EFFECTS OF ANTHROPOGENIC ACTIVITIES ON DISTRIBUTION AND ABUNDANCE OF EPIPHYTIC ORCHID *POLYSTACHYA FUSIFORMIS* (THOU.) LINDL. AT THE MANGA RANGE ECOSYSTEM IN KISII, WESTERN KENYA

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Effects of anthropogenic activities on distribution and abundance of epiphytic orchid *Polystachya fusiformis* (thou.) Lindl. at the Manga range ecosystem in Kisii, Western Kenya

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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To my parents, Mr. Henry Mageto and Mrs. Hellen Mageto, my wife Pauline, and children for giving me easy time during the study.

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ABBREVIATIONS AND ACRONYMS

AM	Arbuscular Mycorrhiza
AMF	Arbuscular Mycorrhizal Fungi
ANOVA	Analysis of variance
FCTC	Fort Cluster Training Center
GPS	Global Positioning System
IUCN	International Union for Conservation of Nature
MENR	Ministry of Environment and Natural Resources
NaOCl	Sodium hypochlorite
NEAP	National Environment and Natural Resources
NMK	National Museums of Kenya
PDA	Potato dextrose agar
SPSS	Statistical Programme for Social Sciences (Version 17)
SSC	Species Survival Commission of IUCN
WRI	World Resources Institute
WWF	World Wide Fund for Nature
FAO	Food and Agriculture Organization of the United Nations
UNESCO	United Nations Education, Scientific and Cultural Organization

ABSTRACT

Orchid diversity which is a major source of income in Kenya is threatened due to rapid loss and fragmentation of habitats, which accounts for up to 80% of natural habitat lose. Since orchids have complex life histories in which there is a varied display of morphological and anatomical adaptations, which are of interest to scientists, photographers, artists, collectors and economists, their conservation is of a necessity. A lot of effort has to be directed to their conservation, especially the critically endangered epiphytic orchid *Polystachya fusiformis* **(Thou.) Lindl.** The present study focused on the factors influencing extermination of the orchid *P. fusiformis* **(Thou.) Lindl.**. The study will provide information on the status of the epiphytic orchid *P. fusiformis* **(Thou.) Lindl.** its distribution and abundance, and its related symbionts in the Manga range ecosystem. Manga range covers an approximate area of 20 km^2. It is situated 5 km to the North-East of Kisii town between $00^o33'$ South and $34^o57'$ East in Kenya along the Kisii-Nyamira counties' common border.

The sampling design method was a two-transect based plan that was oriented from the base of the range where there was a continuous baseline at the foot of Manga range to collect data on the distribution and abundance of the epiphytic orchid *P. fusiformis* **(Thou.) Lindl.** Transects were initiated at the base of the rocky outcrops on the North and North-Western parts of the Manga range. A total of 88 quadrats each measuring $1m^2$ was randomly laid along a 30m long line transect. The GPS co-ordinates where orchid clusters were detected were recorded using a Garmin e-Trex vista Global Positioning System (GPS). Roots of healthy orchids were selected from each quadrat to examine for the presence/absence of fungal symbionts. There was significant variation in the abundance and distribution of epiphytic orchid with change in altitude. Forty one 1m x2m quadrats were found to have a density of 3.2 individuals per unit area; 47 quadrats did not have any orchid. Logging, wood collection, and fire were the key factors which influenced the distribution and abundance of orchid. One way ANOVA Levene's test

for equal variance showed that the density of orchid clusters significantly decreased with increase in altitude ($p = 0.00004$) at α 0.05.

The majority of *P. fusiformis* **(Thou.) Lindl.** plants were clustered around the altitude of 1800m to 1850m above sea level. Orchid cluster abundance was calculated to be 31% of the total sampled area at Manga range ecosystem. Fire is a great threat to *P. fusiformis* **(Thou.) Lindl.** at the lower altitudes as their aerial roots and exposed pseudobulbs burn easily during the dry season when humidity is relatively low. The orchid is sensitive to fire and as such it was limited to parts of the Manga range with high level of water seepage and relictual stands of host trees where it displays a clustered pattern of distribution. Although these studies did not show host-orchid-specificity, the host trees were identified as follows: *Spathodea campanulata*, *Vangueria infausta*, *Ficus thonningii*, *Olea capensis*, *Croton sp. Terminalia sp.* and *Protea sp.* at the time of study (October 2011-March 2012). A total of 64 standing trees and 160 tree stumps of *P. fusiformis* **(Thou.) Lindl.** host trees were detected in the months of October-December 2011. Identification of pure fungal isolates revealed the presence of *Rhizoctonia sp.* and *Fusarium sp.* in the roots of orchid roots. A fungal colonization of the orchid roots did not reveal host-fungus specificity.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The world's biodiversity is being lost at an alarming rate, as such conservation of biological resources is a challenge that all nations must strive to achieve. Biological diversity is important to humans as a source of food, fibre and fuel; agricultural systems are built upon biodiversity; biodiversity is important for ecosystem functioning (Kennedy *et al.,* 2002); conservation of biodiversity is also considered important for "spiritual" reasons. Despite these economic, functional and spiritual importance, very little has been done to halt the sixth biological extinction Pim *et al.,* (1995), and continued efforts are required to halt what may be an irreversible loss (Wilson, 2006).

Orchid diversity in Kenya is threatened due to rapid loss and fragmentation of habitats which accounts for up to 80% of natural habitat lose (World Resources Institute, 1990). Conservation of biodiversity awareness is increasing in the face of Holocene extinction (Canadell & Noble, 2001). Nearly 12.5% of global flora is facing threats of extinction and therefore conserving rare and threatened plants is a worldwide consequence (Walter and Gillet, 1998). The situation is further aggravated by the burgeoning population structure which is exploiting the fragile ecosystem unsustainably, increasing demand for agricultural land, resulting in habitat fragmentation and environmental degradation (Bakamwesiga *et al*., 2000). Orchids have complex life histories in which there is a varied display of morphological and anatomical adaptations, which are of interest to scientists, photographers, artists and collectors; features which can be matched by a few other plant families, but have resulted in the high level of threat to the family (Cribb *et al*., 2003). Threats facing orchids can be narrowed down to human activities including land deforestation for agriculture, fires to clear unwanted vegetation, mining, urban development, weed invasion, introduction of exotic plant species, grazing, and collection of plants for horticulture and ethnobotanical uses. Orchids are cosmopolitan plants which occur in all habitats except glaciers, with the highest concentration being in the tropics especially in Asia, South America, Central America, and Africa. In most of the tropics, vascular epiphytes comprise 0.25% of the flora in such ecosystems (Collins, 1990; Gentry and Dodson, 1987). Epiphytic plants including *Polystachya fusiformis* **(Thou.) Lindl.** are adapted to the life above the soil strata, and as a result rely on stability of environmental conditions (Engwald *et al*., 2000).

Fire is considered as a potent force in environmental modification and as an important land management tool. Fires tend to increase in intensity and extent as the dry season progresses though; later fires may be controlled by networks of earlier burns which reduce the available fuel load. Fire also plays an important role in redistribution of nutrients in the environment as it plays an important role in nutrient recycling. The main types of anthropogenic disturbances at Manga range can be categorized as follows: (i) Severe short term disturbances followed by relatively rapid *Polystachya fusiformis* **(Thou.) Lindl.** recovery. This includes disturbances such as fire (ii) Moderate but continuous disturbances which alter the habitat in such a manner that natural recovery, when possible, would be a long term process. This includes all impacts of logging and introduced exotic species. (iii) Moderate short term disturbance with impacts limited to several individuals or populations. This includes selective logging, collection of “snags” for firewood and picking of herbal and ornamental plants.

1.1.1 Orchidaceae

Orchids are nonvascular perennial plants having simple leaves, parallel venation with flowers which display of a variety of colours and fragrances. Leaves may be ovate, lanceolate or orbiculate with varying sizes. Leaves are normally alternately positioned while the structure of the leaf depends on habitat conditions. Orchids have complex life cycles often involving a fungal partner in mycorrhiza and seed germination, and specific pollinators. Some have single bilaterally symmetrical flowers but most including *Polystachya fusiformis* **(Thou.) Lindl.** have a racemose inflorescence with a large number of flowers. Pollen is released in the form of pollinia which is a waxy mass of pollen grains held together by a glue-like viscin. Orchids tend to have highly specialized pollination systems which reduces chances of being self-pollinated and as such, orchid flowers remain receptive for 2-3 weeks before shriveling. Floral visitors are lured by the shape and colour of labellum (Coates &Dixon, 2007).

Terrestrial orchids form rhizomes, corms or tubers used as food reserves and perenating organs. Epiphytic orchids have modified aerial roots made up of spongy velamen which absorbs humidity. A majority of orchids are perennial epiphytes or lithophytes which grow anchored on trees, shrubs or on rocks. Orchids offer a lot in the study of interactions of plants, fungi and animals (pollinators). Orchid distribution and abundance is more inclined towards the tropics with variations between continents and within regions (Myers *et al*., 2000). Two thirds of orchids are epiphytes while one third comprise the terrestrial species.

1.2 Literature review

1.2.1 Distribution and abundance of epiphytic orchid

Orchidaceae is a plant family composed of five monophyletic clades, which correspond with the currently recognized subfamilies: Apostasioideae, Cypripedioideae, Orchidoideae, Epidendroideae, Vanilloideae (Dressler, 1993; Szlachetko, 1995). *Polystachya fusiformis* **(Thou.) Lindl.** belongs to epidendroid orchids classified into “lower” and “higher” Epidendroids (Figure 1.1). The lower tribes comprise Neottieae, Parmorchideae, Triphoreae and Neurileae while higher Epidendroid tribes comprise Coelogyneae, Arethusae, Malaxideae, Podochileae, Dendrobieae and part of Epidendreae and Arpophyllinae Polystachyinae clade of Epidendreae (Dressler, 1996). Most orchids are photosynthetic at maturity but some 100 species are achlorophyllous (Leake, 2005). Orchids are a diverse family of plants with about 1,000 genera and over 25,000 species (Cribb *et al.*, 2003; Jones, 2006). Orchids usually grow on strata with sufficient moisture and shade. Most orchids emerge during the rainy season when the conditions are favourable (Jalal, 2005).

Orchid diversity and taxonomy is attributed to specialization of two requirements which may occur independently or in combination; specific pollinators and mycorrhizal associations. Epidendroid orchids such as *Polystachya fusiformis* **(Thou.) Lindl.** comprise the largest and most diverse subfamily, which has been the most difficult to interpret and classify phylogenetically and hence has attracted much research. The orchid *Polystachya fusiformis* **(Thou.) Lindl.** can be recognized by fully incumbent anthers, hard pollinia, thickened stems and a typical epiphytic nature. Dressler (1986) tried to subdivide Epidendroideae into more natural subgroups which include those with erect anthers and soft pollinia to a distinct subfamily, Neottioideae and those with stipes and superposed pollinia into Vandoideae. However, Dressler (1993) decided to retain the subgroups, Neottioideae and Vandoideae within Epidendroideae. Epidendroideae are characterized by reed stems and eight pollinia (Dressler, 1990). Epidendroideae is a sub-family to which *P. fusiformis* **(Thou.) Lindl.** belongs and is a polyphyletic clade which has not been easy to be subdivided into old world or new world clades. *Polystachya fusiformis* **(Thou.) Lindl.** belongs to the sub-tribe Polystachyineae.

1.2.2 Impacts of human activities on epiphytic orchids

Anthropogenic activities such as logging and agricultural activities may have resulted in severe damage to the Manga range ecosystem in Kisii, Kenya. Such changes have consequences with a long term effect on the vegetation structure recovery. Epiphytes are some of the first life forms to be affected by changes in primary forests because they occupy forest canopies (Sodhi *et al.,* 2008). Loss of natural habitats through land use and activities such as logging, wood collection, and introduction of exotic tree species such as *Eucalyptus* sp., *Greviella* sp., and collection of wild herbs for medicinal use have contributed to the reduction in the population of *P. fusiformis* **(Thou.) Lindl.** (Instituto de Ecologia, 2008). Habitat alteration, fragmentation, degradation, may result in its total destruction which paves way for the introduction of exotic species such as *Eucalyptus sp.* and *Greviella sp.* Humans comprise a dominant influence on biodiversity and scale of transformation, management and utilization of the ecosystem in the last three centuries such that no part of the world can be considered undisturbed (Heywood, 1995).

Terrestrial orchids face a greater extinction risk due to a series of threats especially from the human activities. In woodlands, species richness can increase with increasing fire frequency up to biennial (Tester, 1989; Brockway & Lewis, 1997) or annual fires (Walker & Peet, 1983). On the other hand, high fire frequencies can reduce the competitive dominance of over storey trees and under storey woody plants (Peterson & Reich, 2008). Even though Manga range is a montane area, it forms a mosaic adapted to natural fires, which has been subjected to two types of fire regimes (Figures 3.3 and 3.5): annual burning by the local farmers at the end of the dry season for the past 50 or more years; deliberate use of fire (once every two years) to clear off unwanted or overgrown vegetation.

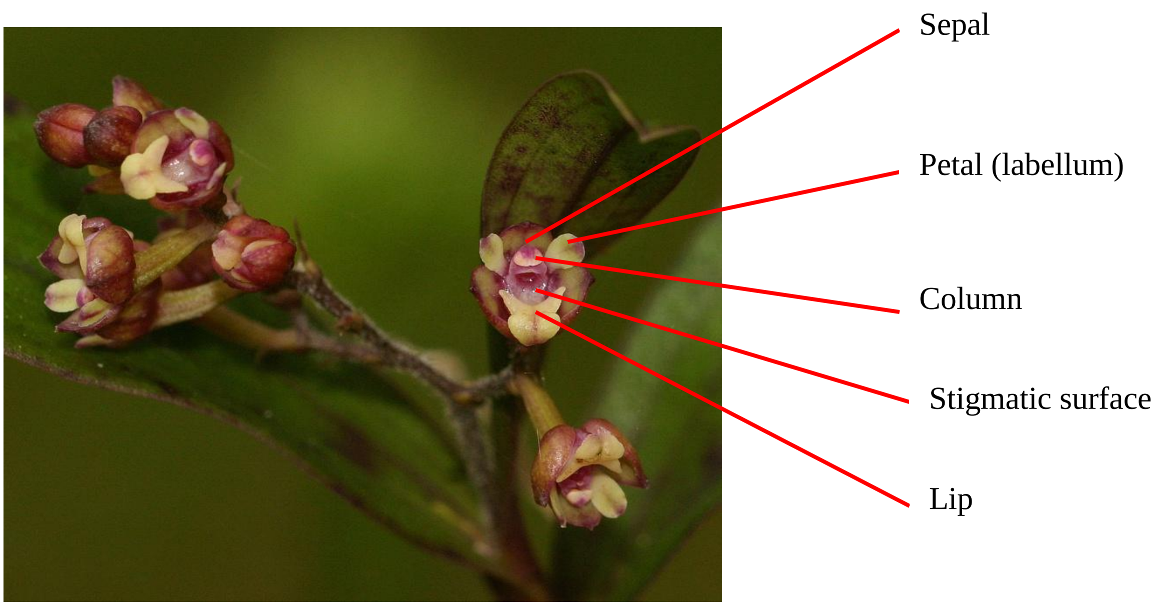


Plate 1.1: A field picture of *Polystachya fusiformis* (Thou.) Lindl. showing flower structure.

Orchids are very sensitive to environmental changes and are good indicators of environmental change. Such orchid species are locally endemic and are vulnerable to threatening processes (Koopowitz *et al*., 2003) like drought or fire. All types of orchids are being sought by collectors such as Sutherland shire Orchid Society and the American Orchid Society who encourage their cultivation, collection, conservation and research. Dressler (1986) tried to subdivide Epidendroideae into more natural subgroups which include those with erect anthers and soft pollinia to a distinct subfamily, Neottioideae and those with stipes and superposed pollinia into Vandoideae.

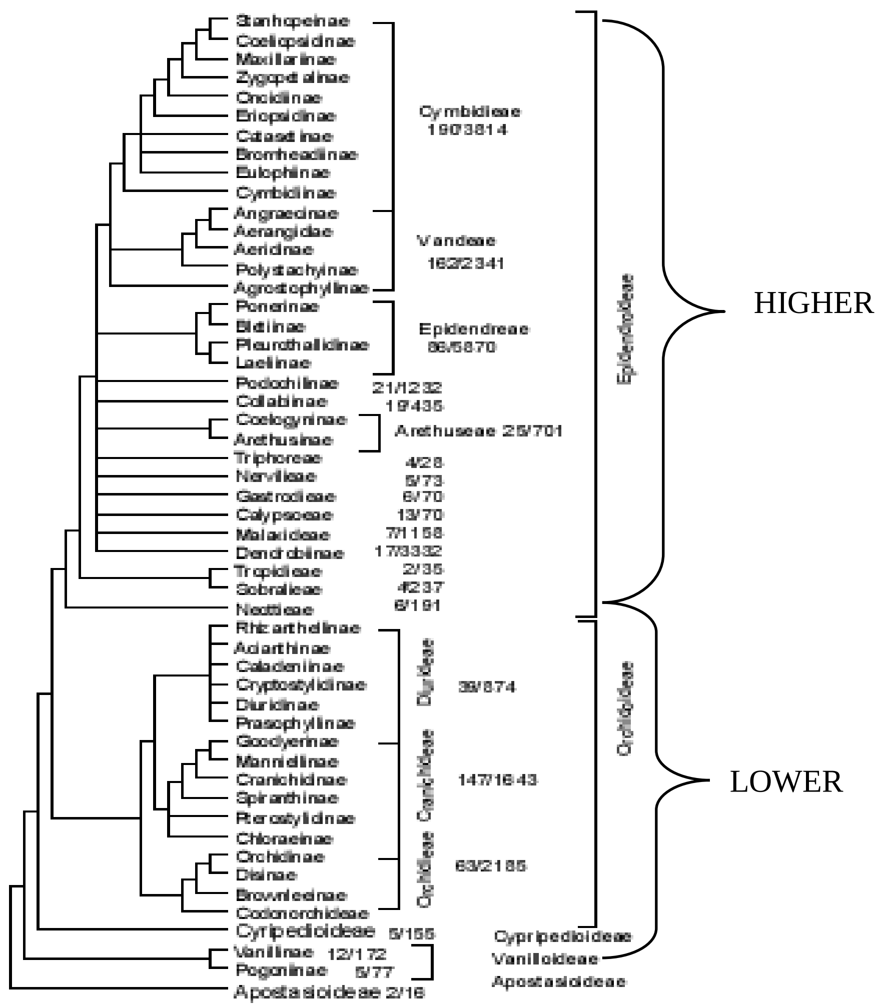


Figure 1.1: Family tree of orchidaceae based on DNA data (Source: Chase *et al.*, 2003).

The degree of biotic interdependency between a given plant or animal species and other organisms increases the risk of extinction of rare species (Brundrett, 2007). The range and abundance of terrestrial orchids may be influenced by the underground (mycorrhizae) and above ground (floral) life history (Woolcock and Woolcock, 1984; Clements, 1988; Dixon, 1989).

Plate 1.2: ***Polystachya fusiformis*** **(Thou.) Lindl. clusters on an old tree stump, November 2011**.

1.2.3 Fungal infestation of orchid mycorrhiza

Underground phase is dependent on an association with fungi forming mycorrhiza (Warcup, 1971; Ramsay *et al*., 1986; Rasmussen, 2002). Above ground phase is dependent on effective transfer of pollinia, fertilization and subsequently proper fruit and seed set (Stoutamire, 1983; Roberts, 2003). Symbiotic mycorrhizal fungi help terrestrial orchids to absorb nutrients from the surrounding environment especially carbon and nitrates. Few studies have revealed mycorrhizal associations in epiphytic plants (Ochora *et al*., 2001). Orchids are obligatory mycorrhizal plants which consistently support mycorrhizal colonization in their young roots. Arbuscular mycorrhizae (AM) fungi are obligately symbiotic with less than 200 fungal species identified as mycorrhizal partners; *Glomeromycetes* which are categorized into four genera; *Gigaspora*, *Glomus*, *Sclerocystis* and *Acaulospora*.

Fungal hyphae penetrate the cell walls of the root hairs into the cortex through the development of pre-penetration apparatus (PPA)/enzymes where they develop dense coils called pelotons. Hyphae formed by mycorrhiza are delicate hygroscopic structures which help in the absorption of water (Bonfante & Genre, 2010) and certain minerals (Suarez *et al*., 2006; Agustini *et al*., 2009). Morphology of fungi associated with epiphytic orchids indicates that they are of anamorphic (asexual) genus *Rhizoctonia sp.* (Athipunyakon *et al*., 2004) and originate mainly from the family Basidiomycetes. Several researches on orchid mycorrhiza have been done on temperate regions but few studies have been done in the tropics (Otero *et al*., 2002). Therefore the study on beneficial orchid fungal relations (Bonfante and Genre, 2010) will be very useful in agricultural practices to improve productivity in the tropics.

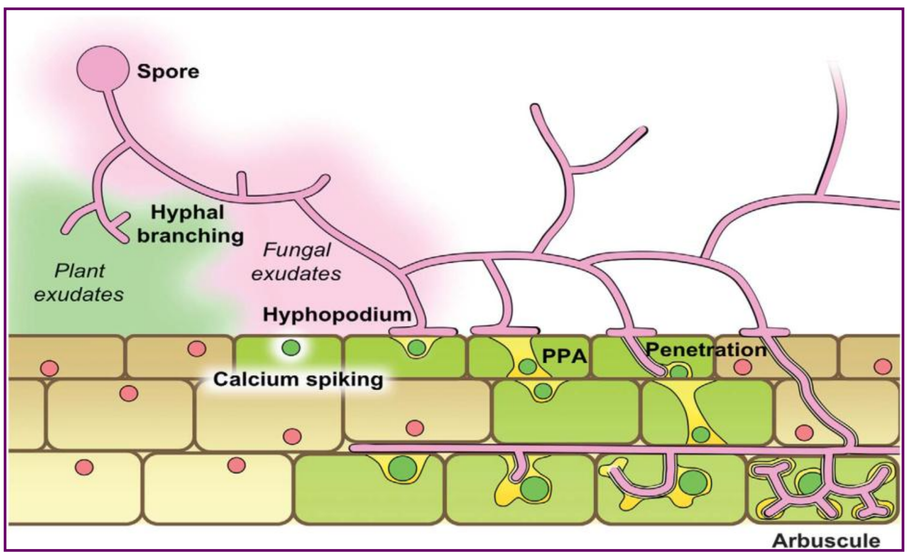


Figure 1.2: Schematic diagram of the orchid root colonization process by mycorrhizal fungi (Source: Bonfante & Genre, 2010).

The germination of mycorrhizal fungi is followed by the production of short explorative mycelium (Figure 1.2). The perception of plant exudates, released by the host root, induces recursive hyphal branching, increasing the probability of a direct contact between the symbionts. In the meantime, fungal exudates are perceived by the root, where they trigger calcium spiking through the activation of the common symbiosis (SYM) pathway. Signal transduction leads to the activation of cellular and transcriptional responses (green cells and nuclei). The contact between the plant and fungi is followed by the adhesion of a hyphopodium to the root surface. This triggers the assembly of a broad aggregation of cytoplasm (yellow), named the pre-penetration apparatus (PPA) in the contacted epidermal cell and underlying outer cortical cell. Subsequent intracellular fungal colonization strictly follows the route of PPAs from the epidermis to the inner cortex. Here, intercellular hyphae can develop along the root axis. The PPA mechanism is then replicated in the contacted inner cortical cells, both before fungal entry and on a smaller scale an extensive surface for nutrient exchange.

1.3 Statement of the problem

Orchid species in Kenya are an important component of plant diversity and are economically important. However, lately orchid habitats are seriously threatened. The major threats include habitat loss, land fragmentation and degradation caused by human activities. As a result of these disturbances vegetation structure and composition have been affected. The Manga ecosystem as highlighted by earlier works (Ochora *et al.*, 2001) comprises a great diversity of vegetation including epiphytic orchids such as *P. fusiformis* **(Thou.) Lindl.** Since there is a disturbance, many biotic and abiotic activities leading to the loss of species, the study needs to be conducted to identify the factors that influence extermination of species in the Manga range ecosystem. Orchids of Manga range such as *P. fusiformis* **(Thou.) Lindl.** has been listed as critically endangered (IUCN, 2016). The effects of these activities are likely to increase because of burgeoning population of adjacent communities, who depend on natural resources within the range for their livelihood. Earlier studies on Manga range focused on identification of orchid species. Studies on the effects of biotic and abiotic factors on the distribution and abundance of orchids at the Manga range have not been hitherto investigated.

1.4 Justification of the study

Since the economy of Kenya is highly dependent on biological resources, nature and conservation areas remain critical from which considerable revenue is generated. The Manga range ecosystem is an important biodiversity hotspot, and a source of a variety ecosystem services that support the livelihood of the surrounding communities. The range with an altitude of 1920m above sea level also contributes to the cultural and aesthetic value of the region and is an important tourist attraction area. Orchid species in the Manga landscape are important ecosystem indicators, which contribute to the floral beauty of the landscape, and intermediate hosts to some pollinators, and have medicinal value. Although loss of orchids in the area signifies environmental degradation, no studies have been hitherto done in the range to provide a link between environmental degradation and declining orchid population. This has led to a situation where ecosystem integrity is continually compromised, leading to decline in provisioning of ecosystem services.

This study will provide information on the status of the critically endangered epiphytic orchid *P. fusiformis* **(Thou.) Lindl.**, its distribution and abundance, and its related symbionts. The information has potential to inform the surrounding communities and the world at large on the importance of biodiversity conservation, especially for the orchid, *Polystachya fusiformis* **(Thou.) Lindl.** This research is important for enforcement of conservation strategies for the orchid species, the habitat and the entire Manga range ecosystem. Data from the study will provide a benchmark against future surveys on the distribution and abundance of orchid species at the Manga Range and other similar habitats.

1.5 Research hypotheses

1. The relative distribution and abundance of the critically endangered epiphytic orchid *P. fusiformis* **(Thou.) Lindl.** at the Manga range ecosystem does not differ between different altitudes.

2. Anthropogenic activities do not affect the distribution and abundance of the critically endangered epiphytic orchid *P. fusiformis* **(Thou.) Lindl.** at the Manga range ecosystem.

3. Mycorrhiza diversity does not influence the distribution and abundance of the critically endangered *P. fusiformis* **(Thou.) Lindl.** at Manga range ecosystem.

4. The distribution and abundance of the critically endangered epiphytic orchid *P. fusiformis* **(Thou.) Lindl.** is not determined by orchid-host specificity at Manga range ecosystem.

1.6 General objective

To determine the factors that influences the distribution and abundance of the critically endangered epiphytic orchid *P. fusiformis* **(Thou.) Lindl.** at Manga range ecosystem.

1.7 Specific Objectives

1. To determine the distribution and abundance of the critically endangered epiphytic orchid *P. fusiformis* **(Thou.) Lindl.** across an altitudinal gradient at Manga range ecosystem.

2. To investigate the effects of anthropogenic activities on the distribution and abundance of the critically endangered epiphytic orchid *P. fusiformis* **(Thou.) Lindl.** at Manga range ecosystem.

3. To determine mycorrhizal diversity and their effect on the distribution and abundance of the critically endangered epiphytic orchid *P. fusiformis* **(Thou.) Lindl.** at the Manga range ecosystem.

4. To determine the effect of orchid-host specificity on the distribution and abundance of the critically endangered epiphytic orchid *P. fusiformis* **(Thou.) Lindl.** at the manga range ecosystem.

1.8 Research questions

The present study will answer the following research questions:

1. What is the impact of high altitudinal gradient on distribution and abundance of the critically endangered epiphytic orchid *P. fusiformis* **(Thou.) Lindl.** at the Manga range ecosystem?

2. What human activities undermine the distribution and abundance of the critically endangered epiphytic orchid *P. fusiformis* **(Thou.) Lindl.** at the Manga range ecosystem?

3. What mycorrhizal fungi influence the distribution and abundance of the critically endangered epiphytic orchid *P. fusiformis* **(Thou.) Lindl.** at Manga range ecosystem?

4. How does host specificity affect the distribution and abundance of the critically endangered epiphytic orchid *P. fusiformis* **(Thou.) Lindl.** at the Manga range ecosystem?

CHAPTER TWO

MATERIALS AND METHODS

2.1 Study area

The Manga range ecosystem was selected for the study based on earlier surveys (Ochora *et al.*, 2001), that recorded endemism of the epiphytic orchid *Polystachya fusiformis* **(Thou.) Lindl.** in the area. Manga range is a natural ecosystem that covers an approximate area of 20 km^2. It is situated 5 km to the North-East of Kisii town between $00^{o}33^{'}$ South and $34^{o}57'$ East in Kenya along the Kisii-Nyamira counties' common border (Figure 2.1). The Range is a rocky highland area of small land holding tenure system owned by the local community in which there are schools, a Catholic mission, tea and *Eucalyptus* plantations. Other vegetation in the highland comprises herbs, shrubs, scrubs and trees. Within the Manga range ecosystem the *P. fusiformis* **(Thou.) Lindl.** occurs in the North and North-Western slopes of the range.

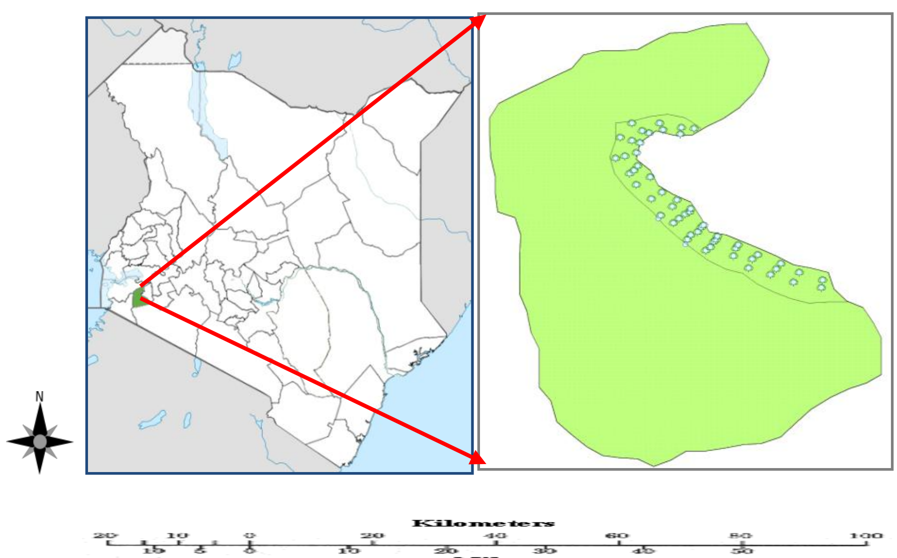


Figure 2.1: Study area at Manga range in Kisii County Kenya. The circular dots on the study area indicate some of the sampled areas.

Rainfall in the region is bimodal with long rains occurring from March to May followed by short rains from August to September. The rainfall averages 2000 mm per annum. The mean annual temperature is 22^{o}C with a maximum and minimum temperature of 15^{o}c and 38^{o}c, respectively.

Manga range extends to the rocky cliffs to the North and North-West facing slopes and the fairly steep slopes on the Eastern side. The range is a habitat to a variety of unique flora (including orchids) and fauna which are endemic to the range. About 50% of the highland is grassland (Ochora *et al.*, 2001). The rocky cliffs limit the farming activities by the community living along the range. However, there are tea plantations on the gentle slopes of the Eastern side of the cliff. The steep slopes are dominated by exotic tree species such as *Eucalyptus, Grevillea robusta* and *Cuppresus lusitanica*. There are also patches of maize and bananas in mixed crop-livestock systems.

2.2 Sampling design for distribution and abundance of epiphytic orchids

The cliffs had an average height of 30 m from the foot of the range to the top. The sampling design was adopted and modified from the Gradient directed transects ("gradsects") by Gillison and Brewer, 1985 (Figure 2.3) which is fairly adaptable to different kinds of environments.

2.2.1 Orchid distribution and abundance along an altitudinal gradient

The sampling design was a two-transect based plan that was oriented from the base of the range where there was a continuous baseline at the foot of Manga range (Figure 2.2). Transects were initiated at the base of the rocky outcrops on the North and North-Western parts of the Manga range. 'Gradsects" are suitable for animal and plant studies (Sandman and Lertzman, 2003) and has been tested in different vegetation types (Wessels *et al*., 1998; Austin & Heyligers, 1989).

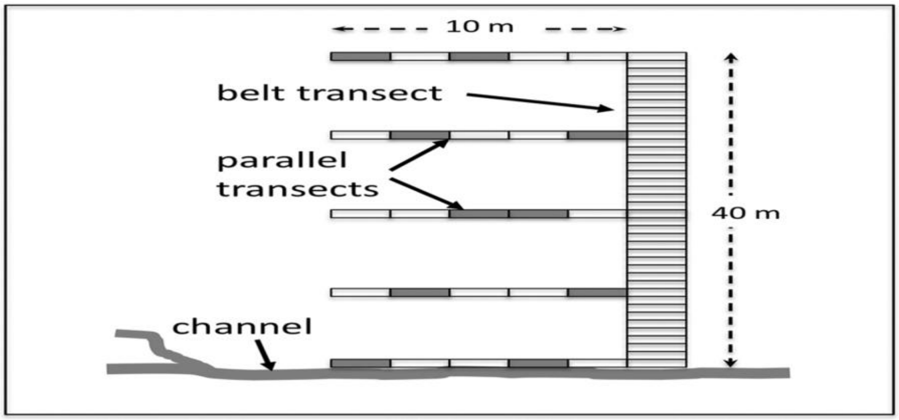


Figure 2.2: Gradient directed transects ("gradsects") Source; Gillison and Brewer (1985).

In the modified design (Figure 2.3), the 1 m x 2 m quadrats were randomly placed along the 30 m long transects as in the original design (Figure 2.2). The 40m dotted line in the "gradisect" represented the baseline in the modified sampling design while the parallel transects of 10m were modified to be 30m length in the new design (Figure 2.3).

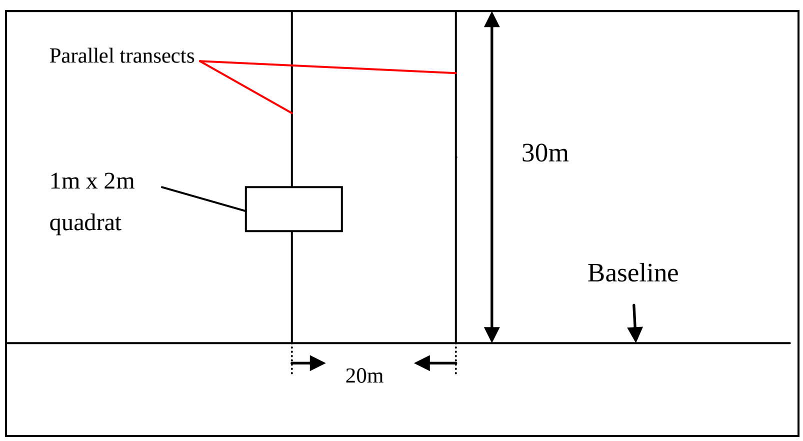


Figure 2.3: Modified sampling plan showing a baseline and a 30m long transect drawn along the slope from the baseline to the top of the cliff at a regular interval of 20m across the range.

Transect lines had to be long enough to capture all phases of the gradient patterns (Grieg-Smith, 1983). The optimum number of transects to be used in the study was calculated using the formulae:

$$n = \frac{N}{1+Ne^2} \text{ (Yamane, 1967);}$$

Where N is the size of the population; e is the level of precision (0.05).

The line transect length of 30m was decided on as it is equivalent to the average distance from the baseline to the top at most sampling points to capture all phases of gradient patterns (Grieg-Smith, 1983). The baseline ran along the foot of the range while transects were drawn from the baseline to the top of the range over the rocky surface (Plate 2.1). The parallel line transects were spaced at regular intervals (20m apart) to accommodate changes in environmental gradients and as a way of developing a baseline study for orchid distribution and abundance at the Manga range. A total of 88 quadrats each measuring $1m^2$ was randomly laid along a 30m long line transect. The line transect was laid using a 30m long tape measure. The interval between one transect and another was 20m. The orchid clusters were counted in each quadrat to establish their distribution and abundance. Plants were photographed and identified without removing them from their growing sites to minimize destructive sampling. The altitudinal variation at Manga range was measured and recorded using a Garmin e-Trex vista-HCx global positioning system (GPS). The GPS (Global positioning system) co-ordinates where orchid clusters were detected were recorded with the exception of the very steep sites where accessibility was difficult, where photographs were taken.

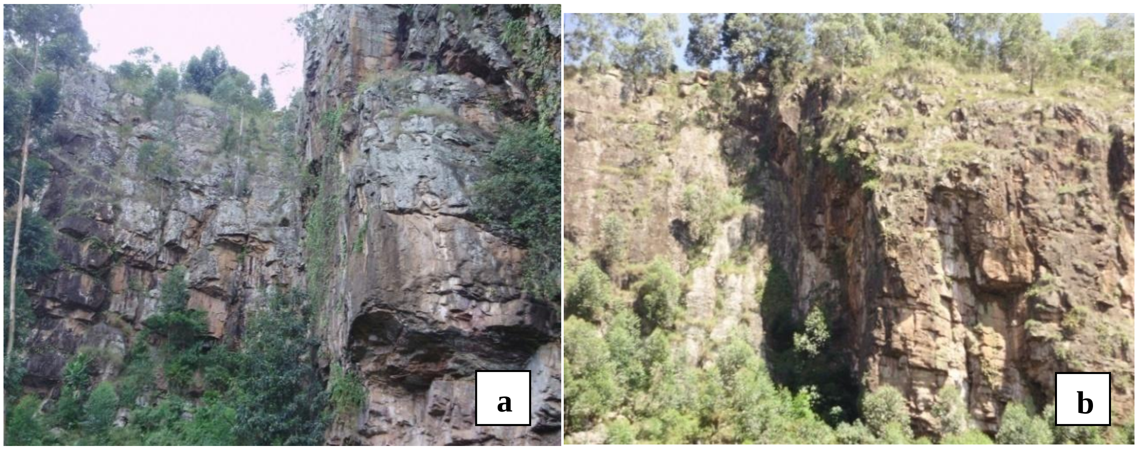


Plate 2.1(a): Sheltered part of the range with scattered orchid cluster population and the encroaching eucalyptus trees on the cliffs 2.1(b): Exposed part of the range with a few orchid clusters (North-Western cliffs of Manga range November 2011).

2.2.2 Anthropogenic activities

2.2.2.1 Logging

During the sampling of the epiphytic orchid *P. fusiformis* **(Thou.) Lindl.** a number of its phorophytes (host trees) were counted along the parallel transect lines in the months of October-December 2011. Samples of trees including the *P. fusiformis* **(Thou.) Lindl.** phorophytes were collected and later taken to the National Museums of Kenya plant herbarium for identification. Most of the trees hosting *P. fusiformis* **(Thou.) Lindl.** were sparsely populated along the sampled area. A record of their count along with the number of orchid clusters growing on the phorophytes was recorded in the data collection sheets. In the second sampling session, it was observed that a number of host tree species in the sampled area along the transect lines had been logged for timber or wood. A count of the logged trees and the remaining standing trees were recorded. The procedure was repeated in the months of February and March 2012.

2.2.2.2 Wood collection

Data on firewood collection activities was collected alongside the data on the distribution and abundance of the epiphytic orchid *P. fusiformis* **(Thou.) Lindl.** The data was collected twice in the months of October-December 2011 and January, February and March 2012. Quadrats (1 m x 2m) were randomly thrown along the parallel transect lines and data on the epiphytic orchid growing on the tree stumps at the beginning (October-December 2011) of the research were recorded on data sheets. Later in the dry season (January-March 2012), data on the remaining tree stumps after human disturbance was also collected and recorded. The number of tree stumps along the transect lines in the sampled area was counted and recorded before and after the human disturbance activities. Sites where the orchids had been disturbed as a result of uprooting of the tree stumps were photographed and recorded in the data sheets.

2.2.2.3 Fire

The forest is often set on fire by the local communities during the dry season to get a good growth of grass following the rains. Sometimes the fire spreads and destroys vast tracts of valuable forests. During the study, many orchid rich localities were found to be affected by fire. For epiphytic orchids, fires at any time of the year can cause a drastic change in plant abundance. They are mainly affected by burning of plants, degrading or removal of the support substrate and alteration of the microclimate resulting from fragmentation of the canopy. Data on the effects of fire was collected along each transect line. Sampling was done in the months of October-December 2011 before occurrence of fire and in February-March 2012 after the occurrence of fire. The burnt host trees and the cut down tree stumps were counted and recorded during each sampling session. Photographs of the sites before and after the fires were taken.

2.2.3 Fungal abundance

Healthy roots from orchids were randomly selected at quadrat sampling points along various transect lines. A total of 60 roots (two per transect) were collected to make a representative sample. Co-ordinates of the sites where roots were obtained were recorded using Garmin GPS. Thereafter the roots were thoroughly washed in running tap water after which they were sterilized with sodium hypochlorite (NaOCl) and then rinsed three times in sterile distilled water. The sterilized roots were picked with sterile forceps and placed on a sterile filter paper where they were sectioned with a sterile scalpel to expose the cortex and the pelotons within the cortex for enhanced fungal germination.

2.3 Determination of sample size

Sample size refers to the optimum number of sampling units which can be suitable for a research study. Appropriate sample size can be defined by the following formula by Van Meirvenne, (1991)

$$n = \left(t_{\propto}\frac{CV}{E}\right)^2$$

Where ***n*** is the number of sampling units, ***t*** is the student ***t*** at $\alpha = 0.05$, $t = 1.96$, CV is the coefficient of variation, and ***E*** is the desired level of relative error (% of mean). CV is given by CV = $\frac{s}{x}100$ where *s* is the standard deviation, x is the sample mean. The number of quadrats (87) calculated using the formula was above the minimum number of quadrats required for the study.

Percentage frequency of *P. fusiformis* **(Thou.) Lindl.** was determined as the degree of dispersion of individual orchids in the study area. Percentage frequency was determined by sampling the study area randomly along each line transect and a record of how many times it occurred in each sampling unit (quadrat) was kept, and then calculated using the equation:

$$\text{Frequency (\%)} = \frac{\textit{Number of quadrats in which the species occurred}}{\textit{Total number of quadrats studied}} x100$$

$$= \frac{41}{87} x100$$

$$= 0.47\%$$

Two sampling sessions (October-December 2011 and February-March 2012) were conducted to establish the distribution and abundance of *P. fusiformis* **(Thou.) Lindl.** The results from these two sampling sessions illustrate the disparities observed before and after an occurrence of fire. Various parameters were measured and recorded during the study including altitude, number of indigenous tree stumps and remaining indigenous trees, orchid plant height, number of orchid clusters and number of orchid plants in a cluster (a cluster is a group of orchid plants growing together and sprouting from the same stem with a common root system).

2.4 Determination of distribution and abundance of P. fusiformis (Thou.) Lindl.

Two sampling sessions (October-December 2011 and February to March 2012) were conducted to establish the distribution and abundance of *P. fusiformis* **(Thou.) Lindl.** using 1m x 2m quadrats along a line transect. Abundance in this study was the number of individuals of *P. fusiformis* **(Thou.) Lindl.** in Manga range per unit area. Random sampling was done at several sampling points (between five and six quadrats) along each line transect and the number of orchids present in each cluster was recorded and how many times it occurred in each sampling unit (quadrat). The sum of individuals in all the quadrats was divided by the total number of quadrats in which the species occurred. It was represented by the equation:

$$\text{Abundance} = \frac{\textit{Total number of individuals of the species in all quadrats}}{\textit{Total number of quadrats in which the species occurred}}$$

$$\text{Abundance} = \frac{1279}{41}$$

$$= 31.195$$

The two sampling sessions were done to capture the variation in the distribution of *P. fusiformis* **(Thou.) Lindl.** during the rainy season and also in the dry season when there was occurrence of fire. A total of 30 line transects with a length of 30 m were drawn at a regular interval of 20 m along the baseline. The parameters measured were altitude, number of indigenous tree stumps and remaining indigenous trees, orchid plant height, number of orchid clusters and number of orchid plants in a cluster. The number of trees and tree stumps was determined by taking the record of trees and stumps along each transect. Heights of the tallest orchids in the clusters were measured using a 3 metre oxford tape measure.

Density expressed the numerical strength of the orchid species where the total number of individuals of orchids in clusters in all the quadrats was divided by the total number of quadrats studied. Density of the orchids was calculated using the expressions of Curtis and McIntosh, (1950) as follows:

$$\text{Density} = \frac{Total\ number\ of\ individuals\ of\ a\ species\ in\ a\ cluster}{Total\ number\ of\ quadrats\ studied}$$

$$\text{Density} = \frac{1279}{87}$$

$$= 14.701$$

2.5 Determination of common human activities at Manga range

Manga range has had an interaction between historical human impacts (land use, logging and fires) and current episodic high intensity disturbances which have led to decline in species diversity and induced significant changes in habitat distribution or species dominance. Natural forests are vulnerable to overutilization and exploitation due to the sensitivity of the complex and highly diverse ecosystem. Deforestation was driven by an increasing human population with an ever increasing demand for natural resources such as land, timber and wood fuel. The consequence was rapid loss of and destruction of tropical forests leading to an unknown number of species becoming extinct without ever being recognized. Such deforestation activities have been a cause of mass extinction wave globally. One such species under threat of extinction is the critically endangered epiphytic orchid *P. fusiformis* **(Thou.) Lindl.**, which is dependent on native trees as its phorophytes for survival.

At lower altitudes there were intense human activities while at higher altitudes human activities reduced, and the indigenous vegetation was relatively intact. The disturbances were surveyed in relation to altitudinal variation. Local landscape fragmentation and degradation in the lower altitudes increased further resulting in changes of plant diversity and distribution. Data collection was done before and after human disturbances especially fires, after wood collection, after tree harvesting, after collection of herbs and cutting of grass for thatching houses.

2.6 Determination of symbiotic fungi infestation on mycorrhiza of P. fusiformis (Thou.) Lindl.

The roots were then cut into 5cm long segments and placed in petri-dishes containing potato dextrose agar (PDA) mixed with streptomycin. The roots were sectioned transversely to expose the cortex and fungal pelotons (fungal coils) for enhanced germination. Microscopic identification of the fungi was based on phenotype; colony or hyphae, characters of spores and reproductive structure. The percentage germination of fungi in petri dishes was estimated when the petri dishes were placed on a graph paper (gridline transect) and then observing under a dissecting microscope at x100 magnification to give a relative measure of colonization at the 5th day when the fungal hyphae would have grown maximally.

2.7 Data analysis

All data was entered onto Excel spreadsheet and analyzed using various software including SPSS 17, Origin pro-7, Unscrambler 9.7, and Microsoft Excel 2007 softwares. Distribution and abundance was analyzed using Origin Pro-7, Microsoft Excel by plotting histograms with error bars on orchid population clusters along an altitudinal gradient and also clustered histograms on clusters against orchid plant heights. Human activities were analyzed using Unscrambler 9.7 by plotting Hoteling's ellipses for the two sampling sessions. The number of host trees and the remaining tree stumps were plotted on clustered histograms. Fungal abundance was analyzed by establishing the rates of germination in culture media using Unscrambler 9.7 software.

CHAPTER THREE

RESULTS

3.1 Distribution and abundance of P. fusiformis (Thou.) Lindl. across altitudinal gradient

There was significant variation in the abundance and distribution of epiphytic orchid with change in altitude. 41 quadrats were found to have a density of 3.2 individuals per unit area; 47 quadrats did not have any orchid. The number of orchid clusters generally decreased with increase in altitude (Figure 3.1). The majority of the *P. fusiformis* **(Thou.) Lindl.** plants were clustered around the altitude of 1800 to 1850 m. At α 0.05 the standard error bars of the means indicate significant difference between 1792 m, and 1836 m; however, there was no significant difference between the clusters at altitude 1886 m and 1905 m.

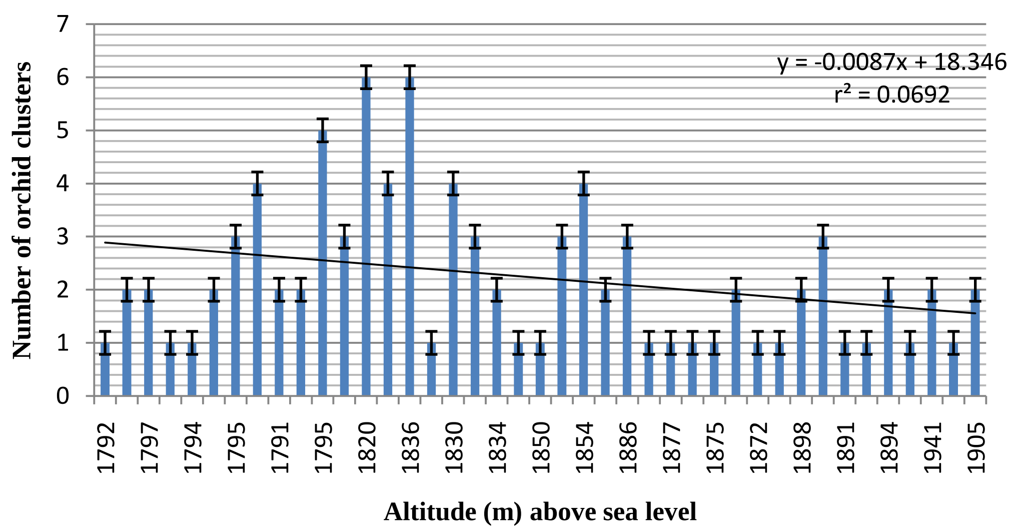


Figure 3.1: Number of clusters against altitude.

A chi-square test was done to establish a relationship between altitude and average orchid plant heights. There was no significant correlation between the altitude in which *P. fusiformis* **(Thou.) Lindl.** occurred and their average heights (appendix 7.2) in the orchid clusters. Figure 3.2 indicated that there was an increase in number of plants in clusters in relation to orchid plant height was not significant (P = 0.069), while the relationship between cluster size and the height of orchids had lower average heights when compared to the parts of the range with fewer clusters which had higher average heights.

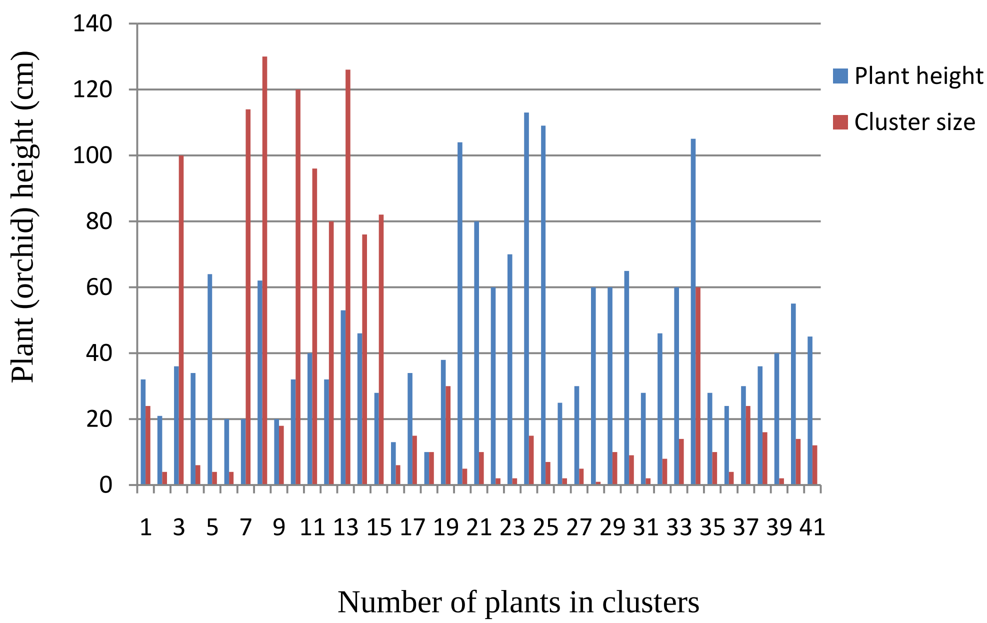


Figure 3.2: Relationship between orchid height and number of orchid plants in a cluster.

3.2 Effect of human activities on P. fusiformis (Thou.) Lindl.

Logging, wood collection, and fire were the key factors which influenced the distribution and abundance of orchid. The factors highlighted have greatly contributed to the decimation of the epiphytic orchid *P. fusiformis* **(Thou.) Lindl.** and other indigenous flora and fauna. These factors were prevalent as the study area is situated in a high density human environment where there is a high demand for natural resources.

3.2.1 Fire

Altitude (PC1), number of clusters (PC2) and plant heights were the three components used in the Hoteling's ellipses. Results in Figure 3.3 and 3.4 illustrate the effects of fire on orchid distribution on fire prone parts of the range. The score plots illustrated orchid distribution which included patterns of establishment, influence of fire, similarities and differences in orchid cluster population before and after the fire (Figures 3.3 and 3.4). Loadings (data values) lying to the right of the score plot had higher values (49-87) for number of orchid clusters and plant height. The scores on the lower part of the scatter plot (8-54) represented the parts of the range where quadrats had zero data values. Zero data values were the quadrats in which no orchid clusters were detected. The density of orchid clusters significantly decreased with increase in altitude ($P = 0.00004$) at α 0.05.

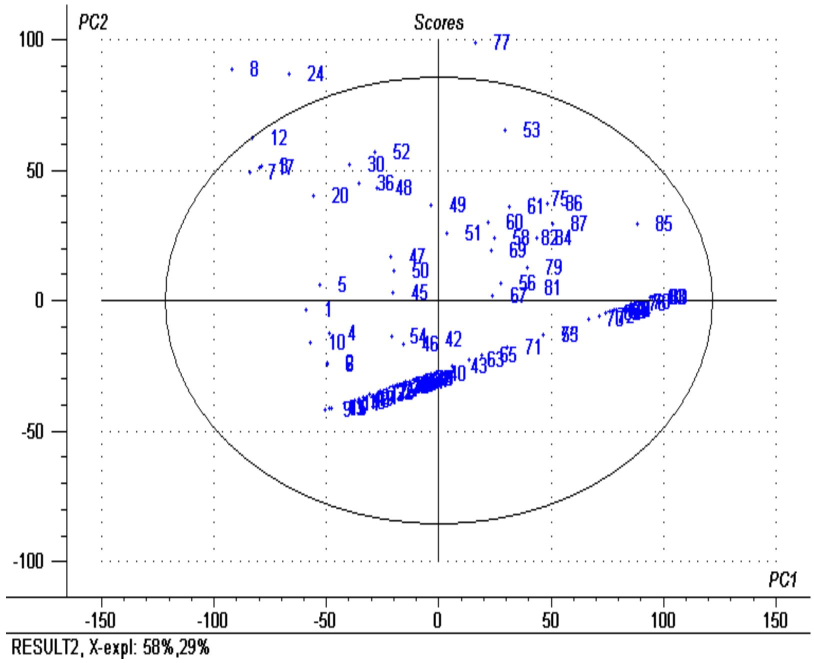


Figure 3.3: Orchid cluster distribution before an intense fire regime (Oct.-Dec. 2011)

Fire incidences in the range were detected to have occurred between December 2011-February 2012 (Plates 3.1 A and B). The fires decimated larger shrubs and stumps from the middle to the upper portions of the range (Figure 3.4). In the normal distribution situation 5% of the samples were expected to lie outside the ellipse. Orchid cluster results for February 2012 indicated that: altitude had a little influence on orchid cluster size. The calculation on orchid abundance indicates that *P. fusiformis* **(Thou.) Lindl.** was abundant in 31% of the total area sampled (Figure 3.3) at Manga range which served to reveal that anthropogenic activities were playing a role in degrading the orchid's natural habitat. Human activities at Manga range increased with increase in demand for arable land resulting in the partial landscape fragmentation and contributed to changes in plant diversity and distribution.

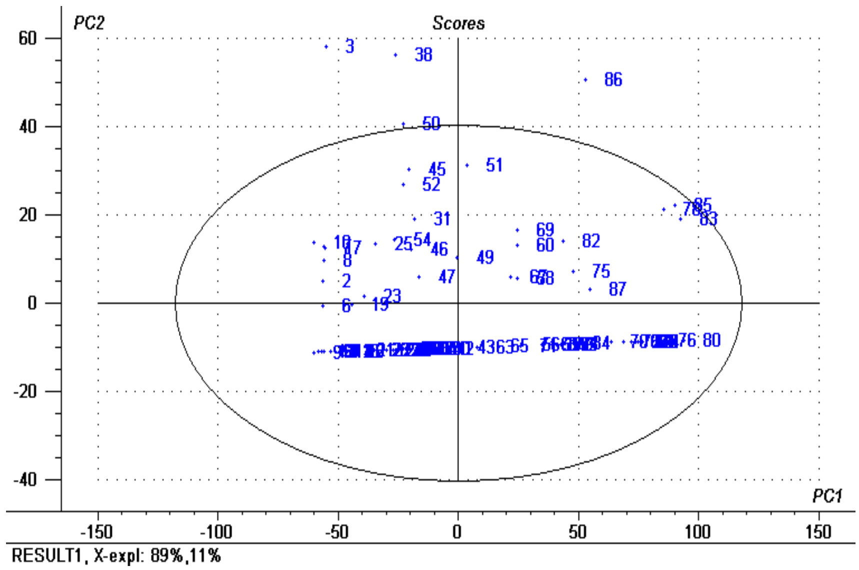
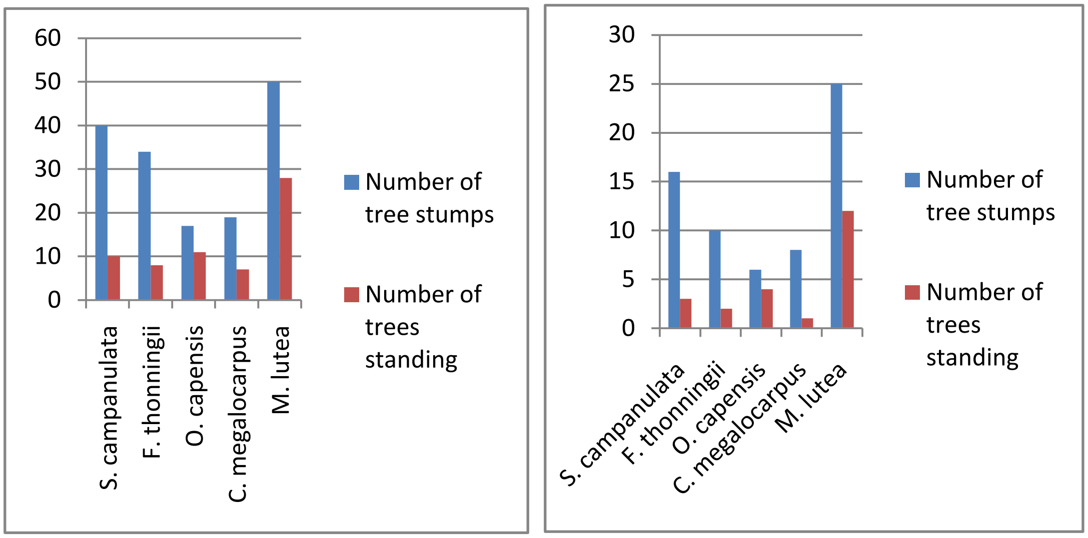


Figure 3.4: Orchid cluster distribution after an intense fire regime Feb-March 2012.

3.2.2 Logging

Manga range had heterogeneity in vegetation composition, but most tree species especially the exotic ones like *Eucalyptus* and *Greviella* did not provide suitable conditions for the establishment of *P. fusiformis* **(Thou.) Lindl.** Native vegetation especially *Spathodea campanulata, Vangueria infausta, Ficus thonningii, Olea capensis, Croton sp. Terminalia sp.* and *Protea sp.* were the host tree species at the range at the time of study (October 2011- March 2012).



(a) (b)

Figure 3.5 (a and b): The distribution of *P. fusiformis* (Thou.) Lindl. host tree stumps and trees (a) October-December 2011 (b) February-March 2012 at Manga range.

During the study, tree phorophytes (Table 3.1) hosting *P. fusiformis* **(Thou.) Lindl.** along the line transect were counted, marked with red strips of clothing and their record kept. A total of 64 standing trees and 160 tree stumps of *P. fusiformis* **(Thou.) Lindl.** host trees were detected in the months of October-December 2011(Figure 3.5 (a)). Later on in February-March 2012, the total number of trees standing was only 22 while the total remaining tree stumps were only 65 (Figure 3.5(b)). This clearly revealed the extent of anthropogenic activities affecting biodiversity of Manga range.

Table 3.1: Standing trees and stumps hosting *P. fusiformis* (Thou.) Lindl. during the study period (2011-2012)

Tree species	Number of tree stumps	Number of trees standing
Spathodea campanulata	16	3
Ficus thonningii	10	2
Olea capensis	6	4
Croton megalocarpus	8	1

The study examined the human activities and their effects on the distribution and abundance of the epiphytic orchid *P. fusiformis* **(Thou.) Lindl.** at Manga range ecosystem and outlined the impacts of logging, wood collection and fire regimes on the orchid (Plates 3.1 A and B).

3.2.3 Wood collection

Typically, only a small number of trees and tree stumps which were colonized by *P. fusiformis* (Thou.) Lindl. at Manga range served as its phorophytes.

Plate 3.1 A: Polystachya fusiformis (Thou.) Lindl. cluster on an old tree stump at one of the sites (B) destroyed site (2011-2012).

Occupancy (i.e. presence/absence) of *P. fusiformis* **(Thou.) Lindl.** on a tree or tree stump was a response variable in the study of host specificity. The distribution and abundance of the orchid correlates axiomatically with two variables i.e. tree age and substrate area (Zotz and Vollrath, 2003). Therefore, when a tree is logged or a stump is uprooted, orchid distribution and abundance is greatly reduced in the particular habitat.

3.2.4 Effect of fire

The forest is often set on fire by the local communities during the dry season to get a good growth of grass following the rains. Sometimes it spreads and destroys vast tracts of valuable vegetation. During the study, many orchid rich localities were found to be affected by fire. For epiphytic orchids, fires at any time of the year can cause a drastic change in plant abundance. They are mainly affected by burning of plants, degrading or removal of the support substrate (Plate 3.2) and alteration of the microclimate resulting from fragmentation of the canopy.

Plates 3.2 A and b: Orchid clusters at some sites A: after a cool fire; B: after an intense fire (2011-2012).

The clustered histogram (Figure 3.6) shows the distribution of the different orchid host tree species and the remaining tree stumps at Manga range. *Croton megalocarpus* had the highest count of trees standing while *S. campanulata* had the least number of trees standing. *Spathodea campanulata* had the highest number of tree stumps while *O. capensis* had the least number of stumps in the period of October 2011-March 2012. There were a few immature indigenous tree species remaining (*S. campanulata*, *F. thonningii*, *O. capensis* and *C. megalocarpus*) at the range that could not be suitable hosts to the epiphytic orchid when compared to the older cut down trees with the right bark texture. Logging played a big role in altering the conditions suitable for the survival of epiphytes such as *P. fusiformis* **(Thou.) Lindl.** in the Manga range habitat.

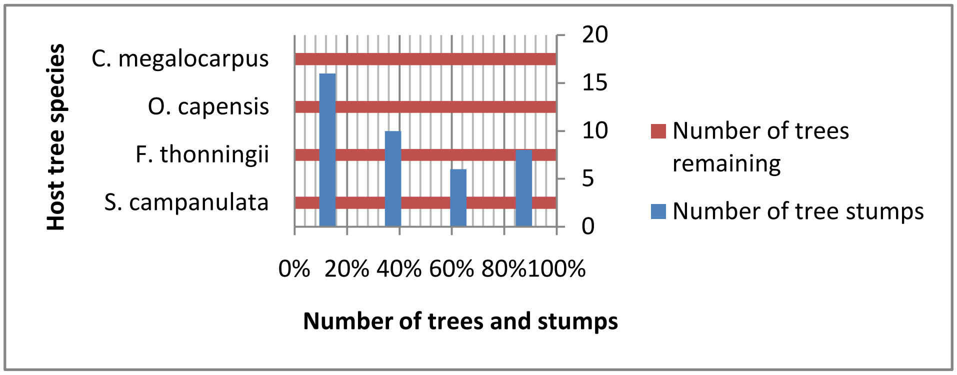
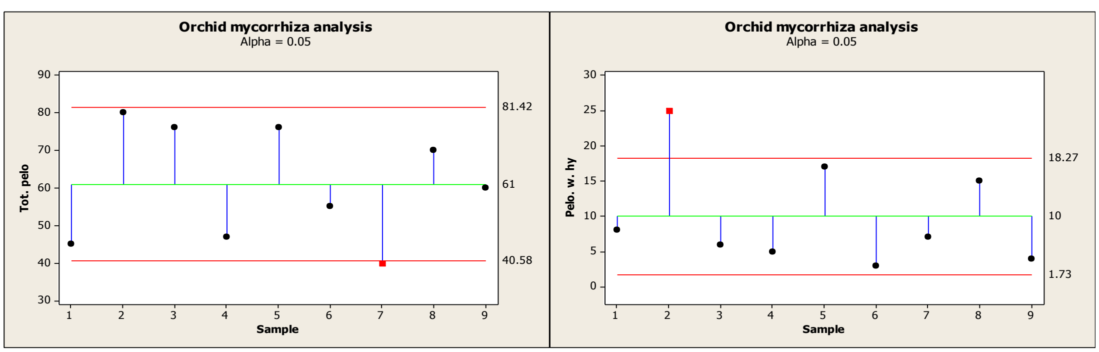


Figure 3.6: Distribution of P. fusiformis (Thou.) Lindl. host tree stumps and trees (2011-2012)

3.3 Identification of mycorrhizal fungal isolates

The selected and sectioned *P. fusiformis* **(Thou.) Lindl.** roots gave results (Figure 3.3 **a** and **b**) that indicated that there was a variation in the rate of germination of fungal endophytes (Plate 3.3 C and D) between the different species cultured during the study. Pure portions of germinated orchid fungal endophytes grew relatively fast than similar portions in impure culture after isolation and sub-culturing in PDA medium. Although all fungi are anamorphs, different fungal species exhibited varying rates of germination.



(a) **(b)**

Figure 3.7: (a) the mean number of pelotons in roots at four sites. (b) Isolated fungi from pelotons in PDA media displaying slow growth/ germination

Plate 3.3 A and B: Emerging hyphae growing on PDA medium in petri dishes.

Analysis and identification of orchid mycorrhizal fungi was mainly based on morphological methods using characters of the phenotype of fungal culture, Colony or hyphae (Plates 3.5 E and F), characteristics of the spore, or reproductive structure, diameter and branching patterns of hyphae, number of nuclei in cells and the capacity of the hyphae to anastomose. Pure fungal isolates revealed the presence of *Rhizoctonia sp.* and *Fusarium sp.* in the roots of orchid roots.

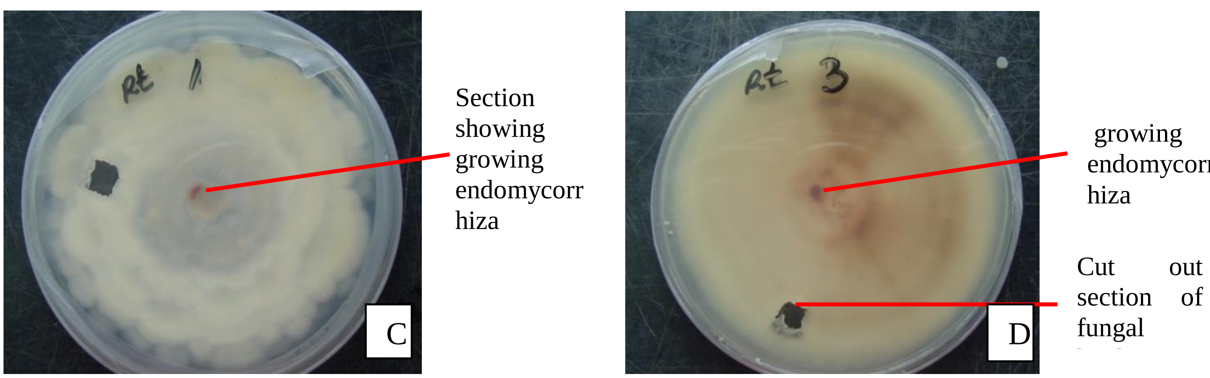


Plate 3.4: Sections C and D: Orchid roots showing germinating fungal endophytes.

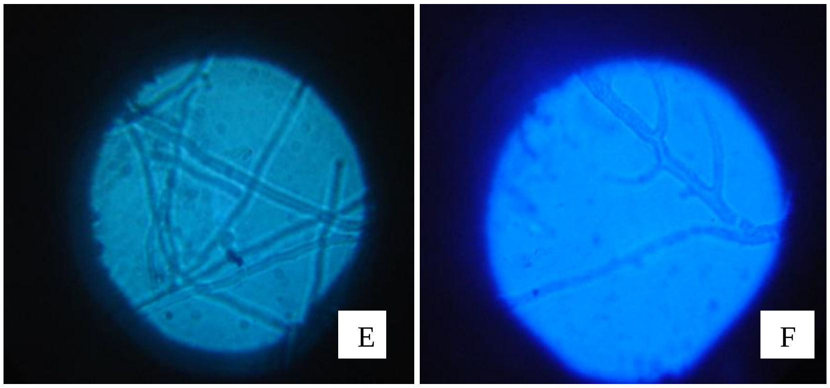


Plate 3.5 E and F: Microscopic details of isolated mycorrhiza fungi from orchid roots. E- *Rhizoctonia sp.* F- *Fusarium sp.*

The results in Figure 3.7 illustrate that there was a close mutual relationship between orchid roots and a diverse range of fungal endophytes. The culture results reflected the antagonistic behaviour of germinating fungal endophytes (Plate 3.4 D). Presence of traces of other fungal species interfered with the rate of fungal germination.

CHAPTER FOUR

DISCUSSION

4.1 Effect of altitude on distribution and abundance of *P. fusiformis* (Thou.) Lindl.

The analysis done on altitude against the number of orchid clusters (Figure 3.1) indicated that a large number of clusters were found on the altitudes 1796 m, 1830 m, 1854 m, 1886 m, 1890 m and 1894 m. Factors that influenced the spread of the orchid *P. fusiformis* **(Thou.) Lindl.** include extent of moss mat on the substrate, quality and quantity of light, bark texture, mycorrhizal associations and available humidity (Koster *et al*., 2013). Orchid assemblages showed a nested subset pattern at Manga range which was significantly related to change in altitude as indicated by the regression analysis (Figure 3.1). Altitude plays a big role in influencing species distribution. The effect of altitude on epiphytes has been attributed to either water balance e. g. drought or correlated to low temperatures.

The relatively low species abundance at low altitudes has been caused by the fact that in this region, few or no pristine habitats remain and extinction which could have occurred in the past due to anthropogenic disturbances and the accompanying habitat fragmentation and deterioration at lower altitudes. The distribution and abundance of *P. fusiformis* **(Thou.) Lindl.** in the Manga range has not previously been documented. Obtaining records of historical disturbance events such as fire regimes, accurate ages of forest fragments was not possible. The range is prime locality for *P. fusiformis* **(Thou.) Lindl.** where the species is endemic.

Altitude is an important factor influencing species distribution as it determines temperature and moisture availability, with lower altitudes having high temperature and moisture. Elevation also negatively influenced species evenness which decreased significantly with increasing altitude (Djordjevic *et al*., 2014). At low elevation with high level of human disturbances, the species richness of orchids was relatively lower than species richness at high altitudes, since most human activities were concentrated at lower elevations. Analysis of paired sample test on altitude against orchid plants in a cluster were significantly different (r, df = 87, P = 0.008). These results are important for the conservation and restoration of *P. fusiformis* **(Thou.) Lindl.** Orchids serve as indicator species of habitat health due to complexity of their ecological relationships and increasing levels of endemism. It was observed that the orchid species *P. fusiformis* **(Thou.) Lindl.** was sparsely distributed on the North and North-west facing rocky slopes of the Manga range. Distribution of epiphytes in general is influenced by the following processes; the host tree size (Hirata *et al.,* 2009), the bark of the host tree as a substrate for epiphytes, the chemical characteristics of host bark structure (Frei and Dodson, 1972), and rugosity (Adhikari *et al.,* 2012), but a combination of the host tree traits appears to be important in determining the epiphytes' presence and diversity (Laube and Zotz, 2006).

4.2 Effect of human activities on *P. fusiformis* (Thou.) Lindl.

Several human activities were observed at the Manga range ecosystem but the most predominant were fire outbreaks, logging and wood collection for firewood.

4.2.1 Fire

The frequent fires have decimated the indigenous tree species which serve as phorophytes for the orchid including *Spathodea campanulata, Ficus thonningii, Olea capensis* and *Croton megalocarpus* thereby greatly affecting the distribution of *P. fusiformis* **(Thou.) Lindl.** In some cases fire can eliminate epiphytes while their phorophytes can remain relatively unharmed (Bartareau and Skull, 1994). Due to these differences, impact of fire and subsequent recovery did not depend exclusively on the burned area itself, but on the characteristics of unburned vegetation. From the study, the orchid species population is patchily distributed (Figure 3.1) on the accumulated moss matting on the rocky outcrops and remains of stems of cut trees and stumps which were not easily accessed by the seasonal fires on the North and North-Western slopes of the Manga range. This is an indication that fire outbreaks contribute a great deal to the decline in orchid cluster population at the Manga range ecosystem.

Fire is a great threat to *P. fusiformis* **(Thou.) Lindl.** at the lower altitudes as their aerial roots and exposed pseudobulbs burn easily during the dry season when humidity is relatively low as illustrated in Figures 3.4 and 3.5. The orchid is sensitive to fire and as such it was limited to parts of the Manga range with high level of water seepage and relictual stands of host trees where it displays a clustered pattern of distribution. The dry pseudobulbs and reed like stems in a cluster act as extra fuel for the fire. This shows that the epiphytic *P. fusiformis* **(Thou.) Lindl.** is at risk and therefore an increase in frequency or intensity of fire may negatively affect sustainable population sizes. High fire frequency has been shown to reduce epiphytic orchids, partly due to decreased numbers of host trees on burnt habitats as observed by Cook (1991).

4.2.2 Logging

Anthropogenic activities such as logging and seasonal fires that have greatly damaged the Manga range ecosystem function and biodiversity are reported for the first time in this study. The anthropogenic activities have revealed that acts of logging, fires, introduction of exotic tree species, harvesting of grass for traditional house construction, firewood collection and collection of herbs for medicinal use have greatly threatened the survival of *P. fusiformis* **(Thou.) Lindl.** Loss of natural habitats due to logging, fires, introduction of exotic tree species such as *Eucalyptus* sp. and *Greviella* sp. have contributed to decline in *P. fusiformis* **(Thou.) Lindl.** population in the Manga range. Some parts especially those with higher number of clusters exhibited different characteristics as compared to those with a low number of clusters. Such sites have vegetation which is dense with less exposure to sunlight and wind and a relatively high humidity. To minimize the loss in epiphyte biodiversity, the maintenance of large, forest-like trees in managed plantations could help to conserve epiphyte diversity, not only in the canopy but also in the understorey (Haro-Carrión *et al.*, 2009). However, from the study it was notable *P. fusiformis* **(Thou.) Lindl.** is not a host tree specific epiphyte.

4.2.3 Wood collection

Manga range has had a heterogeneous vegetation complex with extreme environmental conditions (Ochora *et al.,* 2001). Selective logging of valuable timber species in a forest significantly modified light intensity, humidity and other microclimatic factors affecting the survival of *P. fusiformis* **(Thou.) Lindl.** and may also alter and disturb mycorrhizal relationships of terrestrial species. Large areas of the original vegetation in the Manga range, Kisii have been cleared for timber, firewood, grass for thatching traditional houses and grazing over a long period of time and hence resulted in a significant loss (Figure 3.6) of habitat and biodiversity that has a negative impact on wildlife. Only small remnant patches of some of the indigenous woody tree species remain.

4.3 Fungal diversity

This case study in Manga range presents a baseline study which examines explicitly both the distribution and abundance of the orchid *P. fusiformis* **(Thou.) Lindl.** and the fungal symbionts that are necessary for its survival and growth. Orchids have diverse fungal endophytes which form an important component of its fungal diversity. However, the symbiotic fungi abundance is influenced by a number of factors that affect the orchid including mycorrhizal relationship.

The study intended to identify the species of fungal symbionts in the mycorrhiza that influence the abundance of the orchid *P. fusiformis* **(Thou.) Lindl.** at the Manga range ecosystem. Hyphae from the isolated fungi (Plates 3.6 A and B) were identified with the help of several taxonomic keys (Bailey and Jeger, 1992; Barnett and Hunter, 1998; Carmichael *et al*., 1980; Ellis, 1976; Gerlach & Nirenberg, 1982; Sutton *et al*., 1980). The fungal symbionts isolated during the study were *Verticillium sp, Varicosporium sp,* *Fusarium sp. Rhizoctonia sp, Penicillium sp,* and *Cunninghamella sp* (Figure 3.7). Fungi inhabiting orchid roots are colonizers of plant roots (Brundrett *et al*., 1996). Pelotons were observed to be more in the cortical cells and sparse in epidermal cells but totally absent in the inner vascular region. Distribution, activity and survival of AMF (Arbuscular mycorrhizal fungi) were influenced by several factors including humidity, topography, fire frequency, temperature, light intensity, altitude and environmental disturbance (Hayman, 1982).

Isolation of pelotons was difficult as orchid roots did not have massive mycorrhizal infections. Mycorrhizal infections were identified as brown zones along the length of the roots selected (Plates 3.3 A and B). The strains of fungi isolated and examined belong to the anamorphic form of *Rhizoctonia sp.* fungi (Plates 3.6 A and B) that are rarely observed in teleomorphic forms (Bonnardeaux *et al*., 2007; Yagame *et al*., 2008; Ochora *et al.,* 2001) which do not form spores in culture media. Hyphal morphology, number of nuclei and patterns of anastomosis are stable characters (Sneh *et al*., 1991) of fungi. The results (Figure 3.7) support the hypothesis that there are plant trait and fungal strain specific effects on the growth of *P. fusiformis* **(Thou.) Lindl.** These results are consistent with recent studies on the effect of *Rhizoctonia sp.* fungi on the growth of other orchids. For instance (Chang and Chou, 2007) noted that *Rhizoctonia sp.* enhanced the growth of the orchid *Anoectochilus formosanus* **(Hayata);** (Ochora *et al*., 2001) also noted that orchid spores can only germinate in association with symbiotic *Rhizoctonia sp.*

Tilman *et al*., (1996) noted that mycorrhizal diversity has an influence on host plants indirectly through fungal productivity. If this relationship is true, then the more diverse a mycorrhizal community, the higher the productivity in terms of spores translating into plant growth response. The main nutrient and water sources of epiphytic orchids are precipitation, canopy through-fall, and cloud water which shapes their functional morphologies. *Polystachya fusiformis* **(Thou.) Lindl.** native to the Manga region and thrives in fire prone environments. The orchid dies back during the dry season to leave behind pseudobulbs which undergo vegetative growth during the rainy season. The orchid has mycorrhizae and mycorrhizal pelotons which do not die off when the plant becomes dormant. Changes in the abundance of plant mutualists (e.g. mycorrhizal fungi) and pollinator enemies (predators) affect all interactions between plants and pollinators.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Altitude greatly influences the distribution and abundance of the orchid *P. fusiformis* **(Thou.) Lindl.** as it influences temperature and moisture availability. The lower altitudes have higher temperatures and moisture levels when compared to the higher altitudes. The gradient on the North and North-Western facing slopes negatively influenced the distribution of *P. fusiformis* **(Thou.) Lindl.** with increase in altitude. However, it was notable that the lower altitudes had lower orchid population densities due close proximity to human settlements.

Fire outbreaks/incidences did not significantly affect the distribution and abundance of *P. fusiformis* **(Thou.) Lindl.** at the Manga range. On the negative aspect, fires reduced the litter/dry leaves covering the orchid pseudobulbs. With the onset of the rains, fresh shoots sprouted from the dormant buds. On the positive side, fire incidences encouraged flowering of the undisturbed orchids.

Logging of the host phorophytes contributed to the reduction in orchid cluster count. Fires/logging contributed to lose of forest canopy cover which favours orchid growth. However, it was noted that the orchids had evolved to growing on the moss matting on the rocky outcrops of the north and North-Western facing slopes of the range.

Collection of firewood did not significantly affect orchid cluster distribution as only stumps in the accessible parts of the Manga range were uprooted for firewood.

The diverse mycorrhizal infestations in the orchids form an important component of its fungal diversity. Several fungal symbionts were isolated during the study, but it was not clear how their infestation influenced orchid abundance at the Manga range.

5.2 Recommendations

Long term studies on the life cycle of *P. fusiformis* **(Thou.) Lindl.** are necessary to establish a stronger estimate of recovery time after disturbance. The cliffs and rocky outcrops of the North and the North-Western facing slopes of Manga range should be declared "conservation islands" for the indigenous flora and fauna including *P. fusiformis* **(Thou.) Lindl.**

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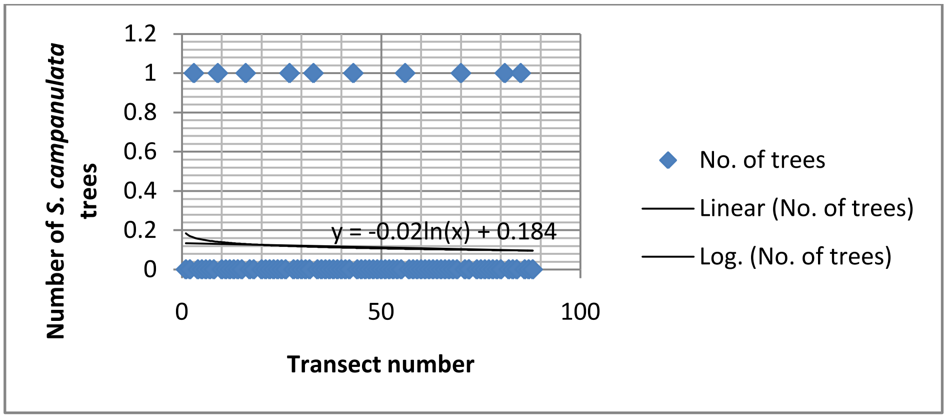
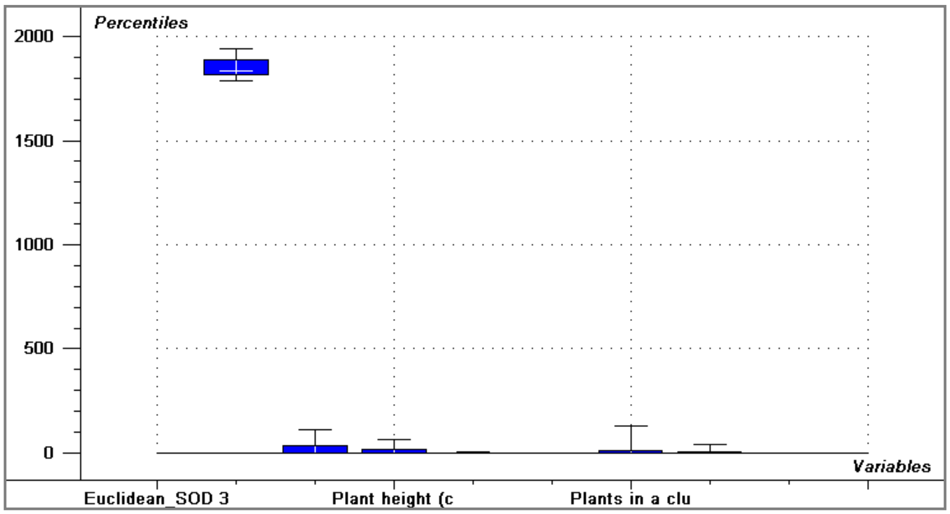
APPENDICES

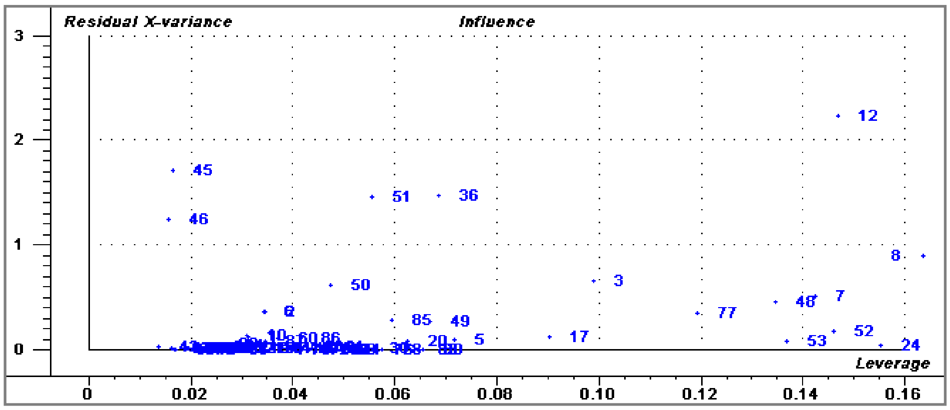
Appendix i: Number of S. campanulata trees along transects



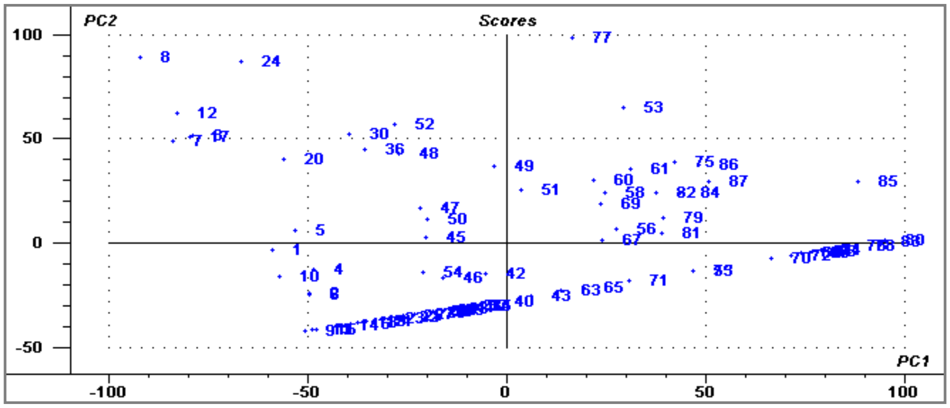
Appendix ii: Percentiles of plant height and plants in a cluster with change in altitude



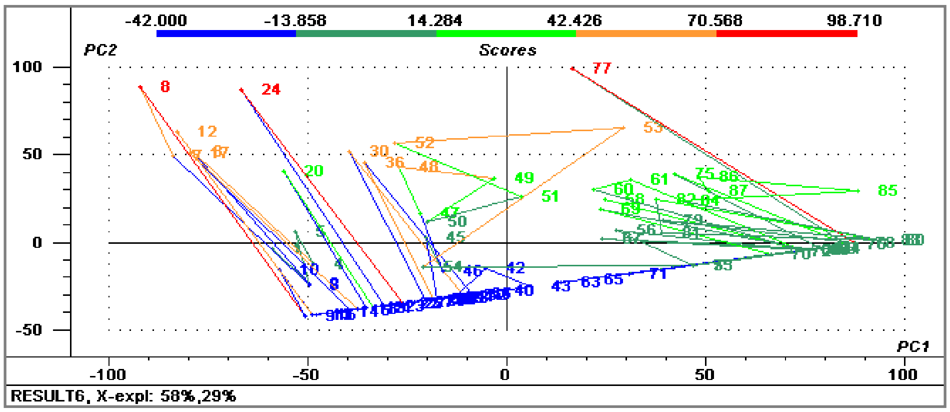
Appendix iii: A scatter plot of orchid cluster distribution after an intense fire (Feb.-Mar 2012)



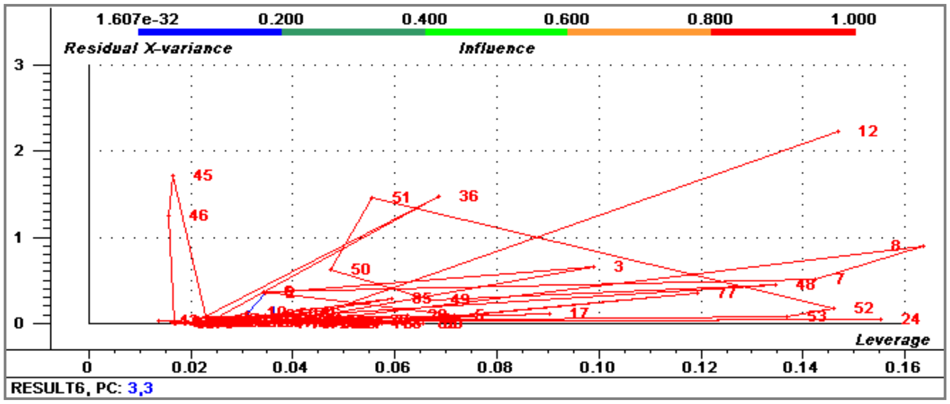
Appendix iv: A scatter plot of orchid cluster distribution before an intense fire (Oct-Dec 2011)



Appendix v: Distribution of orchid clusters along transect lines across the range (Oct-Dec 2011)



Appendix vi: Distribution of orchid clusters along transect lines across the range (Feb-March 2012)



Appendix vii: Analysis of orchid data using SPSS

	N	Correlation	Sig.
Altitude (m) & Plant height (cm)	87	-.009	.937
Altitude (m) & Plants in a cluster	87	-.283	.008
Plant height (cm) & Number of clusters	87	.572	.000
Plant height (cm) & Plants in a cluster	87	.350	.001

Appendix viii: One-Way ANOVA

Levene's Test for Equal Variance

Source	DoF	Sum of Squares	Mean Square	F Value	P Value
Model	2	53950773.9	26975386.9	10.98400	0.00004
Error	120	294705593	2455879.95		

At the 0.05 level, the population variations are significantly different.

APPENDIX ix: Data collected October- December 2011 sampling

Date	Way Point No.	Transect No.	Altitude (m)	Plant height	No. of orchid clusters	Cluster size	Distance from point(cm)
10/10/2011	1	MR001	1792	32	1	24	165
10/10/2011	2	MR001	1794	21	2	4	290, 24
10/10/2011	3	MR001	1797	36	2	100	400, 50
10/10/2011	4	MR001	1797	34	1	6	430
10/10/2011	6	MR002	1794	64	1	4	17
10/10/2011	7	MR002	1794	20	2	4	18, 34
10/10/2011	8	MR002	1795	20	3	114	34
10/10/2011	9	MR002	1795	62	4	130	130, 80, 110, 60
10/10/2011	12	MR004	1791	20	2	18	
10/10/2011	14	MR005	1799	32	2	120	
10/11/2011	19	MR008	1795	40	5	96	
10/11/2011	22	MR009	1814	32	3	80	
10/11/2011	26	MR011	1820	53	6	126	
10/12/2011	32	MR014	1831	46	4	76	

10/12/2011	38	MR017	1836	28	6	82	
13/10/2011	44	MR021	1841	13	1	6	30
13/10/2011	47	MR022	1830	34	4	15	110
13/10/2011	48	MR023	1831	10	3	10	30, 80, 50
13/10/2011	49	MR023	1834	38	2	30	110, 60
13/10/2011	50	MR024	1825	104	1	5	85
13/10/2011	51	MR024	1850	80	1	10	70
17/10/2011	52	MR025	1828	60	3	2	55, 130, 128
17/10/2011	53	MR025	1854	70	4	2	65, 45
17/10/2011	54	MR026	1828	113	2	15	65, 45
17/10/2011	55	MR026	1886	109	3	7	68, 103, 67
17/10/2011	56	MR027	1824	25	1	2	78
17/10/2011	58	MR028	1877	30	1	5	160
18/10/2011	60	MR029	1875	60	1	1	190
18/10/2011	62	MR030	1875	60	1	10	140
18/10/2011	63	MR030	1885	65	2	9	110, 90

19/10/ 2011	69	MR033	1872	28	1	2	120
19/10/ 2011	71	MR034	1875	46	1	8	270
20/10/ 2011	77	MR037	1898	60	2	14	210
20/10/ 2011	79	MR038	1890	105	3	60	30,43, 60
20/10/ 2011	81	MR039	1891	28	1	10	150
21/10/ 2011	83	MR040	1888	24	1	4	150
21/10/ 2011	84	MR040	1894	30	2	24	120, 80
21/10/ 2011	86	MR041	1898	36	1	16	190
21/10/ 2011	87	MR041	1941	40	2	2	180, 60
21/10/ 2011	88	MR042	1904	55	1	14	80
21/10/ 2011	89	MR042	1905	45	2	12	142, 85

Appendix x: Data collected February-March 2012 Sampling

Date	Qua. No.	W.P. No.	Tra. No.	Alt. (m)	Pla. Hght	No. of Cls	Pla. Per Cls
26/02/2012	1	1	MR001	1792	0	0	0
26/02/2012	2	2	MR001	1794	16	1	2
26/02/2012	3	3	MR001	1797	60	2	40
26/02/2012	4	4	MR001	1797	0	0	0
26/02/2012	5	5	MR002	1794	0	0	0
26/02/2012	6	6	MR002	1794	10	1	3
26/02/2012	7	7	MR002	1795	19	2	20
26/02/2012	8	8	MR002	1795	14	1	26
26/02/2012	9	9	MR003	1790	0	0	0
26/02/2012	10	10	MR003	1791	17	1	30
26/02/2012	11	11	MR003	1792	0	0	0
26/02/2012	12	12	MR003	1799	0	0	0
26/02/2012	13	13	MR004	1792	0	0	0
26/02/2012	14	14	MR004	1799	0	0	0
26/02/2012	15	15	MR005	1793	0	0	0
26/02/2012	16	16	MR005	1802	0	0	0
27/02/2012	17	17	MR006	1795	23	1	5
27/02/2012	18	18	MR006	1804	0	0	0
27/02/2012	19	19	MR006	1806	10	1	3
27/02/2012	20	20	MR006	1814	0	0	0
27/02/2012	21	21	MR007	1808	0	0	0
27/02/2012	22	22	MR007	1815	0	0	0

27/02/2012	23	23	MR008	1811	12	2	2
27/02/2012	24	24	MR008	1820	0	0	0
27/02/2012	25	25	MR009	1816	24	1	4
27/02/2012	26	26	MR009	1824	0	0	0
27/02/2012	27	27	MR010	1819	0	0	0
27/02/2012	28	28	MR010	1828	0	0	0
28/02/2012	29	29	MR011	1822	0	0	0
28/02/2012	30	30	MR011	1831	0	0	0
28/02/2012	31	31	MR012	1832	30	1	2
28/02/2012	32	32	MR012	1833	0	0	0
28/02/2012	33	33	MR013	1823	0	0	0
28/02/2012	34	34	MR013	1834	0	0	0
28/02/2012	35	35	MR013	1834	0	0	0
28/02/2012	36	36	MR013	1836	0	0	0
28/02/2012	37	37	MR014	1824	0	0	0
29/02/2012	38	38	MR014	1825	65	2	15
29/02/2012	39	39	MR015	1827	0	0	0
29/02/2012	40	40	MR015	1840	0	0	0
29/02/2012	41	41	MR016	1830	0	0	0
29/02/2012	42	42	MR016	1841	0	0	0
29/02/2012	43	43	MR016	1850	0	0	0
29/02/2012	44	44	MR017	1825	0	0	0
29/02/2012	45	45	MR017	1830	40	2	8
29/02/2012	46	46	MR017	1831	22	1	5
29/02/2012	47	47	MR017	1834	16	1	3

01/03/2012	48	48	MR018	1825	0	0	0
01/03/2012	49	49	MR018	1850	20	1	4
01/03/2012	50	50	MR019	1828	50	2	10
01/03/2012	51	51	MR019	1854	42	1	3
01/03/2012	52	52	MR020	1828	36	2	9
01/03/2012	53	53	MR020	1886	0	0	0
01/03/2012	54	54	MR021	1824	24	1	6
01/03/2012	55	55	MR021	1893	0	0	0
01/03/2012	56	56	MR022	1877	0	0	0
01/03/2012	57	57	MR022	1922	0	0	0
01/03/2012	58	58	MR023	1875	15	1	3
01/03/2012	59	59	MR023	1922	0	0	0
01/03/2012	60	60	MR024	1875	23	1	2
01/03/2012	61	61	MR024	1885	0	0	0
01/03/2012	62	62	MR024	1922	0	0	0
02/03/2012	63	63	MR025	1858	0	0	0
02/03/2012	64	64	MR025	1925	0	0	0
02/03/2012	65	65	MR026	1864	0	0	0
02/03/2012	66	66	MR026	1926	0	0	0
02/03/2012	67	67	MR027	1872	16	1	1
02/03/2012	68	68	MR027	1924	0	0	0
04/03/2012	69	69	MR028	1875	26	1	4
04/03/2012	70	70	MR028	1914	0	0	0
04/03/2012	71	71	MR029	1876	0	0	0
04/03/2012	72	72	MR029	1919	0	0	0

04/03/2012	73	73	MR030	1893	0	0	0
04/03/2012	74	74	MR030	1927	0	0	0
18/3/2012	75	75	MR031	1898	16	1	3
18/3/2012	76	76	MR031	1934	0	0	0
18/3/2012	77	77	MR032	1890	0	0	0
18/3/2012	78	78	MR032	1936	29	1	6
18/03/2012	79	79	MR033	1891	0	0	0
18/03/2012	80	80	MR033	1944	0	0	0
19/03/2012	81	81	MR034	1888	0	0	0
19/03/2012	82	82	MR034	1894	23	1	4
19/03/2012	83	83	MR034	1943	27	1	5
19/03/2012	84	84	MR035	1898	0	0	0
19/03/2012	85	85	MR035	1941	30	1	6
19/03/2012	86	86	MR036	1904	60	1	7
19/03/2012	87	87	MR036	1905	12	2	2

Appendix xi: Sample data collection form

Data Collection Form

Name of researcher…………

Time

Place…………………
Day……………..
Date…………

Weather: Sunny Cloudy Rainy Dry

Transect/Plot No.	MR001	MR002	MR003	MR004	MR005	MR006	MR007	MR008	MR009
GPS Co-ordinates									
Time									
Altitude									
*Soil sample									
Soil sample depth (cm)									
Soil Ph									
Plant height (cm)									
No. of clusters									
No. of plants per cluster									
Number plants per cluster(per quadrant)									
*Peloton samples									

*Samples were taken for laboratory analysis

Appendix xii: Vegetation inventory of Manga ecosystem

Name of species	Habit
Tarchmanthus camphiratus **(L.)**	Shrub
Vernonia adoensis (**Walp.**)	Herb
Vernonia aurantiaca (**D. Hoffm.**) **N.E. Br.**	Climber
Vernonia auriculifera (**Hiern.**)	Herb
Vernonia biafrae (**Oliv. & Hiern**)	Shrub
Vernonia brachycalyx (**O. Hoffm.**)	Shrub
Vernonia cinerascens (**Sch.-Bip**)	Shrub
Vernonia wochstetteri (**Walp.**)	Herb
Vernonia urticifolia (**A. Rich.**)	Climber
Ensete edule (**J.I. Gmel.**) **Horan**	Herb
Acanthera oppositifolia (**Lam.**) **Codd.**	Shrub
Anona senegalensis (**Pers.**)	Shrub
Artabotrys likinensis (**De Wild.**)	Shrub
Clematis brachiata (**Thunb.**)	Climber
Clematis simensis (**Fresen.**)	Climber
Stephania abyssinica (**Dillon & A. Rich**) **Walp.**	Liana
Stephania cyanantha (**Hiern.**)	Climber

Tiliacora funifera (**Miers.**) **Oliv.**	Liana
Tiliacora kenyensis (**Troupin.**)	Liana
Tinospora caffra (**Miers.**) **Troupin.**	Liana
Piper capense (**L.**)	Herb
Piper guineense (**Schum & Thonn.**)	Climber
Piper umbellatum (**L.**)	Herb
Cardaba farinosa (**Forssk.**)	Shrub
Capparis erythrocarpos (**Isert.**)	Climber
Capparis tormentosa (**Lam.**)	Shrub
Maerua angolensis (**DC.**)	Shrub
Maerua decumbens (**Brongn.**) **De Wolf.**	Shrub
Maerua parvifolia (**Pax.**)	Herb
Carpolobia goetzei (**Gurke.**)	Shrub
Securidaca welwitschii (**Oliv.**)	Climber
Phytolacca dodecandra (**L' Herit.**)	Climber
Gnidia lamprantha (**Gilg.**)	Shrub
Gnidia subcordata (**Meisn.**)	Shrub
Struthiola thomsonii (**Oliv.**)	Herb
Faurea saligna (**Harv.**)	Shrub
Adenia cissampeloides (**Hook.**) **Harms.**	Climber
Adenia gummifera (**Harv.**) **Harms.**	Climber
Adenia rumicifolia (**Engl.**)	Climber
Adenia schweinfurthi (**Engl.**)	Climber
Adenia venenata (**Forssk.**)	Climber

Begonia meyeri-johannis (**Engl.**)	Climber
Podocarpus latifolius (**Thunb.**)	Tree
Xymalos monospora (**Harv.**)	Tree
Ocotea argylei (**Harv.**)	Tree
Boscia augustifolia (**A. Rich.**)	Tree
Maerua triphylla (**A. Rich.**)	Tree
Olinia rochetiana (**A. Juss.**)	Tree
Gnidia glauca (**Fresen.**) **Gilg.**	Tree
Peddiea fischeri (**Engl.**)	Tree
Faurea rochetiana (**A. Rich.**) **Pic. Ser.**	Tree
Pittosporum mannii (**Hook. f.**)	Tree
Pittosporum viridiflorum (**Sims.**)	Tree
Caesaria batliscombei (**R. E. Fries.**)	Tree
Caesarea gladiformis (**Mast.**)	Tree
Dovyalis abyssinica (**A. Rich.**) **Warb.**	Tree
Dovyalis macrocalyx (**Oliv.**) **Warb.**	Tree
Flacourtia indica (**Burm. f.**) **Merill.**	Tree
Oncoba routledgei (**Sprague.**)	Tree
Oncoba spinosa (**Forssk.**)	Tree
Rawsonia lucida (**Harv. & Sond.**)	Tree
Scolopia rhamniphylla (**Gilg.**)	Tree
Scolopia zeyheri (**Nees.**) **Harv.**	Tree
Trimeria grandifolia (**Hochst.**) **Warb.**	Tree
Warburgia ugandensis (**Sprague.**)	Tree

Ochna holstii (**Engl.**)	Tree
Ochna inscupla (**Sleumer.**)	Tree
Ochna ovata (**F. Hoffm.**)	Tree
Ouratea densiflora (**De Wild. & Th. Dur.**)	Tree
Ouratea hiernii (**Van tiegh.**) **Exell.**	Tree
Syzygium guineense (**Willd.**) **DC.**	Tree
Syzygium cordatum (**Krauss**)	Tree
Combretum adenogonium (**A. Rich.**)	Tree
Neoboutonia melleri (**Mull. Arg.**) **Prain.**	Shrub
Sapuim ellipticum (**Krauss.**) **Pax.**	Tree
Phyllanthus fischeri (**Pax.**)	Shrub
Suregada procera (**Prain.**) **Croizat.**	Tree
Phyllanthus ovalifolius (**Forssk.**)	Shrub
Synadenium grantii (**Hook. f.**)	Tree
Phyllanthus reticularis (**Poir.**)	Shrub
Hagenia abyssinica (**Bruce.**) **J.F. Gmel.**	Tree
Phyllanthus sepialis (**Mull. Arg.**)	Shrub
Prunus africana (**Hook. f.**) **Kalkm.**	Tree
Rubus apetalus (**Poir.**)	Shrub
Parinari curatellifolia (**Benth.**)	Tree
Delonix elata (**L.**) **Gamble.**	Tree
Rubus niveus (**Thunb.**)	Shrub
Piliostigma thonningii (**Schumach.**) **Milne-Redh.**	Tree
Rubus steudneri (**Schweinf.**)	Shrub

Senna petersiana (**Bolle.**) **Lock.**	Tree
Rubus volkensii (**Engl.**)	Shrub
Senna singueana (**Del.**) **Lock.**	Tree
Caesalpinia decapetala (**Roth.**) **Alston**	Shrub
Pterolobium stellalum (**Forssk.**) **Brenan**	Shrub
Senna bicapsularis (**L.**) **Roxb.**	Shrub
Senna didymobotrya (**Fresen.**) **Irwin & Barneby**	Shrub
Acacia gerrardii (**Benth.**)	Tree
Senna obtusifolia (**L.**) **Irwin & Barneby**	Herb
Acacia hockii (**De Wild.**)	Tree
Senna septemtrionalis (**Viviani**) **Irwin & Barneby**	Shrub
Entada gigas (**L.**) **Faux. & Rendle**	Climber
Acacia persiciflora (**Pax.**)	Tree
Abrus canescens (**Bak.**)	Shrub
Acacia polyacantha (**Willd.**)	Tree
Abrus precatorius **(L.)**	Climber
Acacia seyal (**Del.**)	Tree
Aesychnomene abyssinica (**A. Rich.**) **Vatke.**	Herb
Acacia siberiana (**DC.**)	Tree
Aesychnomene elaphroxylon (**Guill. & Pers.**) **Taub.**	Shrub
Argyrolobium fischeri (**Taub.**)	Herb
Calpurnia aurea (**Ait.**) **Benth.**	Shrub
Albizia granbracteata (**Taub.**)	Tree
Canavalia africana (**Dunn.**)	Climber

Albizia gummifera (**J.F. Gmel.**)	Tree
Albizia petersiana (**Bolle.**) **Oliv.**	Tree
Crotalaria agatiflora (**Schweinf.**)	Herb
Albizia zigia (**DC.**) **Macler.**	Tree
Crotalaria axillaris (**Ait.**)	Herb
Entada abyssinica (**A. Rich**)	Tree
Crotalaria lachnocarpoides (**Engl.**)	Herb
Erythrium excels (**Bak.**)	Tree
Crotalaria lachnophora (**A. Rich.**)	Herb
Ormocarpum tricocarpum (**Taub.**)	Tree
Crotalaria mallensis (**Bak. f.**)	Herb
Sesbania macronata (**Phil. & Hutch**)	Tree
Crotalaria matalita (**Meissn.**)	Herb
Myrica salicifolia (**A. Rich.**)	Tree
Eugenia capensis (**Eckl. & Zeyh.**) **Sond.**	Shrub
Combretum molle (**G. Don.**)	Tree
Combretum collinum (**Fres.**)	Shrub
Combretum paniculatum (**Vent.**)	Shrub
Terminalia mollis (**Laws.**)	Tree
Terminalia brownii (**Fresen.**)	Tree
Hypericum quartinianum (**A. Rich.**)	Shrub
Cassipourea malosana (**Bak.**) **Alston**	Tree
Hypericum revolutum (**Vahl.**)	Shrub
Cassipourea ruwensorensis (**Engl.**) **Alston**	Tree

Psorospermum febrifugum (**Spach.**)	Shrub
Garcinia buchananii (**Bak.**)	Tree
Grewia bicolour (**Juss.**)	Shrub
Harungana madagascarensis (**Poir.**)	Tree
Grewia mollis (**Juss.**)	Tree
Grewia similis (**K. Schum.**)	Shrub
Dombeya rotundifolia (**Hochst.**) **Planch.**	Tree
Grewia tricocarpa (**A. Rich.**)	Shrub
Dombeya torrid (**J.F. Gmel**) **P. Bamps.**	Tree
Grewia mollis (**Juss.**)	Tree
Grewia similis (**K. Schum.**)	Shrub
Dombeya rotundifolia (**Hochst.**) **Planch.**	Tree
Grewia tricocarpa (**A. Rich.**)	Shrub
Dombeya torrid (**J.F. Gmel.**) **P. Bamps.**	Tree
Grewia villosa (**Willd.**)	Shrub
Erythroxylum fischeri (**Engl.**)	Tree
Sparrmannia ricinocarpa (**Eckl. & Zeyh.**) **Kuntze.**	Herb
Acalypha neptunica (**Mull. Arg.**)	Tree
Triumfetta flavescens (**A. Rich.**)	Shrub
Alchornea cordifolia (**Schum. & Thonn.**) **Mull. Arg.**	Tree
Triumfetta rhomboidea (**Jacq.**)	Herb
Alchornea hirtella (**Benth.**)	Tree
Triunfetta tormentosa (**Boj.**)	Shrub
Alchornea laxiflora (**Benth.**) **Pax. & K. Hoffm.**	Tree

Dombeya burgessiae (**Gerrard**)	Shrub
Antidesma venosum (**Till.**)	Tree
Abutilon mauritianum (**Jacq.**) **Medic. Sensu. Lato.**	Herb
Bridelia micrantha (**Hochst.**) **Baill.**	Tree
Bridelia scleroneura (**Mull.**) **Arg.**	Tree
Pavonia kilimandscharica (**Gurke.**)	Herb
Pavonia urens (**Cav.**)	Herb
Acalypha fruticosa (**Forssk.**)	Shrub
Acalypha ornata (**A. Rich.**)	Herb
Croton sylvaticus (**Hochst.**)	Tree
Acalypha racemosa (**Baill.**)	Herb
Drypetes gerrardii (**Hutch.**)	Tree
Erythrococca fischeri (**Pax.**)	Tree
Clutia robusta (**Pax.**)	Shrub
Euphorbia candelabrum (**Kotschy.**)	Tree
Erythrococca atrovirens (**Pax.**) **Prain.**	Shrub
Macaranga kilimandscharica (**Pax.**)	Tree
Erythrococca bongensis (**Pax.**)	Shrub
Macaranga schweinfurthii (**Pax.**)	Tree
Mallotus oppositifolius (**Geisel.**) **Mull. Arg.**	Tree
Euphorbia gossypina (**Pax.**)	Climber
Margaritaria discoidea (**Baill.**) **Webster**	Tree
Flueggea virosa (**Willd.**) **Voigt.**	Shrub
Neoboutonia macrocalyx (**Pax.**)	Tree

Hymenocardia acida (**Till.**)	Shrub
Phyllanthus enflatus (**Hutch.**)	Tree
Jatropha curcas (**L.)**	Shrub
Phyllanthus muellcranus (**O. Kuntzte**) **Exell.**	Tree
Desmodium velutinum (**DC.**)	Herb
Celtis Africana (**Burm. f.**)	Tree
Erythrina abyssinica (**DC.**)	Herb
Celtis gomphophylla (**Bak.**)	Tree
Flemingia grahamiana (**Wight & Arn.**)	Herb
Celtis mildbraedii (**Engl.**)	Tree
Indigofera garckeana (**Vatke.**)	Shrub
Antiaris toxicaria (**Pers.**) **Lesch.**	Tree
Ficus amadiensis (**De Willd.**)	Tree
Indigofera trita (**L.f.**)	Herb
Ficus bubu (**Warb.**)	Tree
Kotschya aeschynomenoides (**Bak.**) **De Wild. & duvign.**	Herb
Ficus cyathistipula (**Warb.**)	Tree
Kotschya africana (**Engl.**)	Shrub
Ficus exasperata (**Vahl.**)	Tree
Kotschya recurvifolia (**Taub.**) **F. White**	Shrub
Ficus glumosa (**Del.**)	Tree
Mucuna gigantea (**Willd.**) **DC.**	Liana
Ficus ingens (**Miq.**) **Miq.**	Tree
Mucuna stans (**Bak.**)	Herb

Ficus lutea (**Vahl.**)	Tree
Pseudarthria hookeri (**Wight & Arn.**)	Herb
Ficus ovata (**Vahl.**)	Tree
Rhynchosia hirta (**Andr.**) **Meikle & Verdc.**	Liana
Ficus saussureana (**DC.**)	Tree
Rhynchosia resinosa (**A. Rich.**) **Bak.**	Liana
Ficus sur (**Forssk.**)	Tree
Sesbania quadrata (**Gillett.**)	Herb
Ficus sycomorus (**L.**)	Tree
Tephrosia acquilata (**Bak.**)	Shrub
Ficus thonningii (**Bl.**)	Tree
Tephrosia interrupta (**Engl.**)	Herb
Ficus vallis-choudae (**Del.**)	Tree
Tephrosia nyinkensis (**Bak.**)	Herb
Milicia excelsa (**Welw.**) **C.C. Berg.**	Tree
Tephrosia vogelii (**Hook. f.**)	Herb
Morus mesozygia (**Stapf.**)	Tree
Trichocladus ellipticus (**Eckl. & Zeyh.**)	Shrub
Trilepisium madagascarensis **DC.**	Tree
Chaetacme aristata (**Planch.**)	Shrub
Ilex mitis (**L.**) **Radik.**	Tree
Ficus asperifolia (**Miq.**)	Shrub
Catha edulis (**Vahl.**) **Engl.**	Tree
Ficus capreifolia (**Del.**)	Shrub

Elaeodendron buchananii (**Loes.**) **Loes.**	Tree
Boehmeria macrophylla (**Hornen.**)	Herb
Maytenus undata (**Thunb.**) **Blavelock**	Tree
Urera hypselodendron (**A. Rich.**) **Wedd.**	Climber
Mystroxylon aethiopicum (**Thunb.**) **loes.**	Tree
Urera trinervis (**Hochst.**) **Friis & Immelman.**	Climber
Apodytes dimidiate (**Arn.**)	Tree
Hippocratea africana (**Willd.**) **Loes.**	Liana
Salvadora persica (**L.**)	Tree
Hippocratea goetzi (**Loes.**)	Liana
Ximenia americana (**L.**)	Tree
Maytenus arbutifolia (**A. Rich.**) **Wilczek**	Shrub
Maesopsis eminii (**Engl.**)	Tree
Maytenus heterophylla (**Eckl. & Zeyh.**) **Robson**	Shrub
Rhamnus prinoides (**L.’ Herit**)	Tree
Maytenus senegalensis (**Lam.**) **Exell.**	Shrub
Rhamnus staddo (**A. Rich.**)	Tree
Salacia cerasifera (**Oliv.**)	Shrub
Scutia myrtina (**Burm. f.**) **Kurz.**	Tree
Azima tetracantha (**Lam.**)	Shrub
Opilia amentacea (**Roxb.**)	Liana
Ziziphus mucronata (**Willd.**)	Tree
Phragmanthera dschallensis (**Engl.**) **Balle.**	Liana
Ziziphus pubescens (**Oliv.**)	Tree

Gouania longispicata (**Engl.**)	Shrub
Fagaropsis angolensis (**Engl.**) **Dale.**	Tree
Helinus mystacinus (**Ait.**) **Steud.**	Climber
Teclea grandifolia (**Engl.**)	Tree
Ventilago diffusa (**G. Don.**) **Exell.**	Liana
Teclea nobilis (**Del.**)	Tree
Ampelocissus africana (**Lour.**) **Merr.**	Shrub
Zanthoxylum chalybeum (**Engl.**)	Tree
Cissus oliveri (**Engl.**) **Gilg.**	Climber
Zanthophylum gillettii (**De Willd.**) **Waterm.**	Tree
Cissus rotundifolia (**Forssk.**) **Vahl.**	Climber
Zanthophylum rubescens (**Hook. f.**)	Tree
Cyphostemma kilimandscharica (**Gilg.**) **Descoings**	Climber
Zanthophylum usambarense (**Engl.**) **Kokwaro**	Tree
Leea guineensis (**G. Don.**)	Shrub
Harrisonia abyssinica (**Oliv.**)	Tree
Rhoicissus tredentata (**L.f.**) **Willd. & Drum.**	Shrub
Balanites aegyptiaca (**L.**) **Del.**	Tree
Clausena anisata (**Willd.**) **Benth.**	Shrub
Ekebergia capensis (**Sparm.**)	Tree
Teclea simplicifolia (**Engl.**) **Verdoorn**	Shrub
Lepidotrichilia Volkensii (**Gurke.**) **Leroy**	Tree
Teclea trichocarpa (**Engl.**) **Engl.**	Shrub
Trichilia emetica (**Vahl.**)	Tree

Toddalia asiatica (**L.**) **Lam.**	Shrub
Turraea robusta (**Gurke.**)	Tree
Allophyllus abyssinicus (**Hochst.**) **Radnik**	Shrub
Allophyllus ferrugineus (**Taub.**)	Tree
Allophyllus africanus (**P. Beav.**)	Shrub
Allophylus kilimandscharicus (**Taub.**)	Tree
Paullinia pinnata (**L.**)	Climber
Allophyllus rubifolius (**A. Rich.**) **Engl.**	Tree
Schefflera volkensii (**Engl.**) **Harms.**	Liana
Blighia unijugata (**Bak.**)	Tree
Heteromorpha trifoliata (**Wendl.**) **Eckl. & Zeyh.**	Herb
Deinbollia kilimandscharica (**Taub.**)	Tree
Erica arborea (**L.)**	Shrub
Dodnaea angustifolia (**L. f.)**	Tree
Erica trimera (**Engl.**) **Beentje**	Shrub
Haplocoelum foliolosum (**Hiern.**) **Bullock**	Tree
Embelia schimperi (**Vatke.**)	Shrub
Lecaniodiscus fraxinifolius (**Bak.**)	Tree
Myrisine africana (**L.)**	Shrub
Lepisanthes senegalensis (**Poir.**) **Leenh.**	Tree
Nuxia congesta (**Fres.**)	Shrub
Pappea capensis **Eckl. & Zeyh.**	Tree
Strychnos henningsii (**Gilg.**)	Shrub
Bersama abyssinica (**Fres.**)	Tree

Chionanthus mildbraedii (**Gilg. & Schellenb.**) **Stearn**	Shrub
Lannea fulva (**Engl.**) **Engl.**	Tree
Lannea schimperi (**A. Rich.**) **Engl.**	Tree
Jasminium abyssinicum **DC.**	Climber
Lannea Schweinfurthii (**Engl.**) **Engl.**	Tree
Lannea triphylla (**A. Rich.**) **Engl.**	Tree
Ozoroa insignis (**Del.**)	Tree
Jasminium pauciflorum (**Benth.**)	Climber
Pistacia aethiopica (**Kokwaro**)	Tree
Oxyanthus speciosus (**DC.)**	Shrub
Pouridiantha paucinervis (**Hiern.**) **Brem.**	Shrub
Pavetta abyssinica (**Fres.**)	Shrub
Pavetta crossipes (**K. Schum.**)	Shrub
Pavetta oliverana (**Hiern.**)	Shrub
Pavetta subcana (**Brem.**)	Shrub
Pavetta ternifolia (**Oliv.**) **Hiern.**	Shrub
Pentas schimperana (**A. Rich.**) **Vatke.**	Herb
Psychotria fractinervata (**Petit.**)	Shrub
Psychotria lauracea (**K. Schum.**)	Shrub
Psychotria orophila (**Petit.**)	Shrub
Psychotria penduncularis (**Salisb.**) **Steyerm.**	Shrub
Psychotria schiebenii (**Petit.**)	Shrub
Psydrax schimperiana (**A. Rich.**) **Bridson**	Shrub
Rothmania longiflora (**Salisb.**)	Shrub

Rothmania urcelliformis (**Hiern.**) **Robyns**	Shrub
Rutidea orientalis (**Bridson**)	Shrub
Rutidea smithii (**Hiern.**)	Climber
Rytigynia acuminatissima (**K. Schum**) **Robyns**	Shrub
Rytigynia bugoyensis (**K. Krause.**) **Verdc.**	Shrub
Tarenna graveolens (**S. Moore**) **Brem.**	Shrub
Tarenna pavettoides (**Harv.**) **Sim.**	Shrub
Vangueria apiculata (**K. Schum.**)	Shrub
Vangueria infausta (**Burch.**)	Shrub
Vangueria madagascarensis (**Gmel.**)	Shrub
Vangueria volkensii (**K. Schum.**)	Shrub
Helichrysum nandense (**S. Moore**)	Herb
Microglossa pyrifolia (**Lam.**) **O. Kuntze**	Herb
Phichea ovalis (**Pers.**) **DC.**	Shrub
Psiadia punctulata (**DC.**) **Vatke.**	Shrub
Solanecio mannii (**Hook. f.**) **C. Jeffrey**	Shrub
Pseudospondias microcarpa (**A. Rich.**) **Engl.**	Tree
Acokanthera oppositifolia (**Lam.**) **Codd.**	Shrub
Rhus longipes (**Engl.**)	Tree
Acokanthera schimperi (**A. DC.**) **Schweinf.**	Shrub
Rhus natalensis (**Krauss**)	Tree
Carissa edulis (**Forssk.**) **Vahl.**	Shrub
Rhus quartiniana (**A. Rich.**)	Tree
Landolphia buchananii (**Hall. f.**) **Stapf.**	Climber

Rhus valgaris (**Meikle.**)	Tree
Saba comorensis (**Bojer.**) **Pichon**	Liana
Alangium chinense (**Lour.**) **Harms.**	Tree
Tabernaemontana ventricosa **A. DC.**	Shrub
Cussonia arboreta (**A. Rich.**)	Tree
Calotropis procera (**Ait.**) **Ait.f**	Shrub
Cussonia holstii (**Engl.**)	Tree
Gmnema sylvetre (**Retz.**) **schult.**	Liana
Polyscias fulva (**Hiern.**) **Harms.**	Tree
Kanahia laniflora (**Forssk.**) **R. Br.**	Shrub
Schefflera abyssinica (**A. Rich.**) **Harms.**	Tree
Mondia whytei (**Hook. f.**) **Skeels**	Climber
Steganotaenia araliacea (**Hochst.**)	Tree
Periploca linearifolia (**Dill. & A. Rich.**)	Climber
Agauria salicifolia (**Lam.**) **Oliv.**	Tree
Secamone africana (**Oliv.**) **Bullock**	Climber
Euclea divinorum (**Hiern.**)	Tree
Secamone punctulata (**Decne.**)	Climber
Euclea racemosa (**Murr.**)	Tree
Secamone stuhlmannii (**K. Schum.**)	Climber
Aningeria adolfi-friedericii (**Engl.**) **Robyns & Gilb.**	Tree
Tacazzea galactogoga (**Bullock**)	Liana
Manilkara butugi (**Chiov.**)	Tree
Mimusops bagshawei (**S. Moore**)	Tree

Chassalia cristata (**Hiern.**) **Bremek.**	Shrub
Mimusops kummel (**A. DC.**)	Tree
Chassalia subochreata (**De Wild.**) **Robyns**	Shrub
Maesa lanceolata (**Forssk.**)	Tree
Craterispernum schweinfurthii (**Hiern.**)	Shrub
Rapanea melanophloeos (**L.**) **Mez.**	Tree
Galiniera saxifraga (**Hochst.**) **Bridson**	Shrub
Anthocleista grandiflora (**Gilg.**)	Tree
Gardenia termifolia (**Schum. & Thonn.**)	Shrub
Anthocleista vogelii (**Planch.**)	Tree
Gardenia volkensii (**K. Schum.**)	Shrub
Bruddleia polystachya (**Fres.**)	Tree
Heisenia diervilleoides (**K. Schum.**)	Shrub
Chionanthus niloticus (**Oliv.**) **Stearn.**	Tree
Hymenodictyon floribundun (**Hochst. & Steud.**) **B. L. Robinson**	Shrub
Olea capensis (**L.)**	Tree
Olea europaea (**L.)**	Tree
Keetia guienzii (**Sond.**) **Bridson**	Climber
Schrebera alata (**Hochst.**) **Welw.**	Tree
Lasianthus kilimandscharicus (**K. Schum.**)	Shrub
Funtumia africana (**Benth.**) **Stapf.**	Tree
Leptactina platyphylla (**Hiern.**) **Wernh.**	Shrub
Rauvolfia caffra (**Sond.**)	Tree
Mussaenda arcuata (**Poir.**)	Shrub

Tabernaemontana stapfiana (**Britten**)	Tree
Mussaenda erythrophylla (**Schum. & Thonn.**)	Climber
Vocanga thoursii (**Roem. & Schult.**)	Tree
Mussaenda microdonta (**Wernh.**)	Shrub
Psydrax parviflora (**Afz.**) **Bridson**	Tree
Nauclea latifolia (**Sm.**)	Shrub
Vernonia hymenolepsis (**A. Rich.**)	Shrub
Cordia africana (**Lam.**)	Tree
Vernonia lasiopus (**O. Hoffm.**)	Herb
Cordia millenii (**Baker**)	Tree
Vernonia myriantha (**Hook. f.**)	Shrub
Halleria lucida (**L.)**	Tree
Vernonia springifolia (**O. Hoffm.**)	Herb
Kigelia africana (**Lam.**) **Benth.**	Tree
Vernonia theophrastifolia (**Oliv. & Hiern.**)	Shrub
Kigelia moosa (**Sprangue**)	Tree
Vernonia wollastonii (**S. Moore**)	Shrub
Markhamia lutea (**Benth.**) **K. Schum.**	Tree
Lobelia gibberoa (**Hemsl.**)	Shrub
Spathodea campanulata (**P. Beav.**)	Tree
Cordia monoica (**Roxb.**)	Shrub
Stereospermum Kunthianum (**Cham.**)	Tree
Ehretia cymosa (**Thonn.**)	Shrub
Prema angolensis (**Gurke.**)	Tree

Solanum aculeastrum (**Dunal.**)	Shrub
Vitex doniana (**Sweet**)	Tree
Solanum giganteum (**Jacq.**)	Shrub
Vitex fischeri (**Gurke.**)	Tree
Solanum incanum (**L.)**	Shrub
Dracaena afromontana (**Mildbr.**)	Tree
Solnaum indicum (**L.)**	Shrub
Cocos nucifera (**L.)**	Tree
Solanum mallense (**Bitter**)	Shrub
Phoenix reclinata (**Jacq.**)	Tree
Solanum mauritianum (**Scop.**)	Shrub
Solanum terminale (**Forssk.**)	Shrub
Withania somnifera (**L.**) **Dunal**	Herb
Ipomoea hidelbrandtii (**Vatke.**)	Shrub
Ipomoea kituiensis (**Vatke.**)	Climber
Ipomoea rubens (**Choisy**)	Climber
Ipomoea spathulata (**Hall. f.**)	Shrub
Bartsia decurva (**Benth.**)	Herb
Acanthopale pubescens (**Engl.**) **C. B. Cl.**	Herb
Acanthus eminens (**C. B. Cl.)**	Herb
Acanthus pubescens (**Oliv.**) **Engl.**	Herb
Barleria ventricosa (**Nees.**)	Herb
Macrorungia pubinervia (**T. Anders.**) **C. B. Cl.**	Shrub
Mimulopsis arborescens (**C. B. Cl.)**	Shrub

Mimulopsis solmsii (**Schweinf.**)	Herb
Pseuderanthmum ludovicianum (**Buettn.**) **Lindall**	Herb
Whitfieldia elongate (**Beauv.**) **C. B. Cl.**	Shrub
Clerodendrum buchholzii (**Gurke.**)	Liana
Clerodendrum capitalum (**Willd.**) **Schum. & Thonn.**	Shrub
Clerodendrum formicarum (**Gurke.**)	Shrub
Clerodendrum johnstonii (**Oliv.**)	Shrub
Clerodendrum myricoides (**Hochst.**) **Vatke.**	Shrub
Clerodendrum rotundifolium (**Oliv.**)	Shrub
Duranta erecta (**L.)**	Shrub
Lantana camara (**L.)**	Shrub
Lantana rhodesiensis (**Moldenke**)	Herb
Lantana trifolia (**L.)**	Herb
Lantana viburnoides (**Forssk.**) **Vahl.**	Herb
Lippia grandifolia (**A. Rich.**)	Shrub
Lippia javanica (**Burm. f.**) **Sprang.**	Shrub
Lippia kituiensis (**Vatke.**)	Shrub
Achyrospermum Schimperi (**Hochst.**)	Herb
Hoslundia opposita (**Vahl.**)	Shrub
Leonotis nepetifolia (**L.**) **R. Br.**	Herb
Leonotis mollissima (**Gurke.**)	Herb
Leucas argentea (**Gurke.**)	Shrub
Leucas calostachys (**Oliv.**)	Herb
Leucas gabrata (**Vahl.**) **R. Br.**	Herb

Ocimum kilimandscharicum (**Gurke.**)	Herb
Ocimum lamiifolium (**Benth.**)	Herb
Ocimum suave (**Willd.**)	Herb
Plectranthus barbatus (**Andr.**)	Herb
Plectranthus ignarius (**Schweinf.**) **Agnew**	Shrub
Plectranthus kamerunensis (**Gurke.**)	Herb
Plectranthus luteus (**Gurke.**)	Herb
Pycnostachys eminii (**Gurke.**)	Herb
Pycnostachys meyeri (**Gurke.**)	Herb
Solenostemon shirensis (**Gurke.**)	Shrub
Tetradenia riparia (**Hochst.**) **Codd.**	Shrub
Tinnea aethiopica **Hook. f.** (**Sensu lato.)**	Shrub
Dracaena fragans (**L.**) **Ker-Gawl.**	Shrub
Dracaena usambarensis (**Engl.**)	Shrub
Arudinaria uasambarensis (**K. Schum.**)	Shrub
Oreobambos buchwaldii (**K. Schum.**)	Shrub