Dunne and Leopold, 1978; Shiklamanov and Kestovsky, 1988). Although interception is not a major factor in most hydrologic calculations, it is believed to affect the water balance of montane forests in Tanzania. Throughfall is the rainfall that falls through and from the leaves and forest canopy to the ground surface whereas stemflow is the water that trickles along twigs, surfaces of branches and finally down to the ground surface via the main trunk.

The Eastern Arc Mountains harbor hydrologically important vegetation in Tanzania. Most of these forests are gazetted forest reserves in mountainous areas that are managed for their role as major sources of water (Lundgren, 1979; Poc's, 1980; Tosi *et al.*, 1982; MLNT, 1989; Bruen, 1989; Munishi and Temu, 1992; Bjondalein, 1992; Rodgers and Homewood, 1993).

I am developing an evaluation of the hydrologic values of the Eastern Arc mountain forests. This work will ultimately include intensive long-term assessments of streamflow and effects of forest management, reforestation and partial harvesting in these areas. The major objective of this study was to evaluate the first components measured, i.e., the above - ground processes of the hydrologic cycle of these catchments: precipitation, throughfall, stemflow, canopy interception, and streamflow in two forests.

MATERIALS AND METHODS

Study Sites

The Eastern Arc mountains stretching from southern Tanzania to southern Kenya run as a range of crystalline mountains near the Indian Ocean coast of Tanzania and Kenya (8° 51' S, 34° 49' E to 3° 2' S, 38° 20' E). The ancient crystalline rocks are part of the Precambrian Mozambique belt composed of highly metamorphosed sediments and minor intrusive igneous bodies (Griffiths, 1993; Lovett, 1996), that originated by block faulting

dating back to the Karoo period approximately 300 million years ago (Griffiths, 1993; Lovett, 1996).

The western Usambara Mountains are in the northern part of the range (4° 25' – 5° 07' S, 38° 10' – 38° 35' E). The climate of the Usambaras is oceanic with bimodal rainfall partly determined by their proximity to the Indian Ocean and the equator. Rainfall peaks in April and November. The mean annual rainfall maximum is 2,000 mm in the wettest areas falling to less than 600 mm in the rain shadow areas. The study site in the Usambaras (Mazumbai forest reserve) is on the wetter side of this range. The monthly rainfall averages > 50 mm and the mean annual rainfall is 1,300 mm (Redhead 1979; Hall, 1980; Tosi, *et al.*, 1982; Munishi, pers. obs.). The Usambara Mountains are composed of late Pre-Cambrian rocks of the Usagara system, metamorphic rocks of the gneiss type. The area contains two highland soil types: the Humic Ferrisols in the drier areas and Humic Ferralitic soils in the more humid and wet areas (Hall, 1980). Moist forests occur from 150 m to 2,285 m elevation, on the wetter eastern, southern and northern sides of the mountains (van der Willigen and Lovett, 1979; Lovett, 1996).

The Uluguru north forest reserve covers a steep summit ridge and the northern half of the Uluguru Mountains between Morogoro town and the Mgeta–Bunduki depression within an altitude range of 1,000 m to 2,340 m. The soils are acidic lithosols and ferralitic red, yellow and brown latosols that have developed over Precambrian granulite, gneiss and migmatite rocks (Rapp *et al.* 1972). In the study area, on a northwest to northeast facing slope (on the Bondwa summit – 2,200-m), hornblende-pyroxene granulites are dominant with injections of granite and gneiss as well as some basic intrusions (Rapp *et al.*, 1972). Mean annual rainfall ranges from 1,200 mm - 4,000 mm $year^{-1}$, and temperatures range from 15° C - 22° C. Rainfall and temperature are oceanic with no marked dry season (Lovett and Poc's, 1993) though short dry periods occur with rainfall peaking in April and November. With the exception of rock outcrops the forest reserve is entirely covered with moist sub-montane and montane forests. The study area falls within the montane evergreen forest zones that form a broad belt around both sides of the mountain.

Data Collection

The methods used were designed for long-term monitoring of internal catchment hydrologic processes and water budget studies in the catchment forests of Tanzania (Norden and Munishi, 1995). Three sampling points were established in the Uluguru mountain forests in April 1995 and in the Usambara mountain forests in April 1999. Though subjectively selected, the sites were established to represent as much as possible the different parts of the forests with respect to altitude, forest structure, and exposure. The distance between sites in the same forest was at least one kilometer. In evaluating the relationship between rainfall and streamflow in the Usambaras, a longer period of rainfall and streamflow data set (1990-1993) was used in order to avoid possible errors that may result from short period measurements. The rainfall data in these analyses were from ordinary rain gauges within the watershed.

Thirty, 100 cm x 25 cm troughs with a collecting area of 2,500 cm^2 were located under the forest canopy in three selected sites in the Ulugurus, ten troughs on each site. In the Usambaras, ten 75 cm x 20 cm troughs with a collecting area of 1,500 cm^2 were installed in three sites with three troughs on each site. The collecting area of the troughs in the Usambaras was reduced after lessons from the Ulugurus that the collecting containers were filling up during medium rainstorms.

In each area, two troughs similar to those inside the forests were placed in open areas outside the forest to measure gross rainfall. The troughs were placed in fixed positions, 75 cm above the soil surface with their long axis perpendicular to the slope direction. They were attached to supporting wooden frames and installed at a slanting angle to enable water to flow into funnels that led into sealed plastic containers. The distance between troughs in each site was 10 m. Stemflow was collected from ten randomly selected trees (18 cm – 60 cm dbh, five on each site) in the Ulugurus, and nine trees (25 cm – 56 cm dbh, three on each site) in the Usambaras. Split plastic tubing was spirally wrapped firmly near the base of the tree (about 1.3 m height) to complete one full circumference of the stem, for collection of water flowing down the stem. One end of the tube was attached onto the lid of a plastic container, allowing water to drain into the container. Both throughfall and stemflow were measured daily. The projected crown areas were estimated for each tree with stem flow

measurements. The mean crown areas for all trees in each forest were used to represent the collecting area for stemflow.

Water levels (stage heights) were measured at stream gauging stations with v-shaped 90-degree weirs established downstream of a stream that drains the forests on the experimental sites. In the Ulugurus, stage heights (cm) were recorded by an automatic water level (chart type) recorder that gives continuous recording of water levels. In the Usambaras, stage heights (cm) were measured from a graduated staff gauge installed in the measuring dam and read three times daily: in the morning, the afternoon, and the evening. The daily water level was the average of the three readings.

Data Analyses

The average daily gross precipitation, throughfall, and stemflow volumes were computed as the total rainfall collected by all troughs or trees divided by the number of troughs or trees in each site. The monthly totals were computed as the sum of the daily averages. These monthly totals were divided by the collecting areas (trough area for precipitation and throughfall, and crown area for stemflow) to convert them into mm of precipitation, throughfall, and stemflow per month. Stage heights (m) were averaged on monthly basis. Throughfall, stemflow and streamflow sample events were regressed against gross rainfall to evaluate their relationships and develop prediction models for throughfall stemflow and streamflow from gross rainfall. Paired t-tests were used to evaluate any difference in throughfall and stemflow between experimental sites in the same forest. Graphs were used to further depict and elaborate the relationships between gross precipitation, throughfall, stemflow, and streamflow.

RESULTS

Gross rainfall, throughfall, stemflow, and interception.

Throughfall was 79.3% of the gross rainfall for the Ulugurus. The mean proportion of monthly precipitation partitioned as stemflow was 1%. Canopy interception was 19.7% of the gross rainfall (Table 1). In the Usambaras, throughfall was 76.9% of the gross rainfall, stemflow was 1% of the gross rainfall, and canopy interception was 22.9% of the gross

rainfall (Table 1). Though stemflow constitutes a relatively small proportion of the gross rainfall delivered to the forest floor compared to throughfall, the two showed similar trends (distribution) when compared with gross rainfall (Figure 1).

The monthly mean rainfall was higher in the Ulugurus than in the Usambaras. The proportions of rainfall partitioned as throughfall, net rainfall and interception did not differ much between the two forests (Table 1). Stemflow contributes relatively small amounts of water (1%) to the forest floors in both forests. The minimum amounts were generally lower in the Usambaras, except for interception and net rainfall whose minimum amounts are higher in the Ulugurus (Table1). The range of interception values was almost four times higher in the Ulugurus (62.4 mm) than in the Usambaras (16.3 mm) (Table 1). For most of the sites, there was a significant difference in throughfall and stemflow between sites within the same forest ($p<0.05$) (Table 2). Both throughfall and stemflow showed the same trend of increasing with increasing amounts of monthly precipitation (Figure 2). Throughfall and stemflow were relatively more variable with low rainfall events, but low rainfall events were among those with relatively high amounts of throughfall (Figure 2).

Net rainfall is the actual amount of the gross rainfall delivered to the forest floor after canopy interception. This proportion is a slightly higher in the Ulugurus than in the Usambaras (Table 1). Canopy interception was higher in the Usambaras despite lower stem density (988 ±376) than in the Ulugurus (1164 ±397) and almost identical diameter distribution (mean dbh 25 ±26 in the Usambaras and 22 ± 22 in the Ulugurus). The differences may be accounted for more by storm characteristics, seasonality and probably tree architecture rather than forest structure. Species composition in the Usambaras was different from the Ulugurus and this may account for tree architectural differences.

Modeling the aboveground hydrologic processes in relation to rainfall

Regression of monthly throughfall and stemflow against gross precipitation showed a significant linear relationship in both forests (Table 3). Individual monthly mean rainfall events showed no correlation with streamflow. Streamflow (stage height) was best modeled using a five-year running average rainfall in the Uluguru and three to four years in the Usambaras. Both gross rainfall and net rainfall showed significant linear relationship with

streamflow ($p < 0.01$) (Table 3 & Figure 3). In the Usambaras, the prediction model for streamflow from rainfall (developed from a shorter period of seven months data set) was almost identical to the one developed from a longer period of three years (Table 3).

DISCUSSION

The distribution of precipitation follows the long-term distribution patterns typical of these areas with bimodal annual rainfall patterns (Hall, 1980; Poc's, 1974, 1976a). The existence of a typical pattern of rainfall and runoff in the study sites makes it possible to adequately model throughfall, stemflow and streamflow from gross rainfall using the present data set. The average proportions of the incident rainfall partitioned as throughfall is lower than those in other studies for montane and lowland tropical rain forests though within same range. Bruijnzeel (1990) had a mean estimate of 81 percent ranging from 75% to 86% for tropical montane rain forest, using data from various tropical rain forests which were considered to be long enough to account for seasonal variations in storm patterns and/or vegetation status. Uebel (1997) reported a 96% throughfall when using a shorter data set (3 months) from the Ulugurus. The minimum percent values for throughfall were lower than those given in other studies (Richards *et al.*, 1996). Studies in tropical rain forests have all found that less than 1% of annual rainfall is partitioned as stemflow (Franken *et al.*, 1982; Helvey & Patric, 1966; Jackson, 1971; Manokaran 1979; Nye, 1961; Steinhardt, 1979; Uebel, 1997). Stemflow in this study was slightly higher than that given in these studies from tropical rain forests. Both throughfall and stemflow increased with increasing amount of monthly rainfall as has been shown in other studies of tropical rain forests (Jackson, 1971; Monokaran, 1979; Richards *et al.*, 1996). Small rain events were among those that resulted in high percentages of throughfall. This may be result from rain events that occured when the canopy is fully saturated such that a small amount of rainfall trigges water to start dripping from the forest canopy. Such small rain events may not be recorded in meteorological stations yet they will have caused substantially measurable amounts of throughfall. In other cases fog condensation (occult precipitation, horizontal precipitation) in the forest canopy may be sufficient to cause measurable amounts of throughfall without any rainfall being recorded in meteorological stations outside the forest. Uebel (1997) found

that in several occasions rainfall measured inside the forest was higher than that measured outside the forest in the Ulugurus. This is common in montane cloud forests such as the ones in this study (Poc's, 1980). Other studies have shown that high percent throughfall are common with small rain events in tropical rain forest (Helvey and Patric, 1966).

Due to their close proximity, the differences in stemflow and throughfall between different experimental sites within the same forest (vegetation type) as observed in this study cannot be explained by differences in rainfall. A relevant explanation is likely to be variations in forest structure, such as stem density and diameter distribution. The variation in stem density between plots within the same forest was relatively high, *i.e.*, CV > 30%, the C.V. for diameter was 104%. This means there are wide site variations in forest structure within individual forests that can greatly influence variations in throughfall and stemflow between different sites. Other possible causes may be tree structural and geometrical differences, *e.g.*, vertical stratification and branching geometry. Some investigators have reported less stemflow in large diameter than small diameter trees in tropical rain forests (Bruijnzeel, 1990; Uebel, 1997).

The interception figures observed in this study are higher than those from other studies for tropical rain forests (Lowe, 1974; Lloyd & Marques, 1988; Lu and Tang, 1995; Asdak *et al.*, 1998). On the other hand, they are lower than studies from New Zealand; 42% for a stand of *Kunzea ericoides* (Rowe *et al.*, 1999), 36% for urban forests of broad-leaved evergreens in Sacramento (Xiao *et al.*, 1998), and 65% -75% for bamboo stands of different species (Saengkoovong *et al.*, 1999).

The similarities between the model from short and long data-sets in the Usambaras confirms the strength of the correlation between rainfall and streamflow in these forests, irrespective of rainfall duration. The strong correlation between rainfall, throughfall and stemflow in the two sites is a good indication that streamflow can be predicted adequately from measurements of rainfall where costs for establishment of stream gauging stations are prohibitive. Such relationships may also be enhanced by the presence of the forest vegetation. Interception and the manner in which rainfall is partitioned in the forest canopy is a measure of how efficient a forest ecosystem can mitigate storm water impacts through reduction of runoff volume and delaying peak flows, an important feature of vegetation

biomes managed for water/soil conservation which is true for the Eastern Arc Forests.

CONCLUSION

Canopy interception accounts for at most 20 percent of the rainfall in the Eastern Arc Forests. On average, more than 75 percent of the incident rainfall is delivered to the forest floor by throughfall. Stemflow delivers 1%. The slow response of streamflow (stage height) with storm events is an indication of the potential of these forests to mitigate storm water impacts by reducing runoff volumes and delaying onset of peak flows. The prediction models for throughfall, stemflow, and streamflow are the first to be developed for the forests of the Eastern Arc Mountains of East Africa. The present description and modeling of these processes given here, though preliminary, are important for future development and testing of water balance models, which can help in resource management planning, especially related to changes in land use and water resource conservation. The models may well be useful in similar forest ecosystems elsewhere in the region. Though variations may exist, the models are good approximations where resource constraints prevent extensive studies of the aboveground components of the hydrologic cycle.

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Table 1. Mean monthly throughfall, stemflow, interception, and net rainfall as a percentage of the gross rainfall in two afromontane rain forests of the Eastern Arc Mountains of Tanzania.

Forest	Parameter	Mean and standard error (mm)		% Gross rainfall and standard error		Range
Usambara	Gross rainfall	122.7	24.6			3.1 - 916.7
	Throughfall	97.2	21.3	76.9	2.20	67.9 – 83.9
	Stemflow	0.2	0.1	0.1	0.02	0.1 – 0.2
	Net rainfall	97.3	21.4	77.0	2.30	67.9 – 84.2
	Interception	25.4	3.8	22.9	2.30	15.8 – 32.1
Uluguru	Gross rainfall	247.9	32.2			41.8 - 212.4
	Throughfall	211.7	29.2	79.3	2.30	37.0 – 99.9
	Stemflow	3.2	0.5	1.0	0.10	0.1 – 2.4
	Net rainfall	214.9	29.6	80.4	2.30	37.6 – 102.3
	Interception	33.2	5.5	19.7	2.40	0.0 – 62.4

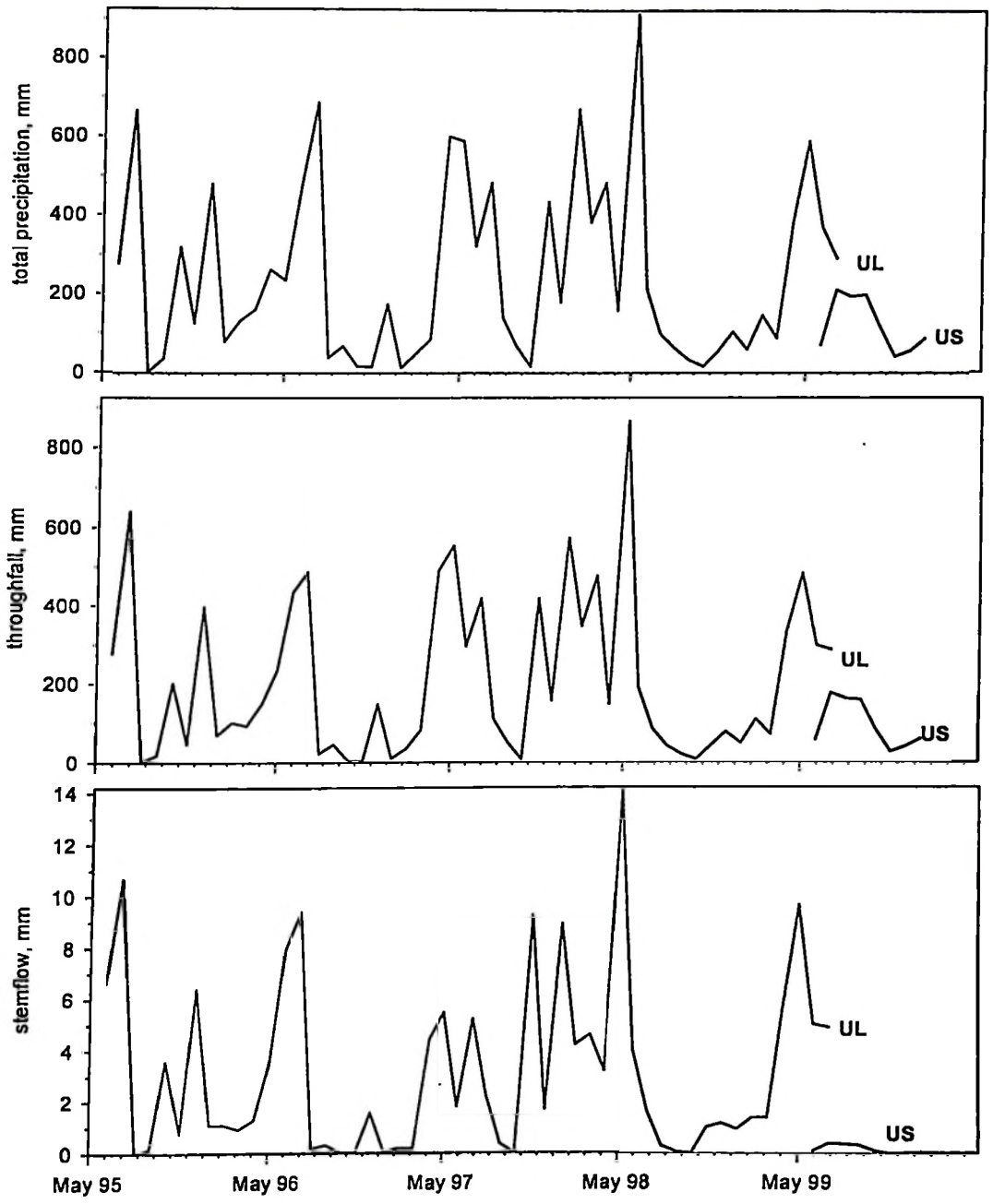

Figure 1. The distribution of monthly mean precipitation, throughfall, and stemflow in two afromontane rain forests of the Eastern Arc Mountains of Tanzania. Stemflow accounts for a relatively small proportion of the net precipitation entering the ecosystem. UL = Uluguru, US = Usambara forests.

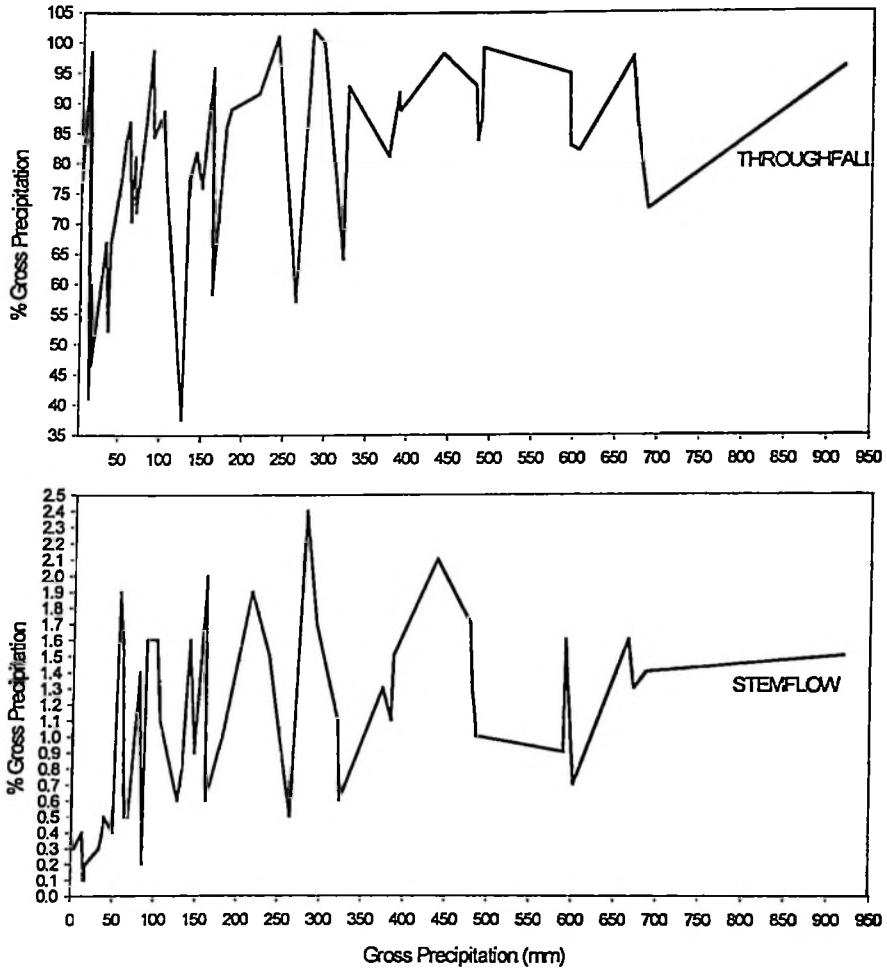

Figure 2. Throughfall and stemflow response to monthly precipitation events in an afromontane rain forest, Ulugurus, Eastern Arc Mountains of Tanzania. The monthly mean throughfall and stemflow were plotted against an increasing monthly mean gross precipitation. There was an increasing trend in throughfall and stemflow with increasing monthly precipitation.

Table 2. Paired t-test (p-values) showing within forest differences in throughfall and stemflow in two afromontane rain forests of the Eastern Arc Mountains of Tanzania. Most of the sites showed significant differences in throughfall and stemflow.

Forest	Site	Throughfall	Stemflow
Usambara	1&2	0.009	0.009
	1&3	0.020	0.010
	2&3	0.004	0.003
Uluguru	1&2	0.030	<0.001
	1&3	0.050	<0.001
	2&3	0.410	0.040

Table 3. Prediction models for throughfall (mm), stemflow (mm), and streamflow from gross rainfall (mm) and net rainfall (mm) in two afromontane rain forests of the Eastern Arc Mountains of Tanzania. Streamflow was measured as stage height (m). The p-value for every model shown is <0.01.

Forest	Model			r^2	Period (months)
ULUGURU	Throughfall	=	0.893Rainfall – 3.94	0.97	50
	Stemflow	=	0.014Rainfall – 0.30	0.86	50
	Streamflow	=	0.00093Rainfall + 0.23	0.67	37
	Streamflow	=	0.00099NetRainfall + 0.25	0.69	37
USAMBARA (a)	Throughfall	=	0.86Rainfall – 8.5	0.99	8
	Stemflow	=	0.002Rainfall – 0.09	0.94	8
	Streamflow	=	0.00091Rainfall + 0.20	0.72	7
	Streamflow	=	0.0009NetRainfall + 0.20	0.72	7
(b)[1]	Streamflow	=	0.0006Rainfall + 0.20	0.73	46

[1] This model was developed using a longer data set from the Usambaras (March, 1990-December, 1993). The model for the short and long data set are almost identical.

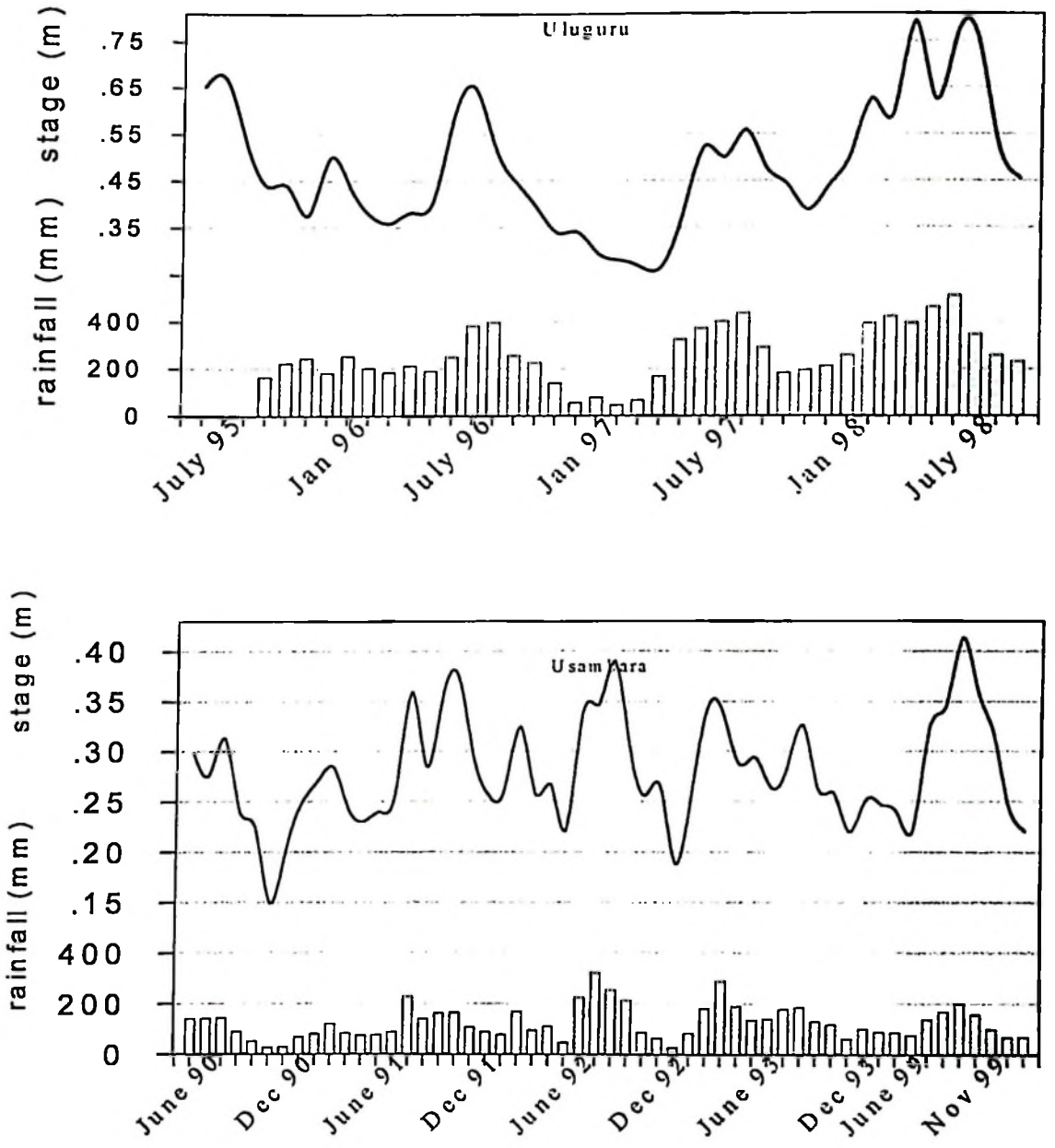

Figure 3. Response of streamflow (stage height) to rainfall in two afromontane rain forests of the Eastern Arc Mountains of Tanzania. The stage height was best modeled using a five month running mean of rainfall in the Ulugurus and four months in the Usambaras.

APPENDICES

Appendix I: Computational Formulae for Vegetation Description

Basal area: Area occupied by a cross section of the stem at breast height

Relative Density: Density of a species/Density of all species

Relative Dominance: Total basal area of a species/Total basal area of all species

Relative Frequency: Number of times a species is encountered in a plot

Diversity: Number of different species in each plot

Richness: Total number of species in a plot

Importance Value Index (IV): the sum of relative density and relative dominance/2.

Index of Dominance: $C = (n_i/N)^2$ where C = index of dominance, n_i = importance value of each species, or number of individuals, or biomass, N = total importance values or total biomass or total number of plants/trees (Ambasht, 1988; Misra, 1989, in References in chapter 3)

Appendix II: A list of tree species ≥ 6 cm dbh enumerated in an afromontane rain forest in the west Usambaras, Eastern Arc Mountains, Tanzania. There were 69 tree species belonging to 36 families. Local names in Kisambaa. Local names are not available for all species.

Code	Local Name	Botanical Name	Family
Acne	Zengangoto	*Acalypha neptunica* Muell. Arg.	Euphorbiaceae
Agsa	Mmandai	*Agauria salicifolia* (Lam.) Oliv.	Ericaceae
Algu	Mshai	*Albizia gummifera* (Gmel.) C. A. Sm.	Mimosaceae
Alst	Msambu	*Allanblackia stuhlmanii* Engl.	Guttiferae
Alab	Mbangwe	*Allophylus abyssinicus* (Horscht) Radlik	Sapindaceae
Anad	Kuti	*Aningeria adolfi-friederici* (Engl.) Robyns & Gilbert	Sapotaceae
Apth	Mdananda	*Aphloia theaeformis* (Willd.) Benth.	Flacourtiaceae
Apdi	Mwazanyiko	*Apodytes diminidiata* E. Meyer ex Arn.	Icacinaceae
Beab	Mbamba	*Bersama abyssinica* Fres.	Melianthaceae
Cawe	Mjambega	*Caloncoba welwitschii* (Oliv.) Gilg.	Flacourtiaceae
Caen	Mkokoko	*Casearia englerii* Gilg.	Flacourtiaceae
Cama	Nekazito	*Cassipourea congoensis* DC.	Rhizophoraceae
Como	Mbuni	*Coffea mongensis* Bridson	Rubiaceae
Cogr	Muungu	*Cola greenwayii* Bren.	Sterculiaceae
Crbr	Mhande	*Craibia brevicaudata* (Vatke) Dunn.	Papilionaceae
Crma	Mshunduzi	*Croton macrostachys* Hochst ex. A Rich.	Euphorbiaceae
Crli	Mtonte	*Cryptocarya liebertina* Engl.	Lauraceae
Cusp	Tendele	*Cussonia spicata* Thunb.	Araliaceae
Cyma	Ong'e	*Cyathea maniana* Engl.	Cyatheaceae
Dale	Kigwande	*Dasylepis leptophylla* Gilg.	Anacardiaceae
Deki	Mbwakabwaka	*Deinbolia kilimandscharica* Taub.	Sapindaceae
Dius	Msizizi	*Dicranolepis usambarica* Engl.	Annonaceae
Dimo		*Diphasia morogorensis* Kokw.	Rutaceae
Draf	Kingwee	*Dracaena afromontana* Mildbr.	Agavaceae
Drus	Kihambile	*Drypetes usambarica* (Pax) Hutch.	Euphorbiaceae
Ende	Mbokoboko	*Entandrophragma deiningeri* Harms	Meliaceae
Erem		*Erythroxylum emarginatum* Schinz & Thorn.	Erythroxylaceae
Fasp	Mhombehombe	*Fagara* sp.	Rutaceae
Faan	Mkunguni	*Fagaropsis angolensis* (Engl.) Dale	Rutaceae
Fila	Mkuka	*Ficalhoa laurifolia* Hiern	Theaceae
Fith	Mvumo	*Ficus thoningii* Blume.	Moraceae
Gavo	Ndemzize	*Garcinia volkensii* Engl.	Guttiferae
Grsu		*Greenwayodendron suaveolens* (Engl. & Diels) Verdc.	Annonaceae
Grri	Mkeampindi	*Grumillea riparia* K.Schum & K. Krause	Rubiaceae
Hiin		*Hippocrata indica* Willd.	Celastraceae
Issc	Mpigamagasa	*Isoberlinia scheflerii* (Harms) Greenway	Caesalpiniaceae
Laki	Ugoroto	*Landolphia kirkii* Dyer	Apocyaceae
Leus	Zonozono	*Leptonichia usambarensis* K. Schum.	Sterculiaceae
Maki	Mkumba	*Macaranga kilimandscharica* Pax.	Euphorbiaceae

Appendix ii cont.

Code	Local Name	Botanical Name	Family
Mala	Mteli	*Maesa lanceolata* Forsk.	Myristicaceae
Maac	Mmamata	*Maytenus acuminatus* (L.f.) Low.	Celastraceae
Maun	Mtundakunguru	*Maytenus undatus* (Thumb) Blackelock.	Celastraceae
Myar	Mkonde	*Myrianthus arboreus* P. Beauv.	Moraceae
Mysa	Mshegeshe	*Myrica salicifolia* Hochst. ex. A Rich.	Myricaceae
Nebu	Mnyasa	*Newtonia buchanani* (Bak.) Gilb. &Bout.	Mimosaceae
Ocho	Ntakua	*Ochna holstii* Engl.	Ochnaceae
Ocus	Mkulo	*Ocotea usambarensis* Engl.	Lauraceae
Pams	Msambia	*Pachystela msolo* Engl.	Sapotaceae
Paex	Muula	*Parinari exelsa* Sabine ssp. *holstii* Engl. R. Grah.	Rosaceae
Papa	Kuyu	*Pauridiantha paucinervis* (Hiern.) Bremek. ssp. *holstii* (K. Schum). Verdc.	Rubiaceae
Pefi	Mkisigizi	*Pediea fisceri* Engl.	Thymelaceae
Phus	Sheruti	*Philippia usambarensis* (Arm + Th.Fr.)	Ericaceae
Pous	Podo	*Podocarpus usambarensis* (Pilg.)	Podocarpaceae
Pofu	Kogo	*Polycias fulva* (Hiern.) Harms.	Araliaceae
Rarh	Mweeti	*Rapanea rhododendroides* (Gilg.) Mez.	Myristicaceae
Ravo	Kiiga	*Rauvolfia volkensii* (Schum.) Stapf.	Apocynaceae
Ryst	Twavuha	*Rytigynia stuhlmanii* Robyns	Rubiaceae
Sale	Kihankongoto	*Salacia lehmbarchii* Loes	Celastraceae
Scrh	Mtiwampaa	*Scolopia rhamniphylla* Gilg.	Flacourtiaceae
Sous	Mkunguma	*Sorindeia usambarensis* Engl.	Anacardiaceae
Stsc	Sangana	*Strombosia schefleri* Engl.	Olacaceae
Sycu	Mwiza	*Syzygium cumini* (L.) Skeels	Myritaceae
Sygu	Mshihwi	*Szygium guineense* (Willd) DC	Myritaceae
Team	Kwati	*Teclea amaniensis* Engl.	Rutaceae
Trro	Mgoimazi	*Trichilia roca* (Forsk.) Chiov.	Meliaceae
Turo	Dwayu	*Turaea robusta* Guerke.	Meliaceae
Vato	Mvilu	*Vangueria tomentosa* Hochst.	Rubiaceae
Vest		*Vepris stolzii* Verdoorn.	Rutaceae
Zegr	Muambe	*Zenkerella grottei* (Harms) J. Lear	Ceasalpiniacea

Appendix III: A list of tree species ≥ 6 cm dbh enumerated in an afromontane rain forest in the Ulugurus, Eastern Arc Mountains, Tanzania. There were 90 tree species belonging to 43 families. Local names in Kiluguru. Local names are not available for all species.

Code	Local Name	Botanical Name	Family
Afvo	Mpekawake	*Afrocrania volkensii* (Harms) Hutch.	Connaceae
Afsp	Msambwa	*Afrosersalisia* sp.	Sapotaceae
Agsa	Myunguvo	*Agauria salicifolia* (Comm. ex Lam.) Hook f. ex Oliv.	Ericaceae
Algu	Mkenge	*Albizia gummifera* (Gmel) C.A. Sm.	Mimosaceae
Alul	Mkani mweusi	*Allanblackia ulugurensis* Engl	Guttiferae
Alab	Msemelele	*Allophyllus abysinicus* (Hochst.) Radlk.	Sapindaceae
Alfe	Lengolengo	*Anthocleista grandiflora* Gilg.	Loganiaceae
Apth	Kihange	*Aphloia theaeformis* (Willd) Benth.	Flacourtiaceae
Basc	Muhombo	*Balthasaria schliebenii* (Melchior.) Verdc.	Theaceae
Beab	Mkande	*Bersama abysinica* Fresen.	Melianthaceae
Brsa	Mgeremamondo	*Breonadia salicina* (Vahl.) Hepper & Wood	Rubiaceae
Brmi	Msumba	*Bridelia micrantha* (Hochst) Baill	Euphorbiaceae
Brsp		*Bridelia* sp.	Euphorbiaceae
Caol	Msada mweupe	*Canthium oligocarpum* Hiern.	Rubiaceae
Cama	Msingizi	*Cassipourea malosana* (Bak.) Alston	Rhizophoraceae
Casp	Msingizi mweupe	*Cassipourea* sp.	Rhizophoraceae
Chdi		*Chassalia discolor* K. Schum.	Rubiaceae
Chpa		*Chassalia parvifolia* K. Schum.	Rubiaceae
Chab		*Chazaliella abrupta* (Hiern) Petit & Verdc.	Rubiaceae
Chgo	Msambwa	*Chrysophyllum gorungosanum* Engl.	Sapotaceae
Chsp	Msambwa	*Chrysophyllum* sp.	Sapotaceae
Cogr	Mkole	*Cola greenwayi* Bren.	Sterculiaceae
Crli		*Cryptocarya liebertiana* Engl.	Lauraceae
Cusp	Mlengela	*Cussonia spicata* Thunb.	Araliaceae
Cyus	Msembe	*Cyathea usambarensis* Hieron	Cyatheaceae
Dain	Mtati mweusi	*Dasylepis integra* Warb.	Flacourtiaceae
Deki	Mnyagengu mwekundu	*Deinbolia kilimandscharica* Taub.	Sapindaceae
Dius	Msizizi	*Dicranolepis usambarica* Engl.	Annonaceae
Dole	Lukwezi	*Dombeya leucoderma* K. Schum.	Sterculiaceae
Drla	Mhenga	*Dracaena laxissima* Engl.	Agavaceae
Fasa	Msomola	*Faurea saligna* Engl.	Proteaceae
Fila	Msese	*Ficalhoa laurifolia* Hiern.	Theaceae
Fiot	Msole	*Ficus ottomifolia* (Miq) Miq. ssp. *ulugurensis*	Moraceae
Fisy	Mkuyu	*Ficus sycomorus* L.	Moraceae
Flsp	Mgogandima	*Flacourtia* sp.	Flacourtiaceae
Gaco		*Galiniera coffeoides* Del.	Rubiaceae
Gahu		*Garcinia huillensis* Oliv.	Gutiferae
Gavo	Mkani mweupe	*Garcinia volkensii* Eng.	Guttiferae
Japi	Mnyagengu	*Jaundea pinnata* (Beauv.) Schell.	Connaraceae

Appendix iii cont.

Code	Local Name	Botanical Name	Family
Lace	Kizangwa	*Lasianthus ceriflorua* E. A. Bruce	Rubiaceae
Lski	Kizangwa	*Lasianthus kilimandscharicus* K. Schum.	Rubiaceae
Lama		*Lasianthus macrocalyx* K. Schum.	Rubuaceae
Lape		*Lasianthus pendunculatus* Bruce	Rubiaceae
Maki	Mgida	*Macaranga kilimandscharica* Pax.	Euphorbiaceae
Mala	Mnguti	*Maesa lanceolata* Forsk.	Myristicaceae
Masp	Mfiro	*Maytenus* sp.	Celastraceae
Maun	Mfuta	*Maytenus undatus* (Thunb.) Blackelock	Celastraceae
Meve		*Memecylon verruculosum* Brenan	Melastomataceae
Myar	Mlowelowe	*Myrianthus arboeus* P. Beanv.	Moraceae
Mysa	Kivumba	*Myrica salicifolia* Hochst. ex A. Rich.	Myricaceae
Nebu	Mkuvi	*Newtonia buchananii* (Bak.) Gilb. & Bout.	Mimosaceae
Ocma		*Ochna macrocalyx* Oliv.	Ochnaceae
Ocmo	Mnyasungu	*Ochna mossambicensis* Klotzch.	Ochnaceae
Ocus	Mseri	*Ocotea usambarensia* Engl.	Lauraceae
Oleu	Mhalasindi	*Olea europaea* L.	Oleaceae
Onsp	Mzona	*Oncoba spinosa* Forsk.	Flacourtiaceae
Ousc		*Ouratea scheffleri* Engl.	Ochnaceae
Oxgo	Mng'ongo	*Oxyanthus goetzei* K..Schum.	Rubiaceae
Oxsp	Mmbugi	*Oxyanthus speciosus* DC	Rubiaceae
Paex	Mngama	*Parinari excelsa* Sabine ssp *holstii* (Engl.) R. Grah.	Chrysobalanaceae
Papa	Mbabala mweupe	*Pauridiantha paucinervis* (Hurn.) Brenn. ssp. holstii (K. Schum) Verdc.	Rubiaceae
Pabr		*Pavetta bruceana* Bremek.	Rubiaceae
Pefi	Chohasesi	*Peddiea fischeri* Engl.	Thymelaceae
Pesu	Choasesi mwekundu	*Pediea subcordata* Donke	Thymelaeaceae
Phos	Ukindu	*Phoenix* sp.	Palmae
Pomi	Kinyanziri	*Podocarpus milanjianus* Radlk	Podocarpaceae
Pofu	Mkongonelo	*Polycias fulva* (Herm.) Hams.	Araliaceae
Posp		*Polysphaeria* sp.	Rubiaceae
Prpo	Msingizi mwekundu	*Pristimera polyantha* (Loes) N. Halle	Celastraceae
Praf	Mgegewe	*Prunus africana* Hook.f.	Rosaceae
Psgo	Mbabala mweusi	*Psychotria goetzei* (K. Schum.) Petit	Rubiaceae
Psys	Mbabala	*Psychotria* sp.	Rubiaceae
Rarh	Mgeremamondo	*Rapanaea rhododendroides*	Myrsinaceae
Raca		*Rauvolfia cafra* Sond.	Apocynaceae
Rare	Chambaza	*Rawsonia reticulata* Gilg.	Flacourtiaceae
Rhch		*Rhipidiantha chlorantha* (K.Schum.) Bremek	Rubiaceae
Scrh	Mwanganapalu	*Scolopia rhamniphylla* Gilg.	Flacourtiaceae
Stsc	Msangana	*Strombosia scheffleri* Engl.	Olacaceae
Strs		*Strychnos* sp.	Loganiaceae
Suza		*Suregoda zanzibarensis* (Baill.) Muell. Arg.	Euphorbiaceae

Appendix iii cont.

Code	Local Name	Botanical Name	Family
Sygl	Mngobwe	*Symphonia globulifera* L.f.	Guttiferae
Syse	Msambwa mwekundu	*Synsepalum seraciferum* (Welw.) Pennington	Sapotaceae
Sygu	Mmusu	*Syzygium guineense* (Willd.) DC	Myrtaceae
Tave	Kigomvu	*Tabernaemontana ventricosa* (Hochst) ex ADC	Apocynaceae
Trsp	Mbefu	*Trema orientalis* (L.) Bl.	Ulmaceae
Tris	Msingizi mweupe	*Tricalysia* sp.	Rubiaceae
Trul	Mng'ongo	*Trichoscypha ulugurensis* Mildbr.	Anacardiaceae
Vest		*Vepris stolzii* Verdoon	Rutaceae
Vido	Mfulu	*Vitex doniana* Schumm. & Thonn.	Verbenaceae
Zesc	Mtati mweupe	*Zenkerella schliebenii* (Harms.) J. Leonard	Caesalpiniaceae

Appendix IV: A list of vascular plants identified in an afromontane rain forest in the West Usambaras, Eastern Arc Mountains, Tanzania. There were 262 species belonging to 81 families. Local names in Kisambaa. Local names are not available for all species

Code	Local Name	Botanical Name	Family
Acsc	Keefu	*Acacia schweinfurthii* Brenan. & Exell.	Mimosaceae
Acne	Zengangoto	*Acalypha neptunica* Muell. Arg.	Euphorbiaceae
Acca		*Achyrospermum carvalhi* Guerke,	Labiatae
Acra		*Achyrospermum radicans* Guerke.	Labiatae
Acal		*Acridocarpus alopecurus* Sprague	Malpighiaceae
Adci	Ghoe	*Adenia cissampeloides* (Planch.) Harms.	Passifloraceae
Afsp		*Afromomum* sp.	Zingiberaceae
Agsa	Mmandai	*Agauria salicifolia* (Lam) Oliv.	Ericaceae
Algu	Mshai	*Albizia gummifera* (Gmel.) C. A. Sm.	Mimosaceae
Alhi	Shaza	*Alchornea hirtella* Benth.f. (Pain) Pax & K. Hoff.	Euphorbiaceae
Alst	Msambu	*Allanblackia stuhlmanii* Engl.	Guttiferae
Alab	Mbangwe	*Allophylus abyssinicus* (Horchst.) Radlk.	Sapindaceae
Amgr	Tongotongo	*Ampelocissus grantii* (Bak.) Planch.	Vitaceae
Anad	Kuti	*Aningeria adolf-freidercii* ssp usambarensis (Engl) Robyns & Gilbert, J.H. Hemsley	Sapotaceae
Atus		*Anthospermum usambarense* K. schum.	Rubiaceae
Apth	Mdananda	*Aphloia theaeformis* (Willd.) Benth.	Flacourtiaceae
Apdi	Mwazanyiko	*Apodytes diminidiata* (Willd.) Benth.	Icacinaceae
Arto	Mlazi	*Arundinaria tolange* K. Schum.	Graminae
Asfa	Uinikanguu	*Asparagus facatus* L.	Liliaceae
Asae	Kishimto	*Asplenium aethopicum* (Brun .f) Becherer	Aspleniaceae
Asba	Kishimto	*Asplenium barteri* Hook.	Aspleniaceae
Asch	Kishimto	*Asplenium christii* Hieron.	Aspleniaceae
Asel	Kishimto	*Asplenium eliottii* C. H. Wright	Aspleniaceae
Asfr		*Asplenium friesiorum* C.Chr.	Aspleniaceae
Asho		*Asplenium holstii* Hieron.	Aspleniaceae
Asme	Kishimto	*Asplenium megalura* Hieron.	Aspleniaceae
Assp	Kishimto	*Asplenium* sp.	Aspleniaceae
Asth		*Asplenium theciferum* (Kunth.) Mett.	Aspleniaceae
Asus	Kishimto	*Asplenium usambarense*Hieron	Aspleniaceae
Basc		*Balthazaria schliebenii* (Melchior.) Verdc. var. greenwayi (Verdc.) Verdc.	Theaceae
Beab	Mbamba	*Bersama abyssinica* var. usambarica Fres ssp. *paulinioides* (Planch) Verdc. (Gurke) Verdc.	Melianthaceae
Blna	Kishimto II	*Blotiella natalensis* (Hook) Tryon	Dennstaediaceae
Brho	Shikizi I	*Brachystephanus holstii* Lindau.	Acanthaceae
Brsp		*Brachystephanus* sp.	Acanthaceae
Brma	Vimbamazi	*Brillantaisia madagascariensis* (TAnders) Lindau.	Acanthaceae
Brte		*Brucea temifolia* Engl.	Simaroubaceae
Bufi		*Bulbostylis filamentosa* Roen. & Schultz.	Cyperaceae
Byor		*Byrsocapus orientalis* (Baill) Bak.	Connaraceae

Appendix iv cont.

Code	Local Name	Botanical Name	Family
Cawe	Mjambega	*Caloncoba welwitschii* (Oliv.) Gilg	Flacourtiaceae
Caol		*Canthium oligocarpum* Hiern.	Rubiaceae
Cach		*Carex chlorosaccus* L.B.CL.	Cyperaceae
Caen	Mkokoko	*Casearia engleri* Gilg.	Flacourtiaceae
Caco	Nekazito	*Cassipourea congoensis* DC	Rhizophoraceae
Cesy		*Senecio syringifolius* O. Hoffm.	Compositae
Chal		*Chassalia albiflora* K. Krawse	Rubiaceae
Chdi		*Chassalia discolar* K. Schum.	Rubiaceae
Chpa	Kuyu I	*Chassalia parvifolia* K. Schum	Rubiaceae
Chum	Shikizi II	*Chassalia umbraticola* (Vatke) ssp. *umbraticola*	Rubiaceae
Chmu	Kishimto	*Cheilanthes multifida* (Swartz.) Swartz.	Adiantaceae
Chfi		*Chlorophytum filipendulum* Baker	Liliaceae
Chde		*Christella dentata* (Forssk) Brownsey & Jermy	Thelipteridaceae
Chmo	Msiwasiwa	*Chrysanthemoides monilifera* ssp. *septentrinoides* (L.) T. Norl	Compositae
Cipa		*Cissampelos parura* L.	Menispemaceae
Ciol		*Cissus oliveri* (Engl.) Kilg.	Vitaceae
Ciro		*Cissus rotundifolia* Vahl.	Vitaceae
Cisp		*Cissus* sp.	Vitaceae
Clan		*Clausena anisata* (Willd.) Brenth	Rutaceae
Clci		*Clenitis cirrhosa* (Schum) Chang	Aspidiaceae
Clce		*Clerodendrum cephalanthum* Oliv.	Verbenaceae
Clmy		*Clerodendrum myricoides* (Thumb) Blakelock	Verbenaceae
Clsc	Mzuma	*Clerodendrum scheffleri* Guerke	Verbenaceae
Clsp	Hanganeka	*Clerodendron* sp.	Verbenaceae
Como	Mbuni	*Coffea mongensis* Bridson	Rubiaceae
Cosp		*Coffea* sp.	Rubiaceae
Cogr	Muungu	*Cola greenwayii* Bren.	Sterculiaceae
Cola		*Commelina latifolia* (A. Rich.)	Commelinaceae
Coae		*Conyza aegyptiaca* (L.) Ait	Compositae
Crbr	Mhande	*Craibia brevicaudata* (Vatke) Dunn. ssp. *schliebenii* (Harms) Gillett	Papilionaceae
Crtr		*Cremaspora triflora* (Thonn) K. Schum.	Rubiaceae
Crri		*Crossandra tridentata* Lindau	Acanthaceae
Crlu		*Crotolaria lukwangulensis* (Harms.)	Papilionaceae
Crsp		*Crotolaria* sp.	Papilionaceae
Crma	Mshunduzi	*Croton macrostachys* Hochst. ex A. Rich.	Euphorbiaceae
Crli	Mtonte	*Cryptocarya liebertiana* Eng.	Lauraceae
Cusc	Kiamdama	*Culcacia scandens* (Willd) P. Beanv.	Araceae
Cusp	Tendele	*Cussonia spicata* Thunb.	Araliaceae
Cyma	Ong'e	*Cyathea maniana* Hieron.	Cyatheaceae
Cyus	Hong'e	*Cyathea usambarensis* Hieron.	Cyatheaceae
Cypl		*Cynorhis pleistadenia* Reichbf.	Orchidaceae
Cymr	Siga	*Cyperus maranguensis* K. Schum.	Cyperaceae

Appendix iv cont.

Code	Local Name	Botanical Name	Family
Cysp	Kangaga	*Cyperus* sp.	Cyperaceae
Cybr	Mzuma	*Cyphostema braunii* (Gilg. &Br.) Gilg Br.	Vitaceae
Cpho	Ngomano	*Cyphostema* sp.	Vitaceae
Dala	Kowa	*Dalbergia lactea* Vatke.	Papilionaceae
Dale	Kigwande	*Dasylepis leplophylla* Gilg.	Flacourtiaceae
Deki	Mbwakabwaka	*Deinbolia kilimandscharica* Taub var. *kilimandscharica*	Sapindaceae
Dead		*Desmodium adscendens* (Sw.) DC.	Papilionaceae
Diei		*Dichapetalum eickii* Ruhl.	Dichapetalaceae
Dius	Msizizi	*Dicranolepis usambarica* Engl.	Annonaceae
Ditr		*Didymochlaena truncatula* (Schwarb.) JSM.	Aspidiaceae
Dihy	Mchunju	*Dioscorea hylophila* Harms.	Dioscoreaceae
Dilo		*Dioscorea longicuspis* K. Kunth.	Dioscoreaceae
Dimo	Mshefu	*Diphasia morogorensis* Kokw.	Rutaceae
Doho	Msimbampuku	*Dorstenia holstii* Engl.	Moraceae
Dosc		*Dorstenia schlechteri* Engl.	Moraceae
Dosp	Msimbampuku	*Dorstenia* sp.	Moraceae
Draf	Kingwee	*Dracaena afromontana* Engl	Agavaceae
Drla		*Dracaena laxissima* Eng.	Agavaceae
Drin		*Dryopteris inaequalis* (Schlecht) Kuntze	Aspidiaceae
Drma		*Dryopteris manniana* (Hook) C. Chr.	Aspidiaceae
Drge		*Drypetes gerrardii* Hutch.	Euphorbiaceae
Drus	Kihambile	*Drypetes usambarica* (Pax) Hutch.	Euphorbiaceae
Ekca	Monko	*Ekebergia capensis* Sparm.	Meliaceae
Elpa		*Elafostema paivaeanum* Wedd.	Urticaceae
Ella	Kiandama	*Elaphoglosum lastii* (Bak) C. Chr.	Umbelliferae
Elmi		*Ellaphoglosum milbraedii* Hieron.	Umbelliferae
Ende	Mbokoboko	*Entandrophragma deiningeri* Harms.	Meliaceae
Erus		*Eragrostis usambarensis* Napper	Graminae
Ersp		*Erlangea* sp.	Compositae
Erem		*Erythroxylum emarginatum* Schinz. & Thorn.	Erythroxylaceae
Fasp	Mhombehombe	*Fagara* sp.	Rutaceae
Faan	Mkunguni	*Fagaropsis angolensis* (Engl.) Dale	Rutaceae
Fila	Mkuka	*Ficalhoa laurifolia* Hiern.	Theaceae
Fith	Mvumo	*Ficus thoningii* Bl.,	Moraceae
Flla	Tufya	*Fleurya lanceolata* Engl.	Urticaceae
Frem		*Fruthrophyllun emargimatum* Schine & Thorn.	Erythroxylaceae
Gavo	Ndemzize	*Garcinia volkensii* Engl.,	Guttiferae
Grso		*Greenwayodendron* sp.	Annonaceae
Grsu		*Greenwayodendron suaveolens* (Engl. & Diels) Verdc.	Annonaceae
Grri	Mkeampindi	*Grumilea riparia* K. Schum & K. Krause	Rubiaceae
Hami		*Habenaria micrandra* Lindl.	Orchidaceae

Appendix iv cont.

Code	Local Name	Botanical Name	Family
Hadi		*Hainsenia diervilleoides* K. Schum.	Rubiaceae
Hecy		*Helichrysum cymosum* ssp. *fruticosum* (L.) Less, (Forsk.) Hedb.	Compositae
Hiin		*Hippocratea indica* Willd.	Celastraceae
Hyku		*Hymenophyllum kuhnii* C. Chr.	Hymenophyllaceae
Imsp	Tuanange	*Impatiens* sp.	Balsamiaceae
Imwa	Tuanange	*Impatiens walleriana* Hook. f.	Balsamiaceae
Issc	Mpigamagasa	*Isoberlinia scheffleri* (Harms) Greenway	Caesalpiniaceae
Islu		*Isoglosa lutea* Lindau	Acanthaceae
Japi		*Jaundea pinnata* (P. Beanv.) Schell.	Connaraceae
Juan		*Justicia anisophylla* (Mildbr.) Stumm.	Acanthaceae
Jups		*Justicia pseudorungia* Lindau	Acanthaceae
Juwh	Tikini	*Justicia whytei* Moore	Acanthaceae
Kequ		*Keetia queinzii* (Sonder) Bridson	Rubiaceae
Laki	Ugoroto	*Landolphia kirkii* Dyer	Apocynaceae
Lasp		*Landolphia* sp.	Apocynaceae
Lski		*Lasianthus kilimandscharica* K Schum.	Rubiaceae
Leus	Zonozono	*Leptonychia usambarensis* K. Schum.	Sterculiaceae
Loho		*Lobelia holstii* Engl.	Lobeliaceae
Lycl		*Lycopodium clavatum* (L.)	Lycopodiaceae
Lysp		*Lycopodium sp.*	Lycopodiaceae
Maki	Mkumba	*Macaranga kilimandscharica* Pax	Euphorbiaceae
Mala	Mtei	*Maesa lanceolata* Forsk	Myristicaceae
Maac	Mmamata	*Maytenus acuminatus* (L f) Loes	Celastraceae
Maun		*Maytenus undatus* (Thumb) Blackelock	Celastraceae
Memi	Fuiza	*Melothria microsperma* (Hook.f.) Cogn.	Cucurbitaceae
Mede	Kihagio	*Memecylon deminitum* Brenan	Melastomataceae
Meve		*Memecylon verruculosum* Brenan	Melastomataceae
Mian		*Microglossa angolensis* O. & H.	Compositae
Mibu		*Milletia bussei* Harms.	Papilionaceae
Mius	Mhafa	*Milletia usambarensis* Taub.	Papillionaceae
Miki	Shikizi	*Mimulopsis kilimandscharica* Lindau	Acanthaceae
Moca	Kishimto	*Mohria caffrorum* (L.) Desv.	Schizaeaceae
Mosp		*Momordica* sp,	Curcubitaceae
Mnsp	Tundakunguru	*Monanthotaxis* sp.	Annonaceae
Moju		*Monodora junadii* Engl. et. Diels. Vel. Aff.	Annonaceae
Mons		*Monodora* sp.	Annonaceae
Muqu	Msoo	*Mucuna quadrialata* Bak.,	Papilionaceae
Myar	Mkonde	*Myrianthus arboreus* P. Beauv.	Moraceae
Mysa	Mshegeshe	*Myrica salicifolia* Hochst. ex A. Rich.	Myricaceae
Nebu	Mnyasa	*Newtonia buchanani* (Bak.) Gilb. & Bout.	Mimosaceae
Ocho	Mtodoti	*Ochna holstii* Engl.	Ochnaceae
Ocus	Mkulo	*Ocotea usambarensia* Engl.	Lauraceae

Appendix iv cont.

Code	Local Name	Botanical Name	Family
Oldi		*Oleandra distenta* G. Kunze	Oleandraceae
Opco	Kokatongo	*Oplismenus compositus* (L.) Beanv.	Graminae
Oxgo		*Oxyanthus goetzei* K. Schum.	Rubiaceae
Pams	Msambia	*Pachystela msolo* Engl.	Sapotaceae
Paho		*Pancovia holtzii* Radlk.	Sapindaceae
Pasp		*Pandiaca* sp.	Amaranthaceae
Paro		*Panicum robynsii* A. Camus.	Graminae
Patr		*Panicum trichocladum* K. Schum.	Graminae
Paex	Muula	*Parinari excelsa* Sabine ssp *holstii* (Engl)R.Grah.	Chrysobalanaceae
Pasc		*Paspalum scrobiculatum* L.	Graminae
Papa	Kuyu	*Pauridiantha pacinervis* ssp. *holstii* (Heirn.) Bren, (K. Schum.) Verdc.	Rubiaceae
Paam		*Pavetta amaniensis* Bremek.	Rubiaceae
Pvho		*Pavetta holstii* K. Schum.	Rubiaceae
Pama	Mtasanya	*Pavetta mazumbaiensis* (Bridson)	Rubiaceae
Pavs		*Pavetta* sp.	Rubiaceae
Past		*Pavetta stenosepala* K Schum.	Rubiaceae
Pevo		*Peddiea volkensii* Gilg.	Thymelaeaceae
Pefi	Mkisigizi	*Peddiea fischeri* Engl.	Thymelaeaceae
Pepv		*Peponium vogelii* (Hook. F.) Engl.	Curcubitaceae
Peli		*Periploca linearifolia* Dill & A. Rich.	Asclepidiaceae
Phus	Sheruti	*Philippia usambarensis* Arm & Th.Fr.	Ericaceae
Phin	Mkeche	*Phyllanthus inflatus* Hutch.	Euphorbiaceae
Piri		*Pilea rivularis* Wedd.	Urticaceae
Pisp		*Pilea* sp.	Urticaceae
Pius		*Pilea usambarensis* Engl.	Urticaceae
Pica	Ng'oko	*Piper capense* L.f.	Piperaceae
Pips	Mzuma	*Piper* sp	Piperaceae
Plpy		*Pleiocarpa pycnantha* (K. Schum) Stapf.	Apocynaceae
Pous	Mse	*Podocarpus usambarensis* Pilg..	Podocarpaceae
Pofu	Kogo	*Polycias fulva* (Hiern) Harms.	Araliaceae
Psal		*Psychotria alsophila* K. Schum.	Rubiaceae
Pscr		*Psychotria cryptogrammata* Petit.	Rubiaceae
Psfa		*Psychotria faucicola* K. Schum.	Rubiaceae
Psgr		*Psychotria griseola* K. Schum.	Rubiaceae
Pspo		*Psychotria porphyroclada* K. Schum.	Rubiaceae
Pssp		*Psychotria* sp.	Rubiaceae
Psys		*Psydrax* sp.	Rubiaceae
Ptaq		*Pteridium aquilinum* (L.) Kuhn.	Polypodiaceae
Ptca	Kishimto	*Pteris catoptera* Kunze	Adiantaceae
Ptsp		*Pteris* sp.	Adiantaceae
Ptus	Kishimto	*Pteris usambarensis* Hieron.	Adianthaceae
Rarh	Mweeti	*Rapanaea rhododendroides* (Gilg.) Mez.	Myrsinaceae
Ravo	Kiiga	*Rauvolfia volkensii* (Schum.) Stapf.	Apocynaceae

Appendix iv cont.

Code	Local Name	Botanical Name	Family
Rhpr		*Rhamnus prinoides* (L. Herit)	Rhamnaceae
Rhsp		*Rhipidantha* sp.	Rubiaceae
Rial		*Ritchira albersii* Calg.	Capparidaceae
Ruap	Mshaa	*Rubus apetalus* Poir.	Rosaceae
Rusp	Mshaa	*Rubus* sp.	Rosaceae
Rust		*Rubus steudneri* Schweinf.	Rosaceae
Ruor		*Rutidea orientalis* Bridson	Rubiaceae
Ryba		*Rytigynia bagshawei* (S. Moore) Robyns.	Rubiaceae
Rybu		*Rytigynia bugouensis* (K. Krawse) Verdc.	Rubiaceae
Ryfl		*Rytigynia flavida* Robyns	Rubiaceae
Ryst	Twavuha	*Rytigynia stuhlmanii* Robyns	Rubiaceae
Ryuh		*Rytigynia uhligii* (K..Schum. & K.Krause) Verdc.	Rubiaceae
Sale	Kihankongoto	*Salacia lehmbarchii* Loes	Celastraceae
Sael		*Sapium ellipticum* (Hochst.) Pax.	Euphorbiaceae
Scba		*Schefflera barteri* (Seem) Harms.	Araliaceae
Scal		*Schrebera alata* (Hochst.) Welw.	Oleaceae
Scbo		*Sckrochiton boivini* C. B. U	Acanthaceae
Scrh	Mtiwampaa	*Scolopia rhamniphylla* Gilg.	Flacourtiaceae
Sesp		*Secamone* sp.	Asclepiadaceae
Sesy	Mchunju	*Senecio syringifolius* ssp. *septentrionalis* (O.Hoffm.), T. Norl.	Compositae
Seme	Meya	*Setaria megaphylla* (Steud) Th. Dun. & Schim.	Graminae
Smkr	Kokozi	*Smillax kraussiana* Meism.	Smilacaceae
Sous	Mkunguma	*Sorindeia usambarensis* Engl.	Anacardiaceae
Spaf	Jeni	*Sphacophyllum africanum* (Oliv.) O. Hoffm.	Compositae
Spag		*Sporobolus agrostoides* Chiov.	Graminae
Stsp		*Stellaria* sp.	Caryophylaceae
Stsc	Sangana	*Strombosia scheffleri* var. *usambarica* Engl., (Guerke) Verdc.	Olacaceae
Sycu	Mwiza	*Syzygium cumini* (L) Skeel.	Myrtaceae
Sygu	Mshihwi	*Syzygium guineense* (Willd.) DC.	Myrtaceae
Taga		*Tacazzea galactagoga* Bullock.	Asclepiadaceae
Team	Kwati	*Teclea amaniensis* Engl.	Rutaceae
Teno		*Teclea nobilis* Del.	Rutaceae
Tege	Kishimto	*Tectaria gemmifera* (Fee) Alston.	Aspidiaceae
Tesp	Kishimto	*Tectaria* sp.	Aspidiaceae
Tevo		*Tephrosia vogellii* Hook. F	Papilionaceae
Tifu	Mkungumaghoi	*Tiliacora funifera* (Miexs.) Oliv.	Menispermaceae
Toas	Mdongonyezi	*Toddalia asiatica* (L.) Lam.	Rutaceae
Trsp	Mbawa	*Tragia* sp.	Euphorbiaceae
Trac		*Tricalysia acidophylla* Robbruht.	Rubiaceae
Tran		*Tricalysia anomala* E. A. Bruce	Rubiaceae
Tris		*Tricalysia* sp.	Rubiaceae

Appendix iv cont.

Code	Local Name	Botanical Name	Family
Trro	Mgoimazi	*Trichilia roka* (Forsk) Chiov.	Meliaceae
Turo	Dwayu	*Turraea robusta* Guerke	Meliaceae
Uvsp		*Uvaria* sp.	Annonaceae
Vaap		*Vangueria apiculata* K. Schum.	Rubiaceae
Vato	Mvilu	*Vangueria tomentosa* Hochst.	Rubiaceae
Veng		*Vepris ngamensis* Verdoon.	Rutaceae
Vest		*Vepris stolzii* Verdoon.	Rutaceae
Veho		*Vernonia holstii* O. Hoffman	Compositae
Vehy		*Vernonia hymenolepis* A. Rich.	Compositae
Vesp	Mkuwanagisa	*Vernonia* sp.	Compositae
Vigu		*Vitaria guineensis* Desv.	Vitariaceae
Xypa		*Xydrax parviflora* (Afzel) Bridson.	
Xlpa		*Xylopia parviflora* (A. Rich.) Benth.	Annonaceae
Zade		*Zanthoxylum deremensis* (Engl.) Kokw.	Rutaceae
Zegr	Muambe	*Zenkerella grotei* (Harms) J. Lear.	Caesalpiniacea

Appendix V: A list of vascular plants identified in an afromontane rain forest in the Ulugurus, Eastern Arc Mountains, Tanzania. There were 445 species belonging to 97 families. Local names in Kiluguru. Local names are not available for all species

Code	Local Name	Botanical Name	Family
Acsc		*Acacia schweinfurthii* Bremen & Exell	Mimosaceae
Acfr		*Acalypha fruticosa* Forsk.	Euphorbiaceae
Acas		*Achyranthes aspera* L.	Amaranthaceae
Acca		*Achyrospermum carvalhi* Giirke	Labiatae
Acma		*Achyrothalamus marginatus* O. Hoffm.	Compositae
Adci	Gole	*Adenia cissampeloides* (Planch) Harms.	Passifloraceae
Afvo	Mpekawake	*Afrocrania volkensii* (Harms.) Hutch.	Cornaceae
Afan		*Afromomum angustifolium* (Sonn) K. Schum.	Zingiberaceae
Afsp	Msambwa mweusi	*Afrosersalicia* sp.	Sapotaceae
Agsa	Myunguvo	*Agauria salicifolia* (Comm. ex Lam.) Hook. ex Oliv.	Ericaceae
Aghe		*Agelaea heterophylla* Gilg..	Connaraceae
Agco		*Ageratum conyzoides* L.	Compositae
Aimi		*Aidia micrantha* (K. Schum.) F. White	Rubiaceae
Alsp		*Alafia* sp.	Apocynaceae
Algu	Mkenge	*Albizia gummifera* (Gmel.) C.A Sm.	Mimosaceae
Alhi		*Alchornea hirtella* Benth.	Euphorbiaceae
Alla		*Alchornea laxiflora* (Benth.) Pax. ex K. Hoffm.	Euphorbiaceae
Alul	Mkani mweusi	*Allanblackia ulugurensis* Engl.	Guttiferae
Alab	Msemelele	*Allophyllus abysinicus* (Hochst.) Radlk.	Sapindaceae
Alfe		*Allophylus ferrugineus* Taub.	Sapindaceae
Alsp	Mgagandima	*Allophylus* sp.	Sapindaceae
Alsc		*Alsodeiopsis schumannii* (Engl.) Engl.	Icacinaceae
Anaf		*Ansellia africana* Lindau	Orchidaceae
Angr	Lengolengo	*Anthocleista grandiflora* Gilg.	Loganiaceae
Anma		*Anthrophyum mannianum* Hook.	Vitaceae
Ansc		*Anthyrium scandicinum* (Willd) C. Presl.	Anthyriaceae
Apth	Kihange	*Aphloia theaeformis* (Willd.) Benth.	Flacourtiaceae
Apdi		*Apodytes dimidiata* (E. Mey) Arn.	Icaunaceae
Asas		*Asparagus asparagoides* (L) Wight	Liliaceae
Asfa	Mvulamvula	*Asparagus falcatus* L	Liliaceae
Asab		*Asplenium abscurum* BL.	Aspleniaceae
Asae		*Asplenium aethopicum* (Burm.f) Becherer	Aspleniaceae
Asba		*Asplenium barteri* Hook.	Aspleniaceae
Asch		*Asplenium christii* Hieron.	Aspleniaceae
Asel		*Asplenium elliotii* L.H. Wright	Aspleniaceae
Aser		*Asplenium erectum* Bory	Aspleniaceae
Asfr		*Asplenium friesiorum* C. Chr.	Aspleniaceae
Asho		*Asplenium holstii* C.H.Wright	Aspleniaceae
Ashy		*Asplenium hypomelas* Kuhn.	Aspleniaceae

Appendix v cont.

Code	Local Name	Botanical Name	Family
Asli		*Asplenium linckii* Kuhn.	Aspleniaceae
Asme		*Asplenium megalura* Hieron.	Aspleniaceae
Asno		*Asplenium normale* D. Don	Aspleniaceae
Asru		*Asplenium rutifolium* (Berg) Kunze	Aspleniaceae
Assp		*Asplenium* sp.	Aspleniaceae
Assp1		*Asplenium* sp1.	Aspleniaceae
Asyp		*Asystasia* sp.	Acanthaceae
Basc	Muhombo	*Balthasaria schliebenii* (Melchior) Verdc	Theaceae
Bana		*Baquaertiodendron natalensis* (Sond.) Hiern. & Hemsl.	Sapotaceae
Bara		*Barringtonia racemosa* (L) Roxb.	Lecythidaceae
Basp		*Barringtonia* sp.	Lecythidaceae
Baza	Kanyuta	*Basananthe zanzibarica* (Mart.) De Wild.	Passifloraceae
Baal		*Basella alba* L.	Basellaceae
Bejo		*Begonia johnstonii* Oliv. Ex Hook.f	Begoniaceae
Beme		*Begonia meyeri-johannis* Engl.	Begoniaceae
Besp		*Begonia* sp.	Begoniaceae
Beab	Mkande	*Bersama abyssinica* Fres.	Melianthaceae
Blsp		*Blabellariopsis* sp.	Malpighiaceae
Blal		*Blechnum altenuatum* (Swartz) Mett.	Blechnaceae
Blau		*Blechnum australe* L.	Blechnaceae
Blun		*Blighia unijugata* Baker	Sapindaceae
Blna		*Blotiella natalensis* (Hook) Tryon	Dennstaedtiaceae
Blst		*Blotiella stipitata* (Alston) Faden.	Dennstaedtiaceae
Boma		*Boehmeria macrophylla* Hornem.	Urticaceae
Braf		*Brachystephanus africanus* S. Moore	Acanthaceae
Brho		*Brachystephanus holstii* Lindau	Acanthaceae
Brsa	Mgeremamondo	*Breonadia salicina* (Vahl) Hepper & Wood	Rubiaceae
Brmi	Msumba	*Bridelia micrantha* (Hochst) Bail	Euphorbiaceae
Brsp		*Bridelia* sp.	Euphorbiaceae
Brma		*Brillantaisia madagascariensis* (T. Anders) Lindau	Acanthaceae
Brisp		*Brillantaisia* sp.	Acanthaceae
Brul		*Brillantaisia ulugurica* Lindau	Acanthaceae
Casy		*Calanthe sylvatica* (Thon) Lindl.	Orchidaceae
Cain		*Canna indica* L.	Cannaceae
Caol	Msada	*Canthium oligocarpum* Hiern.	Rubiaceae
Casp		*Canthium* sp.	Rubiaceae
Caaf		*Cardamine africana* L.	Cruciferae
Caca		*Carvalhoa campanulata* K. Schum.	Apocynaceae
Cama	Msingizi	*Cassipourea malosana* (Bak) Alston	Rhizophoraceae
Casp	Msingizi mweupe	*Cassipourea* sp.	Rhizophoraceae
Cesy		*Cenecio syringifolius* O. Hoff.	Compositae
Chsp		*Chamydocardia* sp.	Acanthaceae
Chal		*Chassalia albiflora* K. Krause	Rubiaceae

Appendix v cont.

Code	Local Name	Botanical Name	Family
Chdi		*Chassalia discolar* K. Schum.	Rubiaceae
Chpa		*Chassalia parvifolia* K. Schum.	Rubiaceae
Chsp		*Chassalia* sp.	Rubiaceae
Chum		*Chassalia umbraticola* ssp. *umbraticola* Vatke	Rubiaceae
Chvi		*Chassalia violacea* K. Schum.	Rubiaceae
Chab		*Chazaliella abrupta* (Hiern) Petit & Verdc.	Rubiaceae
Chni		*Chionanthus niloticus* (Oliv.) Stearn.	Oleaceae
Chsp		*Chlamidostachya* sp.	Acanthaceae
Chls		*Chlamydocardia* sp.	Acanthaceae
Chco		*Chlorophytum comosum* (Thunb.) Jacq.	Anthericaceae
Chfi		*Chlorophytum filipendulum* Baker	Anthericaceae
Chhe		*Chlorophytum heynei* Baker	Liliaceae
Chde		*Christella dentata* (Forsk.) Brownsay & Jermy	Thelypteridaceae
Chgu		*Christella gueintziana* (Mett) Halttum.	Thelypteridaceae
Chgo	Msambwa mweupe	*Chrysophyllum gorungosanum* Engl.	Sapotaceae
Chrs	Msambwa	*Chrysophyllum* sp.	Sapotaceae
Cior		*Cincinnabotrys oreophilla* Gilg.	Melastomataceae
Cipa		*Cissampelos pareira* L.	Menispermaceae
Cipr		*Cissus producta* Afzel.	Vitaceae
Clan		*Clausena anisata* (Willd) Oliv.	Rutaceae
Cldo	Kibamandu	*Clematis dolichopoda* Bren.	Ranunculaceae
Clci		*Clenitis cirrhosa* (Schumach) Ching.	Aspidiaceae
Clla		*Clenitis lanuginosa* (Kaulf.) Lopel.	Aspidiaceae
Clce		*Clerodendrum cephalanthum* Oliv.	Verbenaceae
Clfo		*Clerodendrum formicarum* Guerke	Verbenaceae
Clin		*Clerodendrum incisum* Klotzch.	Verbenaceae
Clsa		*Clerodendrum sansibarense* Guerke	Verbenaceae
Clsp	Mkunguzigi	*Clerodendron* sp.	Verbenaceae
Coad		*Coccinia adoensis* Cogn.	Cucurbitaceae
Comi		*Coccinia mildbraedii* Gilg.. ex Harms.	Cucurbitaceae
Como	Mtunu	*Coffea mongensis* Bridson	Rubiaceae
Cogr	Mkole	*Cola greenwayi* Bren.	Sterculiaceae
Colu		*Coleus luteus* (Guerke) Staner	Labiatae
Cone		*Conyza newii* Oliv. & Hiern.	Compositae
Crbr		*Craibia braunii* Dunn.	Papilionaceae
Crsp		*Crassocephalum* sp.	Compositae
Crsc		*Craterispermum schweinfurthii* Hiern.	Rubiaceae
Crtr		*Cremaspora triflora* (Thonn. K. Schum).	Rubiaceae
Cros		*Crossandra* sp.	Acanthaceae
Crot		*Crossandra tridentata* Lindau.	Acanthaceae
Crli		*Cryptocarya liebertina* Engl.	Lauraceae
Cusc		*Culcasia scandena* (Willd) P. Beanv.	Araceae
Cusp	Mlengela	*Cussonia spicata* Thunb.	Araliaceae
Cyma	Msembe	*Cyathea maniana* Eng.	Cyatheaceae
Cyus	Msembe	*Cyathea usambarensis* Hieron	Cyatheaceae

Appendix v cont.

Code	Local Name	Botanical Name	Family
Cyal		*Cynanchum altiscandens* K. Schum.	Asclepidiaccae
Cyps		*Cyperus pseudoleptocladus* Kukenth.	Cyperaceae
Cybr		*Cyphostemma braunii* (Gilg. &Br.) Gilg Br.	Vitaceae
Dala		*Dalbergia lactea* Vatke	Papilionaccae
Daxa		*Danais xanthorrhoea* (K. Schum) Brem.	Rubiaceae
Dain	Mtati mweusi	*Dasylepis integra* Warb.	Flacourtiaceae
Deki	Mnyagengu mwekundu	*Deinbolia kilimandscharica* Taub.	Sapindaceae
Dere		*Desmodium repondum* Vahl.	Papilionaceae
Desp		*Desmodium* sp.	Papilionaceae
Diru		*Dichapetalum ruhlandii* Engl.	Dichapetalaceae
Dium		*Dicliptera umbellata* (Vahl.) Juss.	Acanthaceae
Dius	Msizizi	*Dicranolepis usambarica* Gilg.	Annonaceae
Ditr		*Didymochlaena truncatula* (Schwarb) JSM.	Aspidiaceae
Didu	Ludelega	*Dioscorea dumentorum* (Kunth.) Pax.	Dioscoreaceae
Dilo	Ludelega	*Dioscorea longicuspis* Kunth.	Dioscoreaceae
Diab		*Diospyros abyssinica* (Hiern.) F. White	Ebenaceae
Disp		*Diospyros* sp.	Ebenaceae
Dimo		*Diphasia morogorensis* Kok.	Rutaceae
Diro		*Dissotis rotindifolia* (Sm) Triana	Melastomataceae
Dosp		*Dolichos* sp.	Papilionaceae
Dole	Lukwezi	*Dombeya leucoderma* K. Schum.	Sterculiaceae
Dosp	Lukwezi	*Dombeya* sp.	Steculiaceae
Doal		*Dorstenia alta* Engl.	Moraceae
Doho		*Dorstenia holstii* Engl.	Moraceae
Dosc		*Dorstenia schlechteri* Engl.	Moraceae
Dors		*Dorstenia* sp.	Moraceae
Dovs		*Dovyalis* sp.	Flacourtiaceae
Draf	Luhenga	*Dracaena afromontana* Engl.	Agavaceae
Drla	Luhenga	*Dracaena laxissima* Engl.	Agavaceae
Drin		*Dryopteris inaequalis* (Schlecht) Kunze	Aspidiaceae
Drma		*Dryopteris maniana* (Hook) C. Chr.	Aspidiaceae
Drge		*Drypetes gerrardii* var. *gerrardii* Hutch.	Euphorbiaceae
Drsp		*Drypetes* sp.	Euphorbiaceae
Drus		*Drypetes usambarica* (Pax.) Hutch.	Euphorbiaceae
Dysp		*Dyschoriste* sp.	Acanthaceae
Ekca		*Ekebergia capensis* Sparrm.	Meliaceae
Elac		*Elaphoglossum acrostichoides* Hook &Grew.) Schelpe.	Lomariopsidaceae
Elmi		*Elaphoglossum milbraedii* Hieron.	Lomariopsidaceae
Ella		*Elaphoglosum lastii* (Bak) C. Chr.	Lomariopsidaceae
Elpa		*Elatostema paivaeacum* Wedd.	Urticaceae
Emsc		*Embelia schimperi* Vatke	Myrsinaceae
Ensp		*Ensete* sp.	Musaceae
Erta		*Erythrococca tatravirens* Prain.	Euphorbiaceae

Appendix v cont.

Code	Local Name	Botanical Name	Family
Erus		*Erythrococa usambarica* Prain.	Euphorbiaceae
Euen		*Euphorbia engleri* Pax.	Euphorbiaceae
Faan		*Fagaropsis angolensis* (Engl.) Dale	Rutaceae
Fasa	Msomola	*Faurea saligna* Harv.	Proteaceae
Fila	Msese	*Ficalhoa laurifolia* Hiern.	Theaceae
Fiin		*Ficus ingens* (Miq.) Miq.	Moraceae
Fiot	Msole	*Ficus ottomifolia* ssp *ulugurensis* (Miq.) Miq	Moraceae
Fisy	Mkuyu	*Ficus sycomorus* L...	Moraceae
Flru	Mgogandima	*Flacourtia rukam* Zoll. & Mor.	Flacourtiaceae
Flsp	Mgogandima	*Flacourtia* sp.	Flacourtiaceae
Gaco		*Galiniera coffeoides* Del.	Rubiaceae
Gabr		*Galium brenanii* Ehend & Verdc.	Rubiaceae
Gahu		*Garcinia huillensis* Walw. ex Engl.	Gutiferae
Gavo	Mkani mweupe	*Garcinia volkensii* Eng.	Guttiferae
Gelo		*Gerrardanthus lobatus* (Logm.) C. Jeffrey	Cucurbitaceae
Glwi		*Glycine wightii* (Wight & Arn) Verdc	Papilionaceae
Goro		*Gomphocarpus rostratus* N.E. Br. Bullock	Aspleniaceae
Goan		*Gongronema angolense* N.E. Br. Bullock.	Asclepiadaceae
Golo		*Gouania longispicata* Engl.	Rhamnaceae
Grbo		*Grandidiera boivinii* Taub.	Flacourtiaceae
Grpu		*Gravesia pulchra* (Gilg.) Wickens	Melastomataceae
Hedi		*Heinsenia diervilleoides* (K. Schum.) Petit	Rubiaceae
Hila		*Hilleria latifolia* (Lam.) H. Watt.	Phytolacaceae
Huop		*Huperzia ophioglossoides* (Lam.) Rothm.	Lycopodiaceae
Hyfo		*Hypoestes forskaolii* (Vahl) R. Br.	Acanthaceae
Hytr		*Hypoestes triflora* (Forsk.) Roem. & Schult.	Acanthaceae
Hysp		*Hypolepis sparsisora* (Schrad.) Kuhn.	Dennstaedtiaceae
Imen		*Impatiens engleri* Gilg.	Balsaminaceae
Imgo		*Impatiens gomphophylla* Bak. f.	Balsaminaceae
Imha		*Impatiens hamata* Warb.	Balsaminaceae
Imke		*Impatiens keilii* Gilg.	Balsaminaceae
Imps		*Impatiens pseudoviola* Gilg.	Balsaminaceae
Imra		*Impatiens raphidothrix* Warb.	Balsaminaceae
Imsp		*Impatiens* sp.	Balsaminaceae
Imwa		*Impatiens walleriana* Hook.f.	Balsaminaceae
Ipsh		*Ipomoea shupangensis* Bak.	Convolvulaceae
Isgr		*Isoglosa gregorii* (S. Moore) Lindau	Acanthaceae
Isla		*Isoglosa lactea* Lindau	Acanthaceae
Isce		*Isoglossa cestediana* Lindau	Acanthaceae
Japi	Mnyagengu	*Jaundea pinnata* (P. Beanv.) Schell	Connaraceae
Juan		*Justicia anisophylla* (Mildbr.) Brum.	Acanthaceae
Juin		*Justicia inaequalis* Brumiff.	Acanthaceae
Jsin		*Justicia interupta* (Lindau) C. B. CC.	Acanthaceae
Jupi		*Justicia pinguior* (Lindau) C.B. CC	Acanthaceae
Jups		*Justicia pseudorungia* Lindau	Acanthaceae

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Code	Local Name	Botanical Name	Family
Jusp		*Justicia* sp.	Acanthaceae
Kala		*Kanahia laniflora* (Fowk.) R. Br.	Asclepidiaceae
Kegu		*Keetia gueinzii* (Sonder.) Bridson	Rubiaceae
Laki		*Landolphia kirkii* Dyer	Apocynaceae
Lace	Kizangwa	*Lasianthus ceriflorua* E. A. Bruce	Rubiaceae
Lagl		*Lasianthus glomentiferus* K. Schum.	Rubiaceae
Lski	Mmbugi	*Lasianthus kilimandscharica* K. Schum.	Rubiaceae
Lama		*Lasianthus macrocalyx* K. Schum	Rubuaceae
Lape	Kimavimavi	*Lasianthus pendunclulatus* Bruce	Rubiaceae
Lasp		*Lasianthus* sp.	Rubiaceae
Lawa		*Lasianthus walacei* Bruce	Rubiaceae
Laxa		*Lasianthus xanthospermus* K. Schum.	Rubiaceae
Lepl		*Leptactina platyphylla* (Hiern.) Vernh.	Rubiaceae
Leus		*Leptonychia usambarensis* K. Schum.	Sterculiaceae
Labo		*Liparis bowkeri* Harv.	Orchidaceae
Loaf		*Loeseneriella africana* (Willd) N. Halle	Celastraceae
Lola		*Loxogramme lanceolata* (Swartz) C. Presl.	Polypodiaceae
Lycla		*Lycopodium clavatum* L.	Lycopodiaceae
Maki	Mgida	*Macaranga kilimandscharica* Pax.	Euphorbiaceae
Mala	Mnguti	*Maesa lanceolata* Forsk.	Myristicaceae
Magu		*Manniela gustavi* Reichb. f.	Orchidaceae
Maum		*Marascus umbelatus* Vahl.	Cyperaceae
Mafr		*Marattia fraxinea* Sm. ex J.F. Gmelin.	Marattiaceae
Maac		*Maytenus acuminata* (L.f.) Loes	Celastraceae
Masp	Mfiro	*Maytenus* sp.	Celastraceae
Maud	Mfuta	*Maytenus undatus* (Thunb.) Blakelock	Celastraceae
Melo		*Mellera lobulata* S. Moore	Acanthaceae
Meer		*Memecylon erubescens* Gilg.	Melastomataceae
Memy		*Memecylon myrstilloides* Markgraf.	Melastomataceae
Mepr		*Memecylon procteria* A. et R. Fernandes	Melastomataceae
Mesa		*Memecylon sansibaricum* Taub.	Melastomataceae
Mesp		*Memecylon* sp.	Melastomataceae
Meve		*Memecylon verruculosum* Brenan	Melastomataceae
Mide		*Microglosa densiflora* Hook.f.	Compositae
Mipa		*Microsorium pappei* (Mett. Ex Kuhn.) Tard.	Polypodiaceae
Mico	Derega	*Mikania cordata* (Burm f.) BL. Robins	Compositae
Misa		*Milletia sacleuxii* Dunn.	Papilionaceae
Miki		*Mimulopsis kilimandscharia* Lindau	Acanthaceae
Miso		*Mimulopsis solmsii* Schweinf.	Acanthaceae
Mosp		*Momordica* sp.	Cucurbitaceae
Mobu		*Monanthotaxis buchananii* (Engl.) Verdc.	Annonaceae
Mopo		*Monanthotaxis poggei* Engl. & Diels	Annonaceae
Mobr		*Mostuea brunonis* Didr.	Loganiaceae
Myar	Mlowelowe	*Myrianthus arboreus* P. Beanv.	Moraceae
Mysa	Kivumba	*Myrica salicifolia* Hochst. ex A Rich.	Myricaceae

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Code	Local Name	Botanical Name	Family
Myae	Mfuta	*Mystroxylon aethiopicum* (Thumb) Loes.	Celastraceae
Nebu	Mkuvi	*Newtonia buchanani* (Bak) Gilb. & Bout.	Mimosaceae
Nosp		*Notonia* sp.	Compositae
Nufl		*Nuxia floribunda* Benth.	Loganiaceae
Ocho		*Ochna holstii* Engl.	Ochnaceae
Ocma		*Ochna macrocalyx* Oliv	Ochnaceae
Ocmo	Mnyasungu	*Ochna mossambicensis* Klotzch.	Ochnaceae
Ocsp		*Ochna* sp.	Ochnaceae
Ocsp1		*Ochna* sp1	Ochnaceae
Ocus	Mseri	*Ocotea usambarensia* Engl.	Lauraceae
Oleu	Mhalasindi	*Olea europaea* L.	Oleaceae
Oldi		*Oleandra distenta* G. Kunze	Oleandraceae
Onla		*Oncinotis lanceolata* Gilg.	Apocynaceae
Onsp	Mzona	*Oncoba spinosa* Forsk.	Flacourtiaceae
Opco		*Oplismenus compositus* (L.) P. Beauv.	Graminae
Ophi		*Oplismenus hirtellus* P. Beauv.	Graminae
Orsu		*Orthosiphon suffrutescens* (Thonn.) Morton.	Labiatae
Ousc		*Ouratea scheffleri* Engl.	Ochnaceae
Oxgo	Mng'ongo	*Oxyanthus goetzei* K. Schum.	Rubiaceae
Oxsp	Mmbugi	*Oxyanthus speciosus* DC	Rubiaceae
Pabr		*Panicum brevifolium* L	Graminae
Pama		*Panicum maximum* Jacq	Graminae
Patr		*Panicum trichocladum* K. Schum.	Graminae
Paex	Mngama	*Parinari excelsa* ssp *holstii* Sabine (Engl.) R. Grah.	Chrysobalanaceae
Papa	Mbabala mweupe	*Pauridianta paucinervis* ssp. *holstii* (Hiern.) Brenn. (K. Schum.) Verdc.	Rubiaceae
Pabr		*Pavetta bruceana* Bremek.	Rubiaceae
Paco		*Pavetta constipulata* Bremek	Rubiaceae
Pafi		*Pavetta filistipulata* Brem.	Rubiaceae
Paga		*Pavetta gardeniifolia* var *gardeniifolia* A. Rich.	Rubiaceae
Paho		*Pavetta holstii* K. Schum.	Rubiaceae
Pahy		*Pavetta hymenophylla* Brem.	Rubiaceae
Paly		*Pavetta lynesii* Bridson	Rubiaceae
Pasp		*Pavetta* sp.	Rubiaceae
Past		*Pavetta stenocepala* K. Schum.	Rubiaceae
Pefi	Chohasesi mwekundu	*Peddiea fischeri* Engl.	Thymelaeaceae
Pesu	Chohasesi	*Peddiea subcordata* Donke	Thymelaeaceae
Pebu		*Pentas bussei* Krause	Rubiaceae
Peab		*Peperomia abyssinica* Miq.	Piperaceae
Pebl		*Peperomia blanda* (Jacq.) Kunth.)	Piperaceae
Pevo		*Peponium vogelii* (Hook.f) Engl.	Cucurbitaceae
Pesp		*Periploca* sp.	Asclepiadaceae

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Code	Local Name	Botanical Name	Family
Phlo		*Phaulopsis longifolia* T. Thoms.	Acanthaceae
Phsp		*Phaulopsis* sp.	Acanthaceae
Phos	Ukindu	*Phoenix* sp.	Palmae
Phre		*Phyllanthus reticulatus* Poir.	Euphorbiaceae
Pijo		*Pilea johnstonii* Oliv	Urticaceae
Piri		*Pilea rivularis* Wedd.	Urticaceae
Pius		*Pilea usambarensis* Engl	Urticaceae
Pica		*Piper capense* L.f	Piperaceae
Piod	Ludaha	*Piper odoratum* C. DC	Piperaceae
Plan		*Platycerium angolense* Engl.	Polypodiaceae
Plsp		*Pleutranthus* sp.	Labiatae
Pomi	Kinyanziri	*Podocarpus milanjianus* Radlk.	Podocarpaceae
Pous	Kinyanziri	*Podocarpus usambarensis* Engl.	Podocarpaceae
Pofu	Mkongonelo	*Polycias fulva* (Hiern.) Hams.	Araliaceae
Pomu		*Polysphaeria multiflora* Hiern.	Rubiaceae
Posp		*Polysphaeria* sp.	Rubiaceae
Poad		*Polystachya adansoniae* Reichb.f.	Orchidaceae
Pote		*Polystachya tesselata* Lindley	Orchidaceae
Polf		*Polystichum fuscopaleacum* Alston	Aspidiaceae
Pope		*Porterandia penduliflora* (K. Schum.) Keay.	Rubiaceae
Pran		*Pristimera andongensis* N. Halle	Celastraceae
Prgr	Msingizi	*Pristimera graciliflora* (Oliv.) N. Halle	Celastraceae
Prpo	Msingizi mwekundu	*Pristimera polyantha* (Loes) N. Halle	Celastraceae
Prcr		*Procris crenata* C. Robinson	Urticaceae
Praf	Mgegewe	*Prunus africana* Hook.	Rosaceae
Psca		*Pseuderanthemum campylosiphon* Mildbr.	Acanthaceae
Pshi		*Pseuderanthemum hildebrandtii* Lindau	Acanthaceae
Pssp		*Pseuderanthemum* sp.	Acanthaceae
Psma		*Pseudolachnostylis maprouncifolia* Pax.	Euphorbiaceae
Psmi		*Pseudospondias microcarpa* (A. Rich) Engl.	Anacardiaceae
Psbr		*Psychotria brevicaulis* K. Schum	Rubiaceae
Psfa		*Psychotria faucicola* K. Schum.	Rubiaceae
Psfr		*Psychotria fractinervata* Petit	Rubiaceae
Psgo	Mbabala mweusi	*Psychotria goetzei* (K. Schum) Petit	Rubiaceae
Psgr		*Psychotria griseola* K. Schum.	Rubiaceae
Psor		*Psychotria orophyla* Petit.	Rubiaceae
Pspa		*Psychotria peteri* Petit	Rubiaceae
Pspo		*Psychotria porphyroclada* K. Schum.	Rubiaceae
Pspu		*Psychotria punctata* Vatke	Rubiaceae
Psri		*Psychotria riparia* (K. Schum. & K. Krause) Petit.	Rubiaceae
Psys		*Psychotria* sp.	Rubiaceae
Psta		*Psychotria tanganyikensis* Verdc.	Rubiaceae
Psus		*Psychotria usambarensis* Verdc.	Rubiaceae
Ptca		*Pteris cartoptera* Kunze	Adiantaceae

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Code	Local Name	Botanical Name	Family
Ptde		*Pteris dentata* Forsk.	Adiantaceae
Ptsp		*Pteris* sp.	Adiantaceae
Ptus		*Pteris usambarensis* Hieron.	Adiantaceae
Puca		*Pupalia cappacea* (L) Juss	Amaranthaceae
Ramu		*Ranunculus multifidus* Forsk.	Ranunculaceae
Rasp		*Ranunculus* sp.	Ranunculaceae
Rarh	Mgeremamondo	*Rapanea rhododendroides* (Gilg.) Mez.	Myrsinaceae
Ravo		*Raufolvia volkensii* (K. Schum.) Stapf.	Apocynaceae
Raca		*Rauvolfia caffra* Sond.	Apocynaceae
Rama		*Rauvolfia mannii* Stapf	Apocynaceae
Ramo		*Rauvolfia mombasiana* Stapf.	Apocynaceae
Rare	Chambaza	*Rawsonia reticulata* Gilg.	Flacourtiaceae
Rhch		*Rhipidantha chlorantha* (K. Schum.) Bremek.	Rubiaceae
Risq		*Rinorea squamosa* (Tul.) Brenth.	Violaceae
Ruap	Fifi	*Rubus apetalus* Poir.	Rosaceae
Rupi	Fifi	*Rubus pinnatus* Willd	Rosaceae
Ruro	Fifi	*Rubus rosifolius* Sm.	Rosaceae
Rusp	Fifi	*Rubus* sp.	Rosaceae
Rust	Fifi	*Rubus steudneri* Schwein.f	Rosaceae
Ruor		*Rutidea orientalis* Bridson	Rubiaceae
Ryce		*Rytigynia celastroides* (Baillon.) Verdc.	Rubiaceae
Ryfl		*Rytigynia flavida* Robyns.	Rubiaceae
Ryli		*Rytigynia lichenoxenos* (K. Schum.) Robyns.	Rubiaceae
Rysp		*Rytigynia* sp.	Rubiaceae
Ryuh		*Rytigynia uhligii* (K. Schum & K. Krause) Verdc.	Rubiaceae
Sasp		*Saintpaulia* sp.	Gesneriaceae
Sael		*Salacia elegans* Oliv.	Celastraceae
Sama		*Salacia madagascariensis* (Lam) DC	Celastraceae
Sael		*Sanicula elata* Don.	Umbeliferae
Sasp		*Sanicula* sp.	Umbeliferae
Scba		*Schefflera barteri* (Seem.) Harms.	Araliaceae
Sclu		*Schefflera lukwangulensis* (Tennant) Bernard	Araliaceae
Scco		*Schizozygia coffaeoides* Baill.	Apocynaceae
Scrh	Mwanganapalu	*Scolopia rhamniphylla* Gilg.	Flacourtiaceae
Seaf		*Secamone africana* (Oliv.) Bullock.	Asclepidiaceae
Sesp		*Secamone* sp.	Asclepidiaceae
Sekr		*Selaginella kraussiana* (Kunze) A. Abraham	Selaginellaceae
Sens		*Senecio* sp.	Compositae
Sesy		*Senecio syringifolius* O. Hoffm.	Compositae
Seme		*Setaria megaphylla* (Stend) Th. Dr. & Schum.	Graminae
Smkr		*Smilax kraussiana* Meism.	Smilacaceae
Sosp		*Solanecio* sp.	Compositae
Sobi		*Solanum bifurcatum* A. Rich.	Solanaceae
Soin		*Solanum indicum* L.	Solanaceae

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Code	Local Name	Botanical Name	Family
Soki		*Solanum kitivuensis* Dammer	Solanaceae
Sosc		*Solanum schliebenii* Wend.	Solanaceae
Sols		*Solanum* sp.	Solanaceae
Sote		*Solanum terminale* Forsk.	Solanaceae
Spaf		*Spirostachys africana* Sond.	Euphorbiaceae
Stsp		*Staurogyne* sp.	Acanthaceae
Stse		*Stellaria sennii* Chiov.	Caryophylaceae
Stes		*Stellaria* sp.	Caryophylaceae
Stca		*Streptocarpus caulescens* Vatke.	Gesneriaceae
Stgl		*Streptocarpus glandulosissimus* Engl.	Gesneriaceae
Stsc	Msangana	*Strombosia scheffleri* Engl.	Olacaceae
Stsc		*Strychnos scheffleri* Gilg.& Burse.	Loganiaceae
Strs		*Strychnos* sp.	Loganiaceae
Suza		*Suregoda zanzibarensis* (Baill.) Muell. Arg.	Euphorbiaceae
Sygl	Mngobwe	*Symphonia globulifera* L.f.	Guttiferae
Syse	Msambwa	*Synsepalum seraciferum* (Welw.) Pennington	Sapotaceae
Syco	Mmusu	*Syzygium cordatum* Hochst	Myritaceae
Sygu	Mmusu	*Syzygium guineense* (Willd) D.C.	Myrtaceae
Sysp		*Syzygium* sp.	Myrtaceae
Taap		*Tacazzea apiculata* Oliv.	Asclepiadaceae
Taga	Lubuli	*Tacazzea galactagoga* Bullock.	Asclepiadaceae
Tasp		*Tacazzea* sp.	Asclepidiaceae
Tave	Kigomvu	*Tabernaemontana ventricosa* (Hochst.) ex A.D.C.	Apocynaceae
Tapa		*Tarrenna pavetoides* (Harv.) Sim.	Rubiaceae
Tafr		*Tarrena friesiorum* (K. Schum.) Brem.	Rubiacea
Taqu		*Tarrenna quadrangularis* Bremek.	Rubiaceae
Team		*Teclea amaniensis* Engl	Rutaceae
Tetr	Lugongandima	*Teclea trichocarpa* (Engl.) Engl.	Rutaceae
Tege		*Tectaria gemmifera* (Fee) Alston	Aspidiaceae
Teul		*Tetrorchidium ulugurense* Verdc.	Euphorbiaceae
Thrh		*Thalictrum rhynchocarpum* A. Rich.	Ranunculaceae
Thsp		*Thumbergia* sp.	Acanthaceae
Tifu		*Tiliacora funifera* (Miers) Oliv.	Menispermaceae
Toas		*Toddalia asiatica* (L.) Lam.	Rutaceae
Trgu	Mbefu	*Trema guineensis* (Schum. &Thinn.) Ficalho.	Ulmaceae
Trsp		*Triainolepis* sp.	Rubiaceae
Tran	Msingizi	*Tricalysia anomala* E.A. Bruce	Rubiaceae
Trel	Msingizi	*Tricalysia elegans* Robrecht	Rubiaceae
Trmy	Msingizi	*Tricalysia myrtifolia* S. Moore	Rubiaceae
Trov	Msingizi	*Tricalysia ovalifolia* Hiern.	Rubiaceae
Trpa	Msingizi	*Tricalysia pallens* Hiern.	Rubiaceae
Tris	Msingizi mweupe	*Tricalysia* sp.	Rubiaceae
Triel		*Trichocladus ellipticus* Sond.	Hamamelidaceae

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Code	Local Name	Botanical Name	Family
Trul	Mnyagengu mweupe	*Trichoscypha ulugurensis* Mildbr.	Anacardiaceae
Trgr		*Trimeria grandifolia* (Hochst.) Warb.	Flacourtiaceae
Tygr		*Tylophora gracillima* Markgraf.	Asclepiadaceae
Urhy	Konge	*Urera hypselodendron* Wedd.	Urticaceae
Uvsp		*Uvaria* sp.	Annonaceae
Uvol		*Uvariodendron oligocarpum* Verdc.	Annonaceae
Veng		*Vepris ngamensis* Verdoon.	Rutaceae
Vest		*Vepris stolzii* Verdoon	Rutaceae
Vept		*Vernonia pteropoda* O & H.	Compositae
Vesp	Kidugutu	*Vernonia* sp.	Compositae
Vido	Mfulu	*Vitex doniana* Sweet	Verbenaceae
Zeem		*Zehneria emirnesis* (Bak) Kerandren	Cucurbitaceae
Zesc	Mtati mweupe	*Zenkerella schliebenii* (Harms.) J. Leonard	Caesalpiniaceae
Ziac		*Zimmermannia acuminata* Verdc.	Euphorbiaceae