STUDIES ON BEE POPULATIONS AND SOME ASPECTS OF THEIR FORAGING HABITS IN MT. KENYA FOREST

By

MARY .W. GIKUNGU, BSC. (Hons), NAIROBI UNIVERSITY

A thesis submitted in the partial fulfillment for the degree of Masters of Science in Biology of Conservation, Department of Zoology, University of Nairobi.

2002

DECLARATION

I hereby declare that this is my original work and has not been presented for award of a degree in any other university.

Mary W. Gikungu

Signature..........................

Date..18/10/02........

This thesis has been submitted for examination with our approval as university supervisors.

1st Supervisor

Dr. G. H. N. Nyamasyo
Department of Zoology
University of Nairobi

Signature..........................

Date...22/10/02........

2nd Supervisor

Dr. J.H. Nderitu
Department of Crop Science
University of Nairobi

Signature..........................

Date....22/10/2002

DEDICATION

Dedicated to my husband Gikungu, and our children Irungu, Mutugi and Wanjiru.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

ACKNOWLEDGEMENTS

I wish to thank all the people and organizations that have worked closely with me to make this work a success. First and foremost I thank my employer, National Museums of Kenya (NMK) for the study leave and facilities to carry out the work. I greatly appreciate the kind financial support by ICIPE and UNESCO (People and Plants Programme) without which this study may not have been possible to undertake. Special thanks and appreciation go to my supervisors Dr. G. Nyamasyo, Dr. J. Nderitu and Dr. B. Gemmill for their earnest supervision and invaluable contribution to my work.

My sincere thanks to my husband, who has been a great source of encouragement in moral support and editorial assistance in this write up. In addition, I am greatly indebted to our children Samuel, Mark and Ruth for their patience during those moments of my absence from the family. Great appreciation to my dear parents, Richard and Edith who thought it was noble to take me to school. I thank my sister Lydiah for giving me moral support and taking care of our children during my field studies. In addition, I thank all my sisters and brothers whose prayers and encouragement cheered me to press on.

Thanks and appreciation to Dr. Koen Maes for facilitating the release of the UNESCO grant and handling the logistics of the same with the National Museums of Kenya. I am also grateful to Dr. Wanja Kinuthia, Head of Invertebrate Zoology Department for her great encouragement, moral and administrative support. Special thanks go to Mr. Jackson Muraguri for helping me scan all the necessary photographs for my thesis. Appreciation and thanks to Palynology Department at NMK and in particular, to Mrs Veronica Muiruri for identifying the pollen samples. Many thanks to all my colleagues and friends who inspired me in one way or another.

Finally, I thank Forest Department Officers, Mr Kariuki and Mr Muindi who offered to risk their lives with me in the forest. Special thanks to Mr Mugo of Kenya Wildlife service (KWS) who fearlessly provided security in the forest as I carried out my work. Sincere thanks to my field assistants, Mr Karoki and Mr Cyrus Mwai for their invaluable support in the work.

Above all, I thank God for providing me with opportunity to study, giving me the strength I needed to work, guidance in decision-making and keeping me in good health throughout the period of study.

ABSTRACT

A study was carried out in the Mt. Kenya forest with the objectives of establishing the species diversity of bees, their major pollen and nectar sources and the influence of physical and environmental parameters have on them. It had been established from the literature that the pollinator diversity in the whole of Africa is poorly known and that the conservation of tropical forest flora and fauna could not be adequately done without taking pollinators conservation seriously. Again, a global initiative on pollinator conservation, "the Saulo Paulo Declaration" was established in Brazil in 1999 with the aim to conserve and sustainably use pollinators in agriculture with emphasis on bees. Bees are known to pollinate about 30 % of food crops and 75 % of flowering plants worldwide. Pollination is an important service in maintaining ecosystem integrity and to humanity's existence as well.

The study was conducted on the south eastern side of the mountain which covers Kirinyaga district accessed via Kerugoya. The data were collected along a 2.5 - 3 km transects running from the edge of the forest inwards for a period of eight months. A total of 80 species of bee plants and 17 species of bees belonging to five families were recorded. during the study. These families included Apidae, Halictidae, Megachilidae, Anthophoridae, Colletidae and Andrenidae. The common bee plant families included compositae, Rubiaceae, Leguminosae and Labiaitae.

The results showed that there was a significant difference ($P<0.002$) in bee species diversity in four different habitats studied (open woodland, closed woodland, shrub land and pine plantation. The highest species diversity of both bee and bee plants was recorded in the open woodland followed by closed woodland. Pine plantation had the lowest number of bees in terms species richness as well as species diversity. Among the physical factors, light intensity was found to be the most important in bee foraging. A significant difference on bee visitation to flower was found between open and tubular flowers. Bees frequently visited open flowers more than tubular flowers. Yellow flowers were more preferred by the bees as compared to pink-white or purple.

It was concluded that the bee community in Mt. Kenya forest faces threat of extinction. The complete absence of sub-family Melliponinae (stingless bees) is still a major question in the conservation of bees in Mt. Kenya forest. Future research and recommendation should include more detailed pollination studies of keystone forest plant species and the effect of forest disturbance on pollinator populations.

CHAPTER ONE

1. INTRODUCTION

1.1 General introduction

Bees belong to class Insecta and the order Hymenoptera which constitutes one of the largest insect orders. Worldwide, there are about 40,000 species of leaf cutter bees, sweat bees, mason bees, sand bees, carpenter bees, minor bees, sander bees and stingless bees. The well-known honeybee is one of only seven species in the genus *Apis* worldwide. The truly social bees have evolved a worker caste, and are confined to the families Halictidae, Xylocopidae and Apidae, the greatest majority of forms being solitary. In East Africa there are about 240 species of bees represented in seven families. These are: Apidae, Anthophoridae, Halictidae, Megachilidae, Melittidae, Colletidae and Andrenidae.

Bees are known to have evolved at the same time or after the angiosperms, for they are dependent on flower products. They can be recognized by a number of characteristics of which the following are the most important: The pronotum is distinct but rather small, usually well separated from and below the tegula. It is extended ventrolaterally as processes that encircle or nearly encircle the thorax behind the fore coxae (Michener *et al.*, 1994).

Several studies have demonstrated that bee fauna is particularly rich in the Mediterranean basin followed by eastward to central Asia, and in the Madrean region of North America (California and the desertic regions of the southwestern United States and the North America) (Michener, 2000). Other studies have shown that bees are also more numerous and diverse in Xeric temperate areas than in the tropics (Ayala *et al.,* 1996). Despite the fact that there are few faunal data on bee populations, Xeric and warm-temperate areas such as Central Chile, Argentina, Australia and western parts of South Africa have been found to possess large bee faunas. Michener, (1954b) suggests that bee fauna in African tropics is richer than that of oriental tropics but, unfortunately, there is no sufficient data to support this observation.

1.2 The role of bees in an ecosystem

In many parts of the world, bees are the primary pollinators of angiosperms, and they constitute the most diverse group of flower visiting insects (Neff and Simpson, 1993). More than two-thirds of all flowering plants depend on insects for pollination. Bees pollinate the majority of 240,000 species of flowering plants worldwide. They have been found to be the most important pollinators of plants, and consequently, play an important part in the propagation of indigenous vegetation, as well as pasture plants. Responsible management and protection of wild land habitats and their populations of pollen vectoring animals and nectar – producing plants ensures that this pollination service is conserved (Meffe, 1997).

According to studies done by Levin, (1978, 1983) and Schmidt (1983) pollen flow by insect pollinators enhances gene flow. The movement of pollinators through the plant population has a profound influence on the breeding and genetic structure of the population. However, the pollinators are influenced by the spatial structure of the plant population because plant density and distribution affect the movements of pollinators and thereby the dispersal pattern of pollen (Levin and Kerster, 1969b; Schaal, 1978; Schmidt, 1983; Roubik *et al.*, 1995). Studies have shown that for the preservation of floral diversity in the ecosystem, conservation of pollinators and pollination services for plants are essential (e.g. Roubik, 1989).

Among the key stone species, bees have been found to be the keystone mutualists as they are absolutely essential to the maintenance of diversity of flowering plants (Lasalle and Gauld, 1993). Keystone species have been defined as those species that have disproportionately large influence on the character or structure of an ecosystem (Solbrig, 1991b). However, amongst the pollinating insects, bees have become the most successful and have co-evolved significant relationship with flowering plants. This relationship dates back to the cretaceous period, approximately 100 million years ago, when the flowering plants evolved.

Oligoletic bees and their pollen plants are the most useful objects for studies on co-evolution in bees and plants. Subsequent studies on morphology, physiology and behaviour of oligolectic bees (bees that specialize on related plant species) and the morphology and physiology of their preferred plant reveals indications of a coevolution between pairs or restricted groups of bee and plant species (Wittmann and Schlindwein, 1995). In order to attract pollinators many angiosperms offer rewards in the form of nectar, pollen or oils and make themselves conspicuous by developing flowers. A number of insect groups evolved because they learnt to exploit these food sources, but none of them exploit them to such an extent as bees (Velthuis, 1992).

1.3 The role of bees in agriculture

Pollination is one of the most important ecological services provided to agriculture. The future of crop production depends largely on pollination. Recent studies have shown that design and management of sustainable agricultural systems are at risk because of ignorance of the contribution of managed and native insect pollinator species (Kevan *et al.*, 1990). Pollination is a prerequisite for fertilization that is usually essential for seed and fruit development. About 30% of world's crops are bee pollinated (O'Toole, 1993). Bees have been found to contribute highly to pollination of crops as compared to other groups of insects.

In many parts of the world, honeybee (*Apis mellifera*) is the most widely used species because it is easy to handle and manage. However, over the last two decades, a major problem has arisen for the world's agricultural production reflecting dangers involved in relying on single species for pollination (Buchmann and Nabhan, 1996). Records of varroa mites, *Varroa jacobsoni* which causes *varroatosis* disease in honeybees, thus reducing their populations have been made in the USA. The outbreak of *varroatosis* disease has caused many farmers and growers to appreciate the pollination service provided by wild bees. Attempts have been made in some countries to manage wild bees for glasshouse crops (Bohart, 1972;Torchio, 1987, 1990). Hence the need to conserve wild bees for crop pollination .

Pollination increases seed production in many entomophilous (insect-pollinated) and anemophilous (wind-pollinated) crops (Roubik, 1998). Studies have shown that one-third of economic worth of the total agricultural production of US depend on insect pollination (McGregor, 1972). Pimentel *et al.*, (1997) estimate the value of pollination worldwide to be US $ 65-70 billions. Most of the world's crops such as cereal, oil seed, vegetable or forage and citrus fruits depend on pollination. Thus reduction in bee populations could have serious implications for both natural and agricultural ecosystems.

1.4 The role of bees in forests

Most of the tree species of tropical forests are insect-pollinated and bees are the key pollinators (Frankie *et al.*, 1990; Jones and Little 1983; Roubik, 1989; and Bawa 1990). Forest management requires understanding of reproductive biology and plant-pollinator interactions of forest plants. However, honeybees are found to be associated with forests globally. Bee foraging is an important part of the biology of both young and established forests. The worker bee shows flower constancy, foraging on a single species at one time thus maximizing pollination efficiency.

Studies done by McCall and Primack (1992) have shown that Apidae, Anthophoridae, and Halictidae are good pollinators of forest plants. Stingless bees of the genera *Meliponula* and *Hypotrigona* have been observed as important pollinators of the plant life of Bwindi Impenetrable National Park in Uganda (Byarugaba, 1996). Pollination is a very important service for the survival of most forest tree species because it ensures a healthy seed production which is an important component in forest regeneration. The mutual benefits of bees and trees have been found to be a very important relationship in any agroforestry system (Hill and Webster, 1995). The flowers of the forest trees provide subsistence for honeybees and the trees physically provide shelter as well as food (pollen and nectar) for colonies and swarms. Pollination is therefore a pivotal ecological process in both natural and managed ecosystems (Kevan and Baker, 1984).

1.5 Another important aspect of bees

Bees are not only beneficial to man through pollination of crops but also in honey production. The ever increasing population of Kenya requires alternative sources of food and income such as bee keeping, which is environmentally friendly and safe if properly managed. Honey has been used for various purposes by different peoples in Kenya. It is used as a sweetener of foods and drinks, as medicine, for brewing, as meat preservative and as a source of income. Honeybee, *Apis mellifera is* the most commonly used species for honey production. However, there are other types of bees in Kenya (for examples stingless bees) which collect and make honey. Honey from stingless bees is highly valued as a medicine. Stingless bees can be kept in small hives and the honey can be harvested daily by means of a teaspoon (Carol, 1997).

1.6 Threats to bee populations

Despite the importance of bees as pollinators, several studies have shown that the numbers of native species are dwindling (Kevan *et al.*, 1990; Frankie *et al.*, 1997; O'Toole 1994). The losses are mostly due to pesticide and herbicide, habitat destruction, diseases and competition from introduced flower visitors. Destruction of natural habitats supporting host flowers, destruction of nesting sites by agriculture, roadways, and deforestation are major factors adversely affecting wild bee populations. Most information comes from temperate regions, but the same problems can be assumed to be equally or more severe in the tropics (Roubik *et al.*, 1988). Habitat destruction affects pollinator population through destruction of food sources, destruction of nesting and mating sites.

1.7 Justification of the study

Conservation of tropical moist forests such, as Mt. Kenya is vital. It plays a critical role in water catchment for the country and holds a rich biological diversity in terms of species especially plant species. The forest constitutes an important store of genetic wealth and has a potential for expanding our knowledge and understanding of complex biological systems. Many forest plants are valued for medicinal use for human beings and livestock by indigenous people. For example, *Senna didymobotrya, Indigofera erecta,* among others, are considered sacred and are used in various ways. Culturally, the forest provides an important location for religion and other rituals for the people living near the forest.

Sustainable utilization of tropical forests in bee keeping cannot be achieved without proper identification and conservation of bee plants. Studies on phenological sequence and distribution of bee plants are important in bee keeping. Flowering phenology is of ecological and evolutionary importance for it affects food sources for pollinating animals. It also influences isolation and speciation on evolutionary timescale (Thery *et al, 1998).*

However, knowledge of the primary bee plants has been scarce in Kenya. Most studies in Kenya have been conducted on honeybees alone (e.g. Kahenya and Gathuru, 1984; Ngethe, 1984). Both honeybees and wild bees are important pollinators of world's flora and there is need to conserve their food sources as well as their nesting sites.

For successful management and conservation of tropical moist forest resources, there is need for increased information on various aspects of the forest, including pollination biology. Conservation of biodiversity in tropical forests largely depends on preservation of plant-pollinator interactions. Several studies have shown that pollination is a threatened ecological service (Buchmann and Nabhan, 1996). Pollinators of most forest plant species are still unknown. Loss of plant pollinators or disruption of pollination service can cause reduced seed and fruit production and ultimately plant extinction (Kearns and Inouye, 1997).

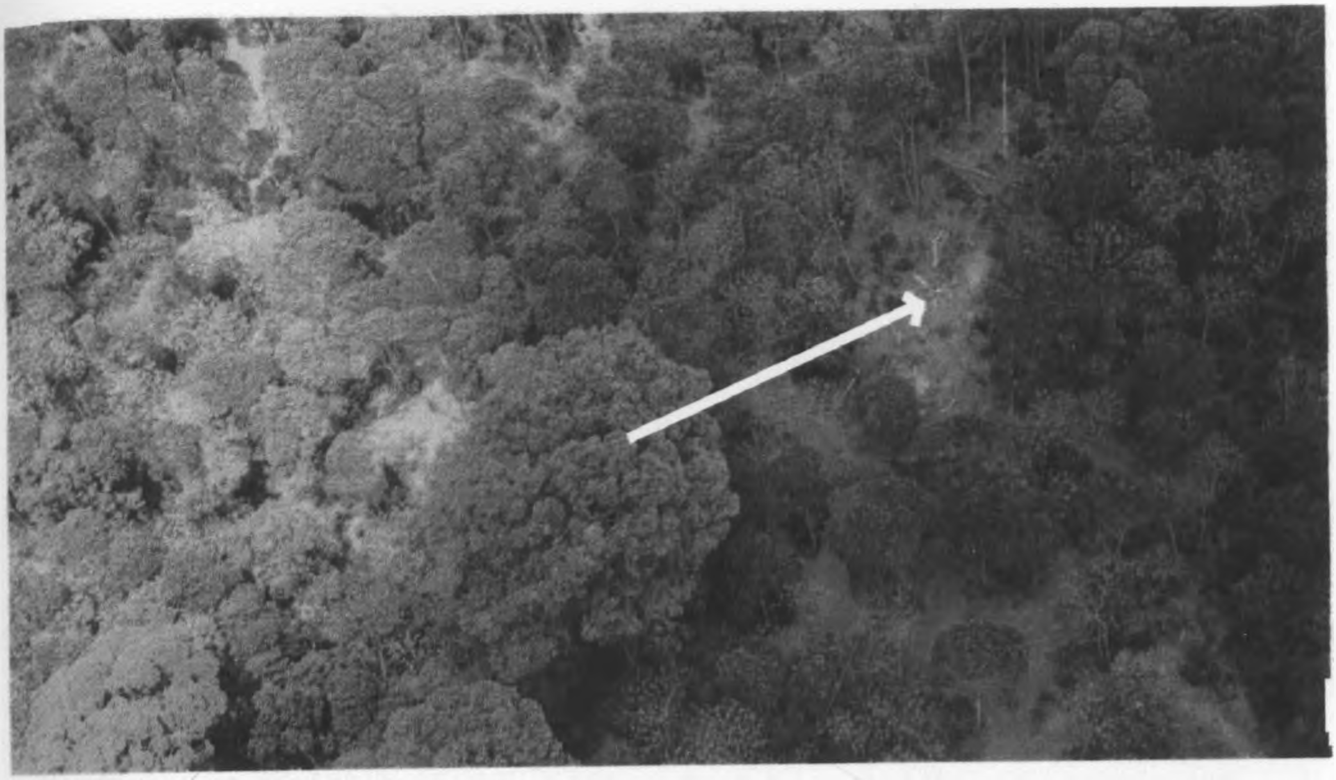
Mt. Kenya forest is one of the Afromontane forests in Kenya that faces massive destruction as a result of constant human encroachment (Gathara, 1999) (Plate 1). At the moment, the forest is in a management vacuum and it has been described as free for all (Daily Nation News Paper, 7/9/2000). The "free for all'' state has opened an avenue to over harvesting of forest resources thus destroying one of the country's main catchment areas.

Plate 1. **Agricultural encroachment: green arrows show tea bushes; yellow one shows a forest fragment in the southeastern part of Mount Kenya forest.**

In many parts of the world, studies on pollinators focus exclusively on managed honeybees (Meffe, 1997). Consequently, there is no clear documentation of global population trends for non-Apis bees or other pollinating animal species (e.g. bats, beetles, birds, butterflies, flies, moths, wasps, primates). Studies have also shown that both eusocial and solitary bees occupying the low to middle elevations are in danger of extinction due to forest destruction in many areas of the world (Roubik, 1983).

The impact of forest destruction and fragmentation on the bee community in Mount Kenya forest has not been studied. Studies done by Gathara (1999) show that farming, grazing of livestock, charcoal burning and uncontrolled illegal logging have continued to threaten the forest of Mount Kenya more than ever before (Plate 2). This is because this forest is completely surrounded by a densely populated farmland area, which has gradually extended into the forest reserve (Lockwood, 1995a).

Bees can be used to monitor environmental stress brought about by introduced competitors, diseases, parasites, as well as by chemical and physical factors, particularly pesticides and habitat modification (Kevan, 1999). There has not been sufficient research on the impacts of forest fragmentation on plant-pollinator interaction in East Africa as well as the whole of the Africa continent. Hence the importance of studying the bee pollinators of forest plant species.



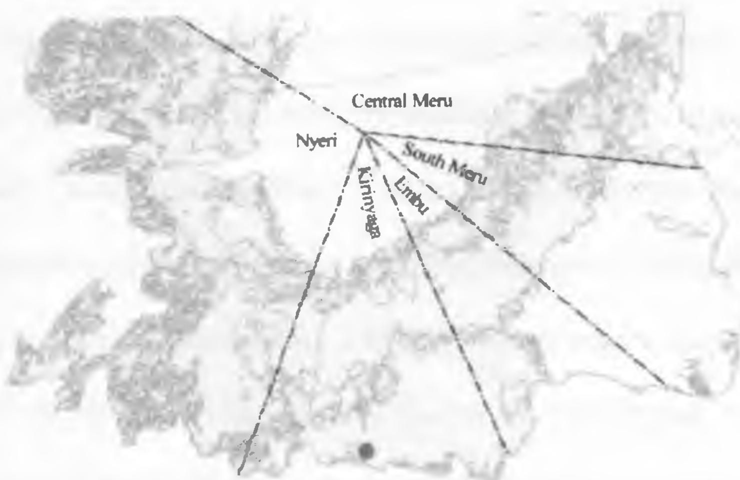


Plate 2. **Logging of indigenous trees (shown by white arrow) in a closed woodland. The red dot shows the spot from where the photograph was taken in the southeastern part of Mount Kenya forest.**

This study aimed to examine the species diversity of bees, the pollen sources and the factors that influence foraging patterns of bees in Mount Kenya Forest. This study will add to the understanding of the general ecology of bees in Mt. Kenya and contribute to their sustainable utilization and in the long-term planning, conservation and management of Mt. Kenya and other tropical forests in Africa.

1.8 Objectives

1. To investigate the species composition of bees in Mt. Kenya Forest
2. To establish the major pollen sources of bees in Mt. Kenya Forest
3. To establish the influence of physical and environmental parameters on bees foraging patterns

1.9. Literature review

1.9.1 Diversity of bees

Bees belong to the Phylum Arthropoda, class Insecta, order Hymenoptera and superfamily Apoidea. The order Hymenoptera is a very diverse group and comprizes bees, ants, wasps, and sawflies. There are about 100,000 described species worldwide and a greater number still awaits scientific description (Prinsloo and Eardley, 1985). The bees, wasps and ants, together with the solitary wasps make up a sub-division of the waisted (or apocrite) Hymenoptera known as the Aculeate the stinging Hymenoptera. Bees are well known for the high level of eusociality that has evolved in certain species, notably in the honeybee (*Apis mellifera*). The advanced eusocial bees in the family Apidae consist of the pantropical stingless bees, *Melipona* and *Trigona* and the four species of honeybees (*Apis mellifera, Apis florea, Apis dorsata* and *Apis cerana)*. The genus *Apis* is found in the palearctic region to southern Norway and the maritime provinces of Russia and in the entire African and oriental regions (Michener, 2000). Literature shows that *Apis mellifera* was introduced worldwide by human activity. They show specialized traits in that they have clear-cut morphological differences between the castes and workers communicate the direction of food and other resources (O'Toole, 1986). The primitive eusocial bees include the Halictidae and Bombinae. Bombinae are the most familiar social bees in temperate regions (O'Toole, 1986).

Bees appear to attain their greatest abundance, greatest number of species, and probably the greatest numbers of genera and sub-genera, not in the tropics, but in various warm-temperate, xeric regions of the world (Michener, 2000). Mediterranean basin, California, Central Chile and the western part of southern Africa have been recorded as the leading areas in bee species abundance and diversity. However bee fauna becomes impoverished as one approaches and enters the Arctic (Michener 2000). The data from the tropics indicate that tropical bee faunas are not as large as those of some temperate xeric and mesic areas (Friese, 1914b). Nevertheless, African and American tropics have been found richer in bee fauna as compared to oriental tropics despite lack of supportive data in Africa. However, the abundance of bees in xeric areas is associated with minimal fungal attacks of food stored in the bee cells. In humid environments, the loss from fungal attacks on such food and immature bees is substantial and sometimes catastrophic (Michener, 2000).

However literature on bee biology in East Africa and Africa as a whole has been scarce. It is only in South Africa, Egypt, Chad and Ghana where a few studies on bee ecology have been documented. In Kenya, studies on bee ecology have been biased on honey bees (Mbaya, 1983; Kahenya, 1984; Kigatiira, 1984). It was not until recently that a few studies on wild bees started in Kenya especially their importance as pollinators of wild flora and crops (Orim *et al.*, 1979; Gemmill and Ochieng, 1999). There has not been any literature on bees in Mt. Kenya forest. Salt (1987) documented the invertebrates of Mt. Kenya and Mt. Ruwenzori forests but did not make records on bee species. Other invertebrate studies in Mt. Kenya forest include survey of snail diversity and distribution by Warui (1999).

1.9.2. Bees and plants

The development of flowers containing nectar in spurs made possible the evolution of flowering-feeding Hymenoptera, Lepidoptera and Diptera (Selman, 1979). There are about 20,000 species of bees, which differ in size and are entirely dependent on flowers for their food: the geographical and ecological distribution of the bees almost perfectly correlates with that of the angiosperms. For example, the distribution of the monkshood is determined by the distribution of the genus *Bombus* (Selman, 1979).

About 75 % of most forest trees in both temperate and tropical forests are insect pollinated, but many kinds of bushes, small trees and herbaceous plants are bee pollinated. Bee pollination ensures preservation of vegetation cover for wildlife and prevention of soil erosion (Michener, 2000). Studies have shown solitary bees are good pollinators of forest plants (McCall and Primack, 1992). Stingless bees and honeybees are important pollen vectors of many tree species in the tropics (Frank *et al.*, 1997). O' Toole

(1993) showed that the loss of bee diversity would be accompanied by the loss in flowering species. Thus a high species diversity of bees is necessary to maintain high diversity of angiosperms (Neff and Simpson, 1993).

Bees have been considered as the most important example of Keystone mutualists among the Hymenoptera, as they are absolutely essential in the maintenance of diversity of the flowering plants (Lasalle and Gauld, 1993). Studies in the southwestern United States have shown that solitary bees are the dominant pollinators of angiosperms in the semi-arid areas and they constitute the most diverse group of flower visiting insects in these areas. Several studies have shown that preservation of floral diversity in the ecosystem, conservation of pollinators and pollination services for plants are essential (e.g. Roubik, 1989). Roubik (1998) suggests that the value of pollination far much exceeds that of the hive products like honey.

The importance of bee pollination in agriculture cannot be over emphasized. Studies have shown that two-thirds of the world's 3,000 species of agricultural crops require animals for pollination. Thousands of species of animals are responsible for this service e.g. bees, birds, wasps, beetles, butterflies, moths and flies (Buchmann and Nabhan, 1996, Kevan, 1999). Many agricultural crops are bee pollinated e.g. Garden flowers, most fruits, vegetables, fiber-like flax and cotton. Bee pollination has been found to increase seed production. The annual value of pollination service in the U.S. has been calculated at US$ 6-8 billion and the estimate worldwide is US$ 65-70 billion (Braulio and Imperatriz-

Fonseca, 1999. Wild bees have also been recorded as important pollinators of agricultural crops (O'Toole, 1993, Tepedino, 1987; Torchio, 1991; and Richards, 1993).

Examples of wild bees already commercially used are *Osmia comiferous*, which pollinates fruit trees in Japan, *Megachile rotunda*, which pollinates alfalfa in many areas, and *Bombus terrestris*, which pollinates tomatoes in European green houses (Michener, 2000). In Kenya, two species of wild bees, *Xylocopa senior* and *Nomia sp* have been recorded as effective pollinators of eggplant (Gemmill and Ochieng, 1999). Further studies have shown that agriculture and other equally vital economic ventures cannot do without the variety of pollinators. The refugia sites or nature reserves for crop pollinators need to be studied and conserved in order to enhance agricultural production.

1.9.3 The influence of physical factors on bee foraging patterns

Studies have shown that the foraging patterns of bees are influenced by both intrinsic and extrinsic factors. The intrinsic factors include sensory information, memory and decision making during foraging. Extrinsic factors include the aspect of environment to which the pollinators respond to, including floral colour, shape, density, number and distribution of plant species, wind velocity, and the distribution of nectar rewards (Waddington and Heinrich, 1981).

Further studies have shown that, coevolution of insects and flowering plants lead to development of colours that make them more conspicouous to insects. Honeybees have been found to respond to only four areas of the spectrum: yellow-green (650-500 mμ), blue-green (500-480 mμ), blue-violet (480-400 mμ) and Ultra violet (400-310 mμ) (Brewer, 1984). Red flowered plants are, therefore known to be bird pollinated (Brewer, 1984).

Some weather factors have been found to be important variables in determining visitation rates. For example, insects are less active when temperatures are exceptionally high, and when conditions are cool, cloudy or windy (Hagerup, 1932; Kevan and Baker, 1983; Arroyo *et al.*, 1985). A combination of light and temperature have been found to be important factors at the onset of foraging activity and both become unimportant later in the day. Similar observations were made by Shricker (1965) and Mbaya (1981). In the Snowy Mountain of Australia, it was observed that the frequency of flower visits was positively affected by temperature and light, but negatively affected by wind speed (Inouye and Pyke, 1988).

Other studies have shown that flower shape, temperature, light, and season appear to be the most important variables influencing the visitation rates (McCall and Primack, 1992). The time of day has also been recorded as an important factor in insect foraging. Different plant species produce nectar with varying sugar concentration at different times of the day. Thus, bees and other pollinators have been found to sample and visit more frequently flowers which are perceived to provide the highest net intake of calories per unit time (Heinrich, 1979b). The calorific worth of nectar rewards is based on the volume and concentration of the same.

The degree of disturbance that brings changes in vegetation structure in a given habitat has been found to influence the foraging pattern of pollinators. Studies have shown that bees prefer relatively disturbed environments such as agricultural fields and are responsible for pollination of crops such as cucurbits. Kevan (1989) shows that honeybees forage on resource-rich, scented patches within resource-rich patches. They forage in patches with more polleniferous patches (pollen rich areas) as compared to other patches.

1.9.4 Threats to bees

Despite the importance of bees in many ecosystems, several studies have shown that pollen sources and nesting sites of bee fauna are affected by human activities. Populations of many native plants and their pollinators are being diminished and lost due to habitat fragmentation and degradation (Kearns and Inouye, 1997). It has been observed that, conversion of formerly continuous forests into small-scaled fragments can lead to disruption of the mutual pollinator-plant interactions consequently resulting in further loss of biodiversity. In extreme conditions, habitat fragmentation can accelerate the extinction rates of local plant populations through inbreeding, genetic drift, and stochastic processes (Rathcke and Jules, 1993).

The destruction of food sources is best illustrated by examples of the removal of vegetation, which provides pollinator food when the crops are not in bloom from agricultural areas. The destruction of nesting and oviposition sites has been documented in Central Canada for the demise of populations of leaf cutter bees (Megachilidae), which were left without nesting sites in stumps, and logs (Roubik, 1998). In South Africa, it has been observed that collection of wood for fuel reduces the availability of twigs that provide the nesting sites for bees (Gess and Gess, 1983). Kearns and Inouye (1997) also found that fire reduces the nesting sites for bees due to loss of dead wood. In addition, as forest becomes less dense due to clearing and burning of native vegetation, ground temperature increases, becoming too high for bees to develop normally in the existing nests.

Habitat fragmentation has been found to be the cause of "ecological traps" (these are isolated fragments where pollinators get confined due to fear of predation) (Stebbins, 1979). Several studies have shown that endangered plant species often exist in "ecological traps" where they lack genetic diversity that would allow them to colonize other different habitats. Lamount *et al.*. (1993) further found that habitat fragmentation leads to small populations which are sometimes by passed by the pollinators because some of the pollinators exhibit density foraging behaviour, preferring large floral displays to isolated flowers.

Corbet *et al.*, (1991b) document serious regional losses of bumblebee species, honeybees and the numerous species of solitary bees in the National Red Data Books of United Kingdom. The losses were mainly associated with habitat fragmentation, destruction of semi-natural habitats, and intensive cultivation of arable land. Fragmented regions may also habour fewer pollinators and the plants that remain thus suffer reduced reproduction success (Jennersten, 1988). He further observed that visitation rates to flowers in the continuous areas were approximately three times higher than to flowers in habitat fragments.

CHAPTER TWO

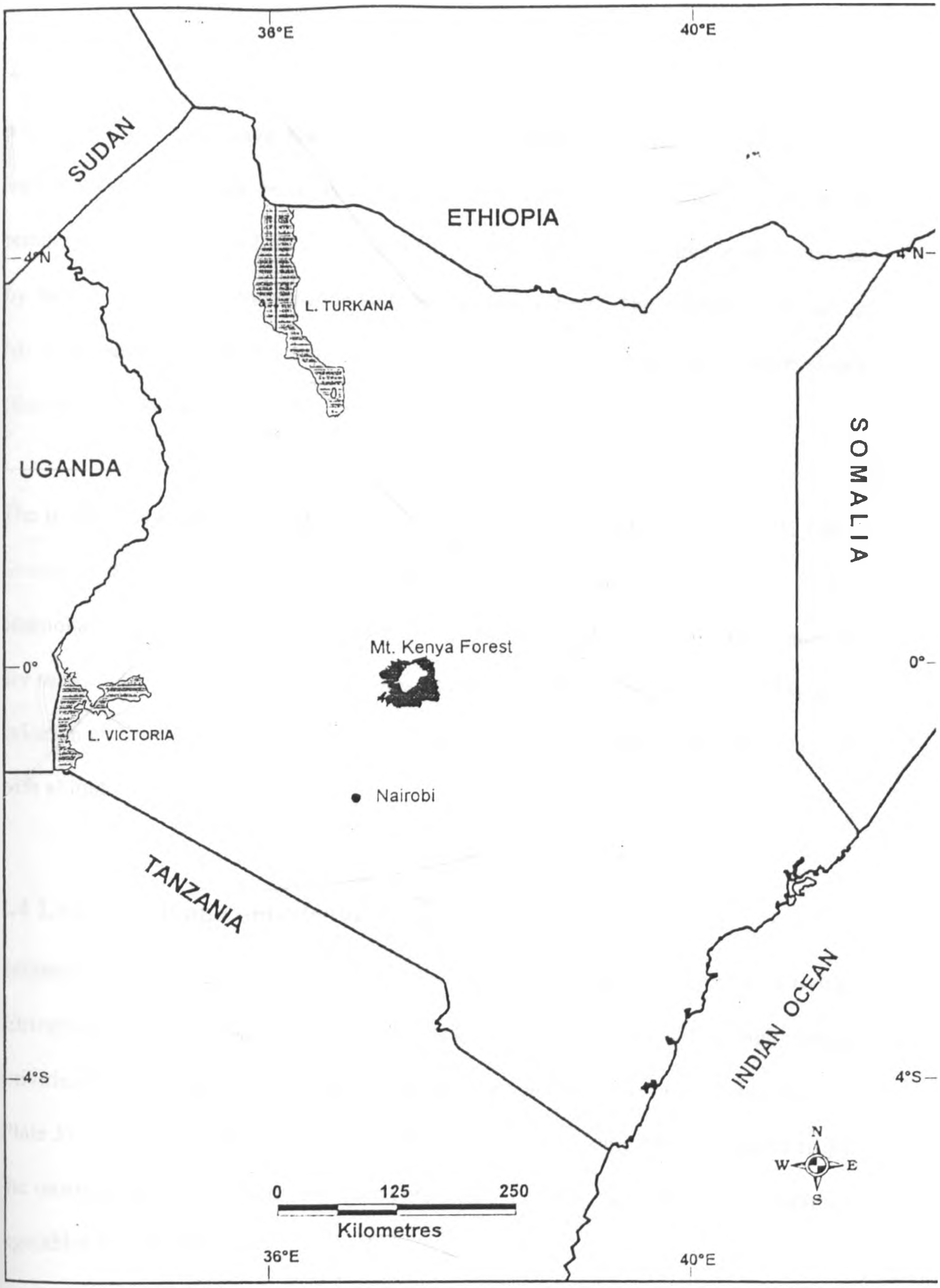
2. 0 Some geographical, historical and ecological facts about the south eastern part of mount Kenya forest

2.1 Introduction

Mount Kenya Forest is located about 180km north of Nairobi on the eastern side of the Great Rift Valley (Fig.1). It occupies 200,870 ha of gazetted high potential forest comprises 20% of Kenya's natural forest, being the largest continuous indigenous forest in the country. The equator crosses the northern foothill of the mountain. The main peaks are Batian (5199m) and Nelion (5188m) and represent the remnants of hard volcanic plug. Seven administrative districts surround the forest, namely Meru, Tharaka-Nthi, Nyambene, Embu, Kirinyaga, Nyeri and Laikipia (KIFCON, 1994a). This study was conducted in the forest reserve of south eastern part of Mt Kenya Forest covering Kirinyaga district and accessed via Kerugoya .

2.2. The History of the forest

Mount Kenya Reserve was gazetted in 1932 covering 228,340 ha (KIFCON, 1994a). The major change was the creation of Mount Kenya National Park in 1949 which reduced the forest reserve area by 71,500 ha while the neighbouring forest has an area of 631 ha (KIFCON 1994a). A recent report on the massive destruction of this forest elicited a government ban on various human activities in the forest. The ban on tree felling was effected towards the end of 1999.



Source: KIFCON - NMK 1994

Figure 1. Map of Kenya showing the location of Mt. Kenya forest

2.3 Climate

The climate of Mt Kenya National Park and its environs is characterized by small variations in the mean monthly temperatures and a dramatic daily fluctuation in temperatures. Nocturnal frost occurs down to 2500m altitudes. The area is characterized by two rainy seasons (March-June and October-December). The amount of rainfall in Mt Kenya ranges from 900 mm in the north to 2300 mm on the southeastern slopes (Survey of Kenya 1959, 1966).

The intensity and duration of dry seasons however, vary with some areas. Castle Forest Station on the Southwestern side shows no dry period at all, while other areas have some additional rainfall in August. Stations on the northwestern side of the mountain show the dry season very clearly, e.g. Nanyuki forest station. According to Bussman (1994), solar radiation and radioactive emission in Mt Kenya National Park and its environs increase with altitude.

2.4 Land use in and outside the Park

National parks and game reserves are in some conflict with development activities (Etringham, 1984; Kiringe, 1990). The park surrounding areas suffer high human activities that continue to destroy the forest ecosystem and possible nesting sites for bees (Plate 3). The adjacent areas to the forest are used for tea growing and subsistence crops. The most common food crops in this area are maize, bananas, tomatoes, beans, potatoes, vegetables and citrus fruits.

Plate 3. A tree felled for timber and firewood collection which could have been a potential nesting site (yellow arrow) for bees.

2.5 Vegetation

The vegetation of Mt Kenya forest is highly diverse (Fig. 2) and highly influenced by altitude and rainfall as well as local variations in aspect and relief (KIFCON 1994a; Bussman 1994; Traphell and Burnt, 1987; Beentje 1990). There are three characteristic forest zones: the sub-alpine forest, occurring mainly between 2,800 m and 3,100 m dominated by *Hagenia* and *Hypericum revoltum*, the montane forest, found mainly between 2,400 m and 2,900 m and which include extensive stands of bamboo, and the sub-montane forest, with an upper limit of 2,400 m and characterized by occurrence of *Macaranga capensis*, *Octoea usambarensis* and *Eubuotonia macrocalyx*. Hedberg (1951) described three main vegetation belts while Trapnell and Brunt (1987) and Beentje (1990) distinguished seven forest types.

Bussman (1994) reviewed the vegetation types of Mt. Kenya forest and came up with the following forest formation namely, evergreen montane bamboo, evergreen, xeromorphic montane forest, evergreen broad-leaved montane forest, and evergreen sub-alpine forests. He described four new vegetation classes with more detailed information including orders, alliances, associations and sub-associations. In his classification, Bussmann (1994) described the higher vegetation following their altitudinal zonation and gave special attention to succession and the regeneration process of the main vegetation classes.

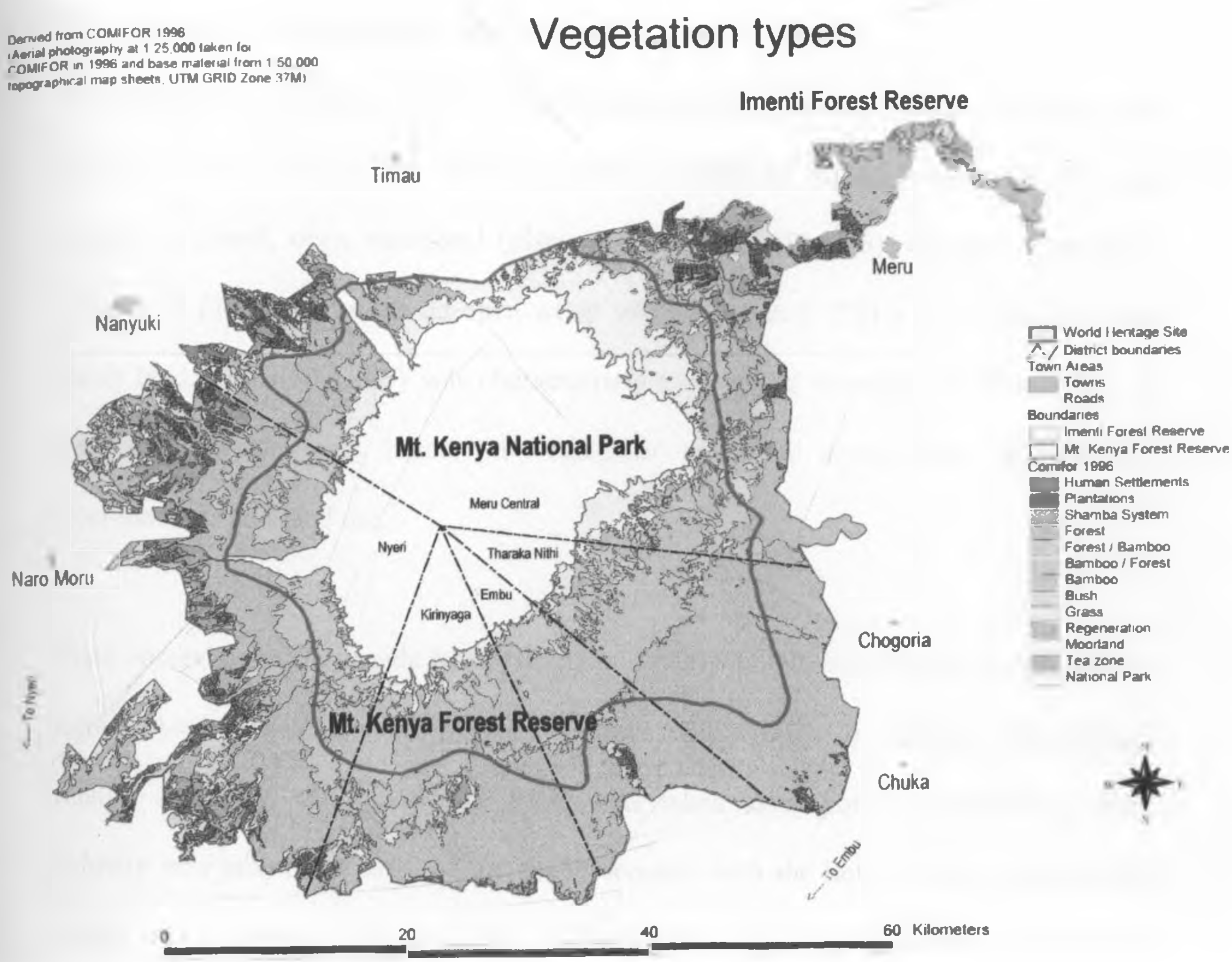


Figure 2. Map of Mt. Kenya forest showing vegetation types. Published by KWS, the map shows the area included in the WHS, National Park and Forest Reserve

CHAPTER THREE

MATERIALS AND METHODS

3.0. General materials and methods

Three transects measuring 2.5 km each were established in three different areas of the study site. The areas of the forest fragments covered by transects were identified as closed woodland, open woodland (plate 4), shrub land (Plate 5), and pine plantation. Transect 1 (T1) cut through an open wood while transect 2 (T2) a pine plantation and shrub land. Transect 3 (T3) was characterized by a closed woodland. The selection of transects or sites was based on vegetation structure, accessibility, diversity of microhabitats and land use.

Field observations were made from 9.00 a.m. to 5 00 p.m. No observations were made on rainy days. Measurements of physical variables (light intensity, ambient temperature, relative humidity, wind speed and time) were taken using portable equipment. Wind velocity was monitored for a period of 30 seconds with the help of wind meter (Sims Model MSC, Forestry Suppliers, Inc, Jackson, MS). Sling psychrometer was used to measure incident light. Light intensity was measured in lux with the help of a light meter (Sekonic L-248 camera). In addition, floral characteristics (colour, morphology, open, tubular or closed) and records of the number and varieties of foraging bees were also made at all sampling sites. Replication of data was done in terms of days. Each habitat was sampled for three days each month.

Plate 4. Open woodland, an example of one of the sites considered in the study

Plate 5. A shrub land, an example of one the sites considered in the study

3.1 To investigate species diversity of bees

Along each transect, observations were made on sampling plots of 1 m x 1 m. The plots were demarcated along transects at an interval of 100m and all the foraging bees in each plot were observed for a period of ten minutes. Different species of bees that touched either the anthers or the stigma were recorded using the method described by Arroyo *et al.*, 1985 and later used by Inouye and Pyke (1988). This method involves making careful observations on flower visitors, which get into contact with the reproductive organs of the flower on given set of flowers or sampling plot.

In order to differentiate different bee species in the field, the bee species observed were collected using a sweep net and assigned different codes. Observations were also made on other insect flower visitors. The samples of bees collected together with other insects were captured in the sweep net were pinned in the boxes for further identification in the National Museums of Kenya.

In the laboratory, all the sampled bees species were identified to the highest taxa possible with the help of a dissecting microscope using the recent identification keys (Michener, 2000). Most of the species were only identified up to genus level by a bee specialist, Roy Snelling and are referred to in the text as sp A, B C, D, E. After the identification the materials were preserved in the National Museums of Kenya as reference collection.

In order to study the spatial and temporal variation of bees in the study area, it was necessary that basic population parameters such as species number and diversity be established. Shannon diversity index (H') was used to compare species diversity of bees collected in four different habitats of the forest. The Shannon index is the most widely used index in community ecology. This index was described by Shannon and Weaver and it is sometimes referred to as Shannon and Weaver index (Krebs 1985). It attempts to combine both species richness and evenness into a single value. H' has two properties that have made it a popular measure of diversity:

H'= 0 if and only if there is one species in the sample, and

H' is maximum only when all S species are represented by the same number of individuals.

$H' = -\sum P_i \ln P_i$

Where,

P_i = the proportion abundance of the ith species = n_i/N

$\ln P_i$ = the logarithim of P_i (n/N)

As compared to other diversity index such as Margaref index (Dmg) and Brillouin index (HB), Shannon diversity index does not vary providing the number of species and their relative proportions remain constant. Most ecologists using information theory measures of diversity prefer the Shannon index for its computational simplicity (Magurran, 1983).

3.2 To investigate major pollen sources of bees

Quadrats of 1 m x 1 m were established along transects at an interval of 100 m. In every quadrat, flowering plants were observed for 10 minutes, and the number of plants touched by the bees on either the anthers or stigma were recorded using the method first described by Arroyo *et al.*, (1985) and Inouye and Pyke (1988). The maximum foraging height where field observations were made was limited to 4 m.

To establish the pollen sources from high canopy layers and the diversity of bee plants in the Mt. Kenya forest, additional data on pollen sources were collected from the pollen grains on the bee bodies. In each study site, a sample of 20 bees was collected at random using a sweep net and analyzed for pollen. A small piece of fuchsin gel was used to extract pollen grains from the bees by rubbing it against different parts of the body. Three slides of pollen sample were made from each bee and analyzed in the Palynology Department at National Museums of Kenya.

All the data collected during field observations and pollen analysis were combined to establish the major pollen and nectar sources of bees in the Mt. Kenya forest. To ensure that no plant species found outside the forest was included in the established bee plant list, the recent plant checklist for the Mt. Kenya forest by Bussman (1994) was used.

3.3 To investigate the influence of physical factors on bees foraging patterns

During this study, four important weather parameters were measured using simple portable instruments. These were light intensity, temperature, relative humidity, and wind speed. Light intensity was measured using a Sekonic L-248 light meter to determine the incident light in lux. Wind speed in meters per second was monitored and measured with hand wind meter for 30 seconds and the highest speed was recorded. Sling Psychrometer was used to measure ambient air temperature in centigrade and relative humidity. At every sampling point elevation in meters was recorded using a portable Altimeter.

3.4 The effects of floral factors on bee foraging

Flower shape and morphology have been found to limit the type of flower visitors in plants. It was therefore necessary to collect data on flower colours and shapes visited by the bees and other insects. Flower colours were categorized as yellow, blue, white, pink, purple and red.

Other floral factors, studied included flower morphology which comprised of two main types, open and tubular. The nature of the flower, that is, open or tubular was determined by the shape of the corolla. Flowers with exposed anthers and stigma such as compositae were considered as open while those with bell shaped corolla were regarded as tubular.

3.5 Statistical analysis

Three statistical packages were used to analyze the above-mentioned data. These included: Excel, Stastistica and SPSS. The packages were applied according to their applicability to different kinds of data collected and availability. Data on bees in every observation were subjected to log transformation before the analysis due to skewdness and kurtosis. Analysis of Variance (ANOVA) was used to compare species of bees in different habitats.

In addition, Multivariate Analysis of Variance (MANOVA) was carried out to test any significance difference between habitats, bees and other flower visiting insects. Pearson chi-square test (χ^2) was applied to test the dependence of floral colour and type of habitat. It was also used to test the dependence of bees on different types of habitat. Data on weather characteristics was analyzed using multiple regressions.

CHAPTER FOUR

4. RESULTS

4.1 Species composition of bees recorded in southeastern part of Mount Kenya forest.

A total of 1840 bees were sampled in four types of habitats in the study area. These comprised 17 species in 5 families with Apidae having the highest number of individuals in every habitat, followed by the family Halictidae (Table1). The families Andrenidae, Megachilidae (leaf cutter bees) and Colletidae were the least represented. Halictids (sweat bees) were the most diverse in the open woodland with about ten species. Eight of these species belonged to one genus, *Lasioglossum.* The forest pathways and open grassland patches with compact soils offered good nesting sites for most wild bees especially the sweat bees.

In the shrubland, the honeybees were the most dominant foragers mainly on the dominant pioneer plant species, *Crassocephalum mutuosum* (Plate 6*).* In closed woodland, wild bees were the most dominant foragers in the lower canopies especially on shrubs and herbs. Pine plantation had the least number of bees as compared to other habitat and the dominant herbaceous layer was mainly grass. A lot of grazing activity was observed in the pine plantations especially by both goats and livestock.

Plate 6. ***Crassocephalum mutuosum*, a common bee plant in a shrubland**

Table 1: Bee species recorded in four different habitats of southeastern part of Mount Kenya forest. Figures in parenthesis are percentage proportion of each Genus.

Family	Species	CW	OW	SL	PP	Total
Halictidae	*Lasioglossum sp A*	38 (2)	50 (2.7)	5 (0.3)	1(0.1)	94
Halictidae	*Lasioglossum sp B*	32 (1.7)	80 (4.3)	20(1.1)	4(0.2)	136
Halictidae	*Lasioglossum sp C*	12 (0.6)	27 (1.5)	6 (0.3)	1(0.1)	46
Halictidae	*Lasioglossum sp D*	15 (0.8)	33 (1.7)	0 (0)	0(0)	48
Halictidae	*Lasioglossum sp E*	13 (0.7)	3 (0.2)	7(0.3)	5(0.3)	28
Halictidae	*Lasioglossum sp F*	23 (1.2)	3 (0.2)	11(0.5)	2(0.1)	39
Halictidae	*Lasioglossum sp G*	14 (0.7)	27 (1.4)	1(0.1)	1(0.1)	43
Halictidae	*Lasioglossum sp H*	5 (0.3)	1(0.1)	2(0.1)	0(0)	8
Halictidae	*Halictini*	21 (1.1)	17 (0.3)	3(0.2)	0(0)	41
Colletidae	*Colletes sp*	4 (0.2)	0 (0.9)	16(0.9)	0(0)	20
Megachilidae	*Megachile sp*	2 (0.1)	16 (0.8)	7(0.4)	0(0)	25
Megachilidae	*Heriades sp*	0 (0)	1(0.1)	1(0.1)	0(0)	2
Anthophoridae	*Xylocopa sp A*	0 (0)	0 (0)	0(0)	20(1.1)	20
Anthophoridae	*Xylocopa sp B*	0 (0)	0 (0)	0(0)	10(0.5)	10
Adrenidae	*Andrena sp*	1 (0.1)	5 (0.3)	1(0.1)	0(0)	7
Apidae	*Apis mellifera*	212(11.5)	286(15.5)	575(31.2)	186(10.1)	1259
Total		396	554	660	230	1840

Key for abbreviations:

CW- Closed woodland　　SL- Shrubland

OW- Open woodland　　PP- Pine plantation

Table 2a. Diversity index value for bee species recorded in closed woodland in the southeastern part of Mount Kenya forest

N=1838	N	P*i*	Ln	P*i*lnPi
Lasioglossum sp A	38	0.020	3.64	0.073
Lasioglossum sp B	32	0.017	3.467	0.058
Lasioglossum sp C	12	0.006	2.485	0.015
Lasioglossum sp D	15	0.008	2.708	0.021
Lasioglossum sp E	13	0.073	2.564	0.187
Lasioglossum sp F	23	0.012	3.135	0.037
Lasioglossum sp G	14	0.007	2.639	0.018
Lasioglossum sp H	5	0.0.02	1.609	0.003
Halictus sp	4	0.002	1.386	0.002
Halictini sp	21	0.011	3.044	0.033
Colletes sp	4	0.002	1.386	0.002
Megachile sp	2	0.001	0.693	0.0006
Xylocopa sp A	0	0	0	0
Xylocopa sp B	0	0	0	0
Andrenidae sp	1	0.0005	0	0
Heriades sp	0	0	0	0
Apis mellifera	212	0.115	5.356	0.616
ΣP*i*LnP*i* (H')				**1.063**

Table 2b.Diversity index value for bee species recorded in the open woodland in the southeastern part of Mount Kenya forest

N=1838	N	P*i*	Ln	P*i*lnP*i*
Lasioglossum sp A	50	0.027	3.912	0.105
Lasioglossum sp B	80	0.043	4.382.	0.188
Lasioglossum sp C	27	0.014	1.431	0.020
Lasioglossum sp D	33	0.018	3.496	0.063
Lasioglossum sp E	3	0.002	1.098	0.002
Lasioglossum sp F	3	0.002	1.098	0.002
Lasioglossum sp G	27	0.014	1.431	0.020
Lasioglossum sp H	1	0.0005	0	0
Halictus sp	5	0.002	1.609	0.003
Halictini sp	17	0.009	2.833	0.025
Colletes sp	0	0	0	0
Megachile sp	16	0.008	2.772	0.022
Xylocopa sp A	0	0	0	0
Xylocopa sp B	0	0	0	0
Andrenidae sp	5	0.002	1.609	.003
Heriades sp	1	0.0005	0	0
Apis mellifera	212	0.115	5.356	0.615
ΣP*i*lnP*i* (H')				**1.0438**

Table 2c. Diversity index value for bee species recorded in the shrubland in the southeastern part of Mount Kenya forest

N=1838	N	P*i*	Ln	P*i*lnP*i*
Lasioglossum sp A	5	0.003	1.609	0 .004
Lasioglossum sp B	20	0.010	2.995.	0.029
Lasioglossum sp C	6	0.003	1.791	0.005
Lasioglossum sp D	0	0	0	0
Lasioglossum sp E	7	0.003	1.945	0.005
Lasioglossum sp F	11	0.005	2.397	0.012
Lasioglossum sp G	1	0.0005	0	0
Lasioglossum sp H	2	0.003	0.693	0.002
Halictus sp	5	0.002	1.609	0.003
Halictini sp	3	0.001	1.098	0.003
Colletes sp	16	0.008	2.772	0.022
Megachile sp	7	0.003	1.945	0.005
Xylocopa sp A	0	0	0	0
Xylocopa sp B	0	0	0	0
Andrenidae sp	1	0.0005	0	0
Heriades sp	1	0.0005	0	0
Apis mellifera	575	0.312	6.354	1.982
ΣP*i*lnP*i* (H')				**2.072**

Table 2d. Diversity index value for bee species recorded in the Pine plantation in the southeastern part of Mount Kenya forest

N=1838	N	P*i*	Ln	P*i*lnP*i*
Lasioglossum sp A	1	0.0005	0	0
Lasioglossum sp B	4	0.002	1.386.	0.002
Lasioglossum sp C	1	0.0005	0	0
Lasioglossum sp D	0	0	0	0
Lasioglossum sp E	5	0.003	1.609	0.004
Lasioglossum sp F	2	0.001	0.693	0.0006
Lasioglossum sp G	1	0.0005	0	0
Lasioglossum sp H	0	0	0	0
Halictus sp	0	0	0	0
Halictini sp	0	0	0	0
Colletes sp	0	0	0	0
Megachile sp	0	0	0	0
Xylocopa sp A	20	0.011	2.995	0.033
Xylocopa sp B	10	0.005	2.302	0.011
Andrenidae sp	0	0	0	0
Heriades sp	0	0	0	0
Apis mellifera	186	0.101	5.225	0.527
ΣP*i*lnP*i* (H')				**0.578**

The highest species diversity of bees was recorded in the shrubland (2.07) followed by closed woodland (1.06) and open woodland (1.04). Pine plantation had the lowest species diversity (0.58).

4.1.1 Variation of bees in four different habitats of the southeastern part of Mount Kenya forest.

Analysis of variance was performed to show whether there was a significant difference in number of bee species in different habitats.

Table 3. Means ± S.E of number of honeybees recorded in 1 m x1 m plots along different transects in the southeastern part of Mount Kenya forest

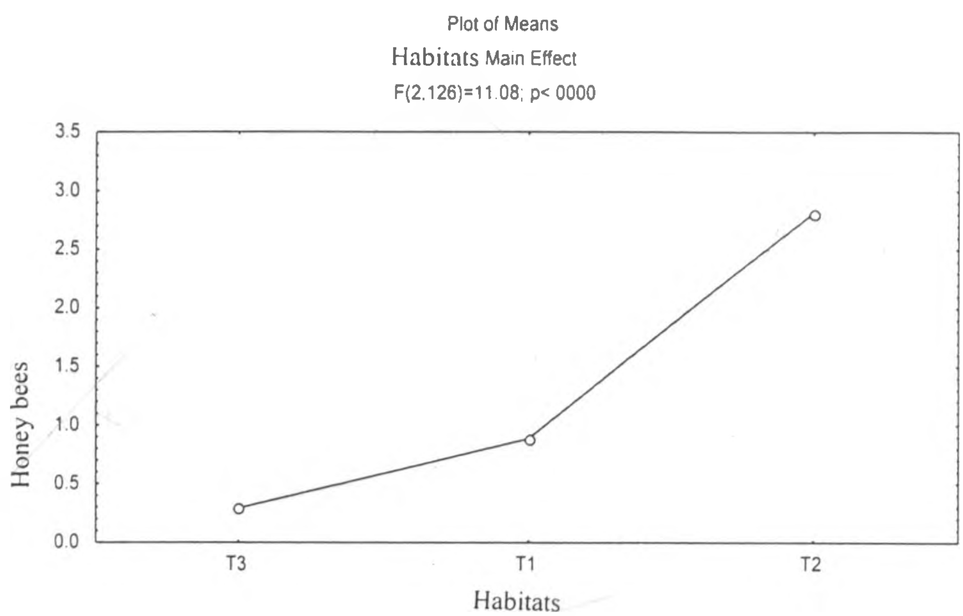
Habitats	Sample size (n)	Mean ± S.E number of bees
Shrubland	139	2.81 ± 0.47
Open woodland	139	0.89 ± 0.25
Closed woodland	139	0.29 ± 0.14

Table 4. Means ± S.E of wild bees recorded in 1 m x 1 m plots along different transects in different habitats of the southeastern part of Mount Kenya forest

Habitats	Sample size (n)	Mean ± S.E number of bees
Closed woodland	139	1.11 ± 0.65
Open woodland	139	0.58 ± 0.21
Shrubland	139	0.51 ± 0.13

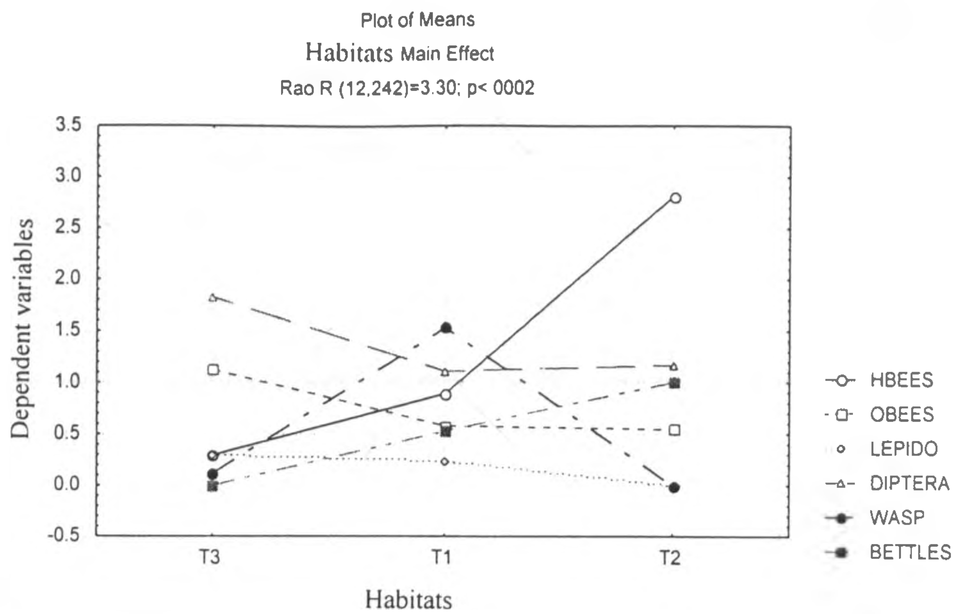
Results of analysis of variance (ANOVA) test showed that there was a significant difference ($p<0.0004$) in mean number of bees in the four different habitats. Shrubland (T2) had more honeybees than open woodland (T1). There was also a significant difference ($p<0.004$) between the mean abundance in shrubland and closed woodland (T3) for the honeybees. Shrubland had more honeybees than closed woodland.

Fig. 3. Similarity of habitats with reference to honeybees recorded during the study



Using cross tabulations and ANOVA test, habitats were also compared to show the degree of similarity in terms of honeybee abundance. Values on the left side of the graph represent mean number of honey bees in three different habitats (T3- Closed woodland, T1- Open woodland and T2- Shrubland). Open woodland and closed woodland had small difference in honeybee abundance but shrubland was quite different from the two.

Fig. 4. Relationships between bees and other insect pollinators recorded in different habitats of the southeastern part of Mount Kenya forest.



Key for the abbreviations

HBEES Honey bees

OBEES Wild bees

LEPIDO Butterflies and moths

The above test on associations of bees with other insects in different habitats was done using multivariate analysis of variance (MANOVA) test (Rao R(12,242) = 3,30, P<0.002). In the above test, the mean values of different insect pollinators (referred to as dependent variables) are shown on the left side of the graph. A significant difference between different insect groups and habitats was found. Diptera were found to be more associated with wild bees than honeybees. However, among the other insect pollinators, wasps showed a significant difference in the three habitats. Significant differences were found between open woodland and closed woodland (p<0.02) and between open woodland and shrubland (p<0.0003).

4.2 Bee plants recorded in the study area

Eighty species of bee plants representing thirty-two families were recorded as the pollen/nectar sources of bees in the southeastern part of Mount Kenya Forest. These results are presented in Table 5. The major pollen /nectar sources for a wide variety of bees identified belong to the following plant families Compositae, Labiatae, Rubiaceae, Euphobiaceae, Begoniaceae, Rosaceae, Tiliaceae and Phytolaceae. In the family Compositae, the species contributing most pollen and nectar were *Crassocephalum muotuosum* (S.Moore) Milne-Redh, *Vernonia amplifolia*, *Botriocline fusca* (S. Moore) M.G. Gilbert, *Microglossa pyridifolia* (Lam.) O.Ktze and *Ageratum conzyzoides* L.

Several species of family Labiatae were recorded as major nectar sources of both honey bees and solitary bees. These included *Plectranthus luteus* (Gurke) Gath, *Plectranthus albus* Gurke and *Plectranthus laxiflorus* Beuth. Observations made from the family Rubiaceae show that *Psychotria fractinervata* Pelit and *Psychotria orophila* Pelit had the longest flowering period among the woody species.

Other major pollen nectar sources of bees were *Croton macrostachyus* (Retz.) E.H.Walker, *Rubus steudneri* Schweinf and *Begonia meyeri-johannis* Engl . Additional data on major food sources of bees was derived from pollen grains on bee bodies. Examples of pollen grains processed for identification are shown by plate 7, 8 and 9.

However, most bee plant species were recorded at elevation 2000 m to 2300 m but elevation 2000 m to 2100 m had the highest record (Fig.5). Comparison between different forest fragments showed that open woodland followed by closed woodland had the highest number of bee plants. Shrublands that were recently under cultivation were characterized by mass flowering. The lowest number of bee plants was recorded in pine plantations. The dominant bee plant species in secondary forests were *Croton macrostachyus* (Retz.) E. H. Walker (Plate 10), *Crassocephalum muotusum* (S. moore) Milne-Redh and *Plectranthus* species. These plant species were good indicators of forest disturbance. However, bee plants were found to decrease with increase in altitude (Fig. 5).

Certain bees such as *Xylocopa* species were found to forage on specific plant species. During the entire sampling period *Xylocopa* species were only recorded on *Senna dimobotyra.* This plant was found only in disturbed areas or along forest edges. Pollinators such as bees are highly influenced by edge effects due to changes in microclimate and habitat conditions. "Edge" is defined as a population sink for forest interior species living at the periphery of the core area. Other solitary bees belonging to the genus *Lasioglossum* showed preference for certain plant species such Labiatae and Begoniceae species.

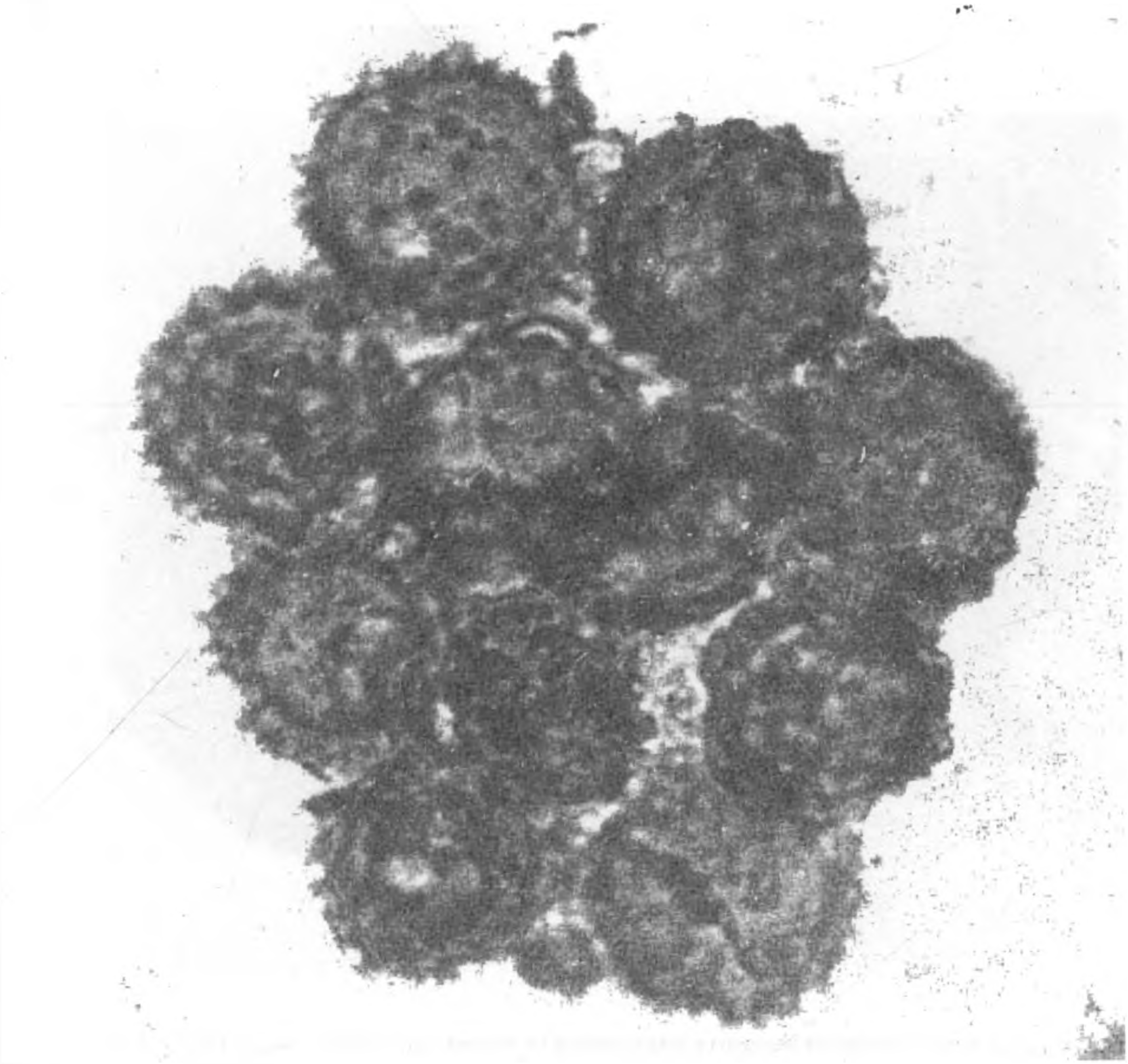


Plate 7. Compositae, *Ageratum sp*, an example of pollen grains processed for identification from the bee bodies

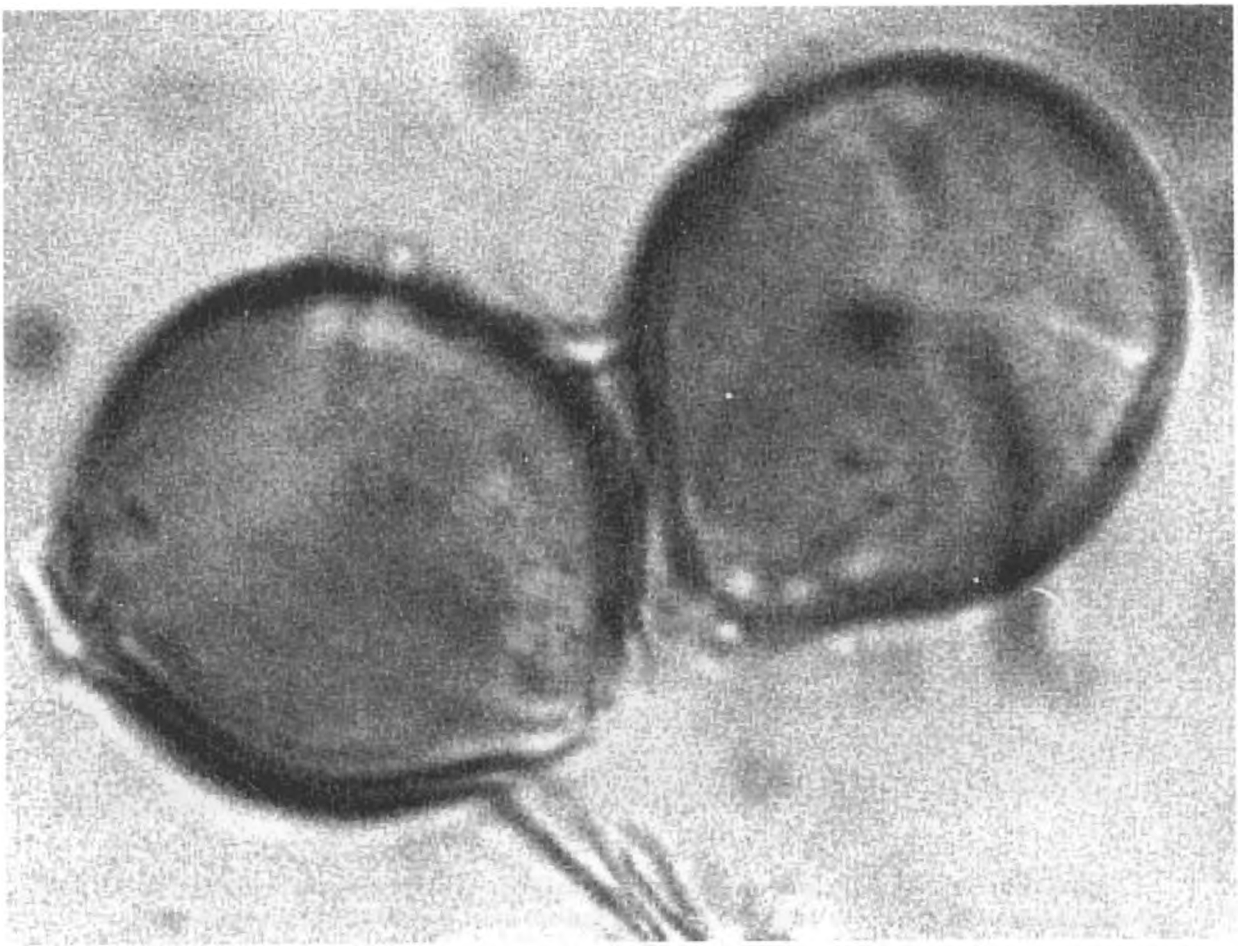


Plate 8. Lobeliaceae, *Lobelia sp*, example of pollen grains processed for identification from the bee bodies

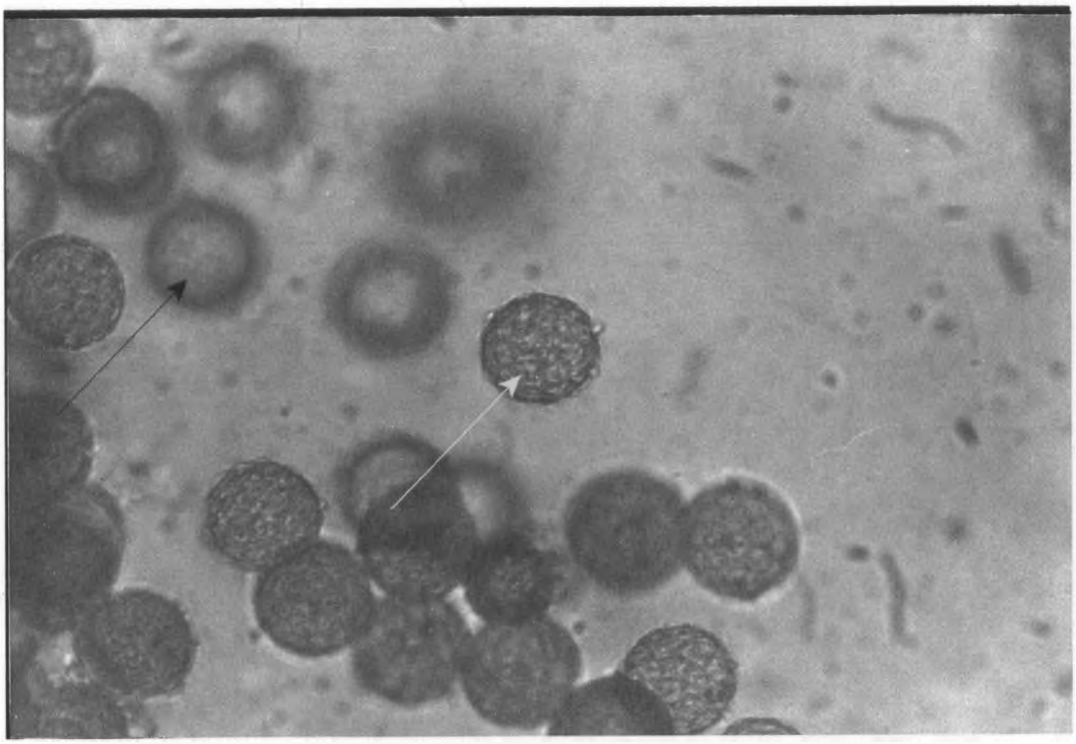


Plate 9. A mixture of Amaranthaceae and Gramineae pollen grains, examples of pollen grains processed for identification from the bee bodies. The yellow arrow shows pollen grains of the family Amaranthaceae while the black one shows the family Gramineae

Fig. 5. Variation of bee plant frequency (in percentage) in relation to altitude in the southeastern part of Mount Kenya forest

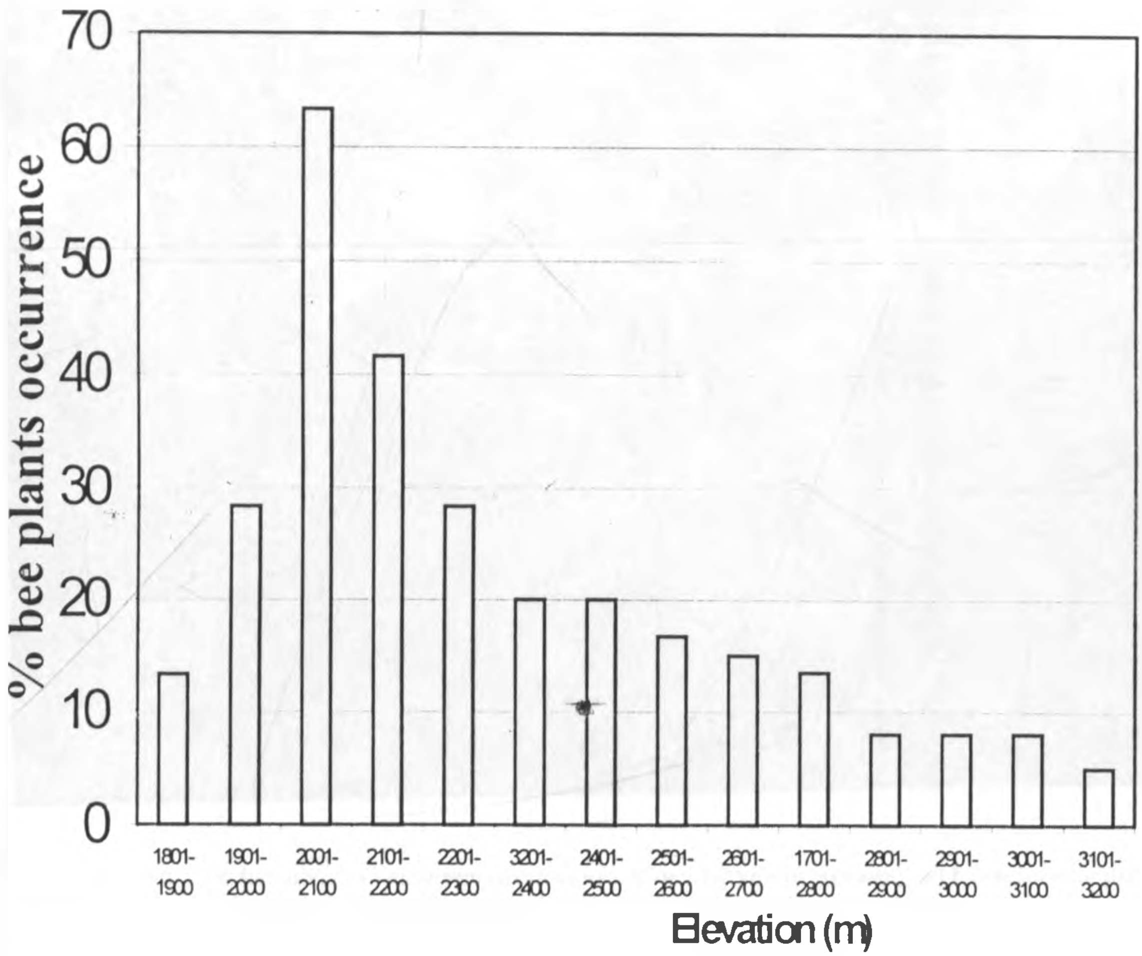


Plate 10. **A bee plant, *Croton macrostachyus* (shown by yellow arrows), a characteristic plant species in a secondary forest**

Table 5. Bee plants and their related bee genera recorded in the southeastern part of Mount Kenya forest

Key to abbreviations: Ap-*Apis mellifera*; Me-*Megachile sp;*La-*Lasioglossum sp; Xy-Xylocopa sp; Hs-Halictus sp; He-Heriades sp;*Hi-*Halictini;* Co-*Colletes sp;* Ad-*Andrena sp;* (+)-bee plants foraged by the particular Genus of bees; (-)-bee plants not foraged by the particular Genus of bees; GF-Growth forms; H-Herb (Any plant species below 1 m in height); S-Shrub (Any plant species above 1 m to 5 m in height); T-Tree (Any plant species above 5 m and beyond).

Plants species			**BEES**								
Compositae	**Elevation**	**GF**	**Ap**	**La**	**Hs**	**Hd**	**Co**	**Ad**	**Me**	**Xy**	**He**
Ageratum conzyzoides L	2000	H	-	+	+	-	-	-	-	-	-
Crassocephalum muotusum Milne -Redh	1900-2300	H	+	+	+	+	+	+	+	-	+
Crassocephalum crepidiodes Benth) S. Moore	1900-2300	S	-	+	+	-	-	-	-	-	-
Conza sumatrensis (Retz) E.H. Walker	2100	S	-	+	+	-	-	-	-	-	-
Gamolepis chrysanthemoides	1980	S	+	+	-	-	-	-	-		-
Galinsoga pavifora Cav	2000-2100	S	-	+	-	-	-	-	-	-	-
Botriocline amplifolia (O. Hoffm. &Muschi.)	2060	S	+	+	+	+	+	+	+	-	+
Botriocline fusca (S. Moore) M. Gilbert	1900-2380	S	+	+	+	+	+	+	+	-	+
Vernonia amplifolia	2110	S	+	+	-	+	+	+	+	-	-
Vernonia syringiforia		S	+	+	+	+	+	+	+	-	+
Microglossa pyridifolia (Lam) O.Ktze	2040	S	+	+	+	-	-	-	-	-	-
Helichrysum foetidum (L.) Lass	2100	S	-	+	+	-	-	-	-	-	-
Helichrysum ? formsissimum (L.) Lass	2500-3050	S	-	+	+	-	+	-	-	-	-
Stoeba ? kilimanscharica O. Hoffm. Var	2500-3050	S	+	-	-	-	-	-	-	-	-
Labiatae											
Achrospernum scimperi (Hochst.) Perkins	2050	H	+	+	+	-	-	-	-	-	-
Leucas ?glabrata (Vahl.) R. Br.	1780-2150	H	-	+	+	-	-	-	-	-	-
Platostoma africanum P. Beav	2000	H	-	+	-	+	-	-	-	-	-
Plectranthus edulis (Vatke) Agnen	1960	H	+	+	+	+	+	-	-	-	-
Plectranthus luteus (Guerke) Gath	2140	H	+	+	+	+	-	-	-	-	+
Plectranthus sylvestris Guerke	2120	H	+	+	+	+	+	+	-	-	+
Plectranthus parvus	2100	H	+	+	+	+	+	+	-	-	+
Plectranthus laxiflorus Benth	1580-2320	H	+	+	+	-	-	-	-	-	-
Plectranthus albus (Guerke)	2500	H	+	+	+	+	+	+	+	-	+
Pychostachys meyeri Guerke	1900-2100	H	-	+	+	+	+	-	-	-	+
Plectranthus assurgen (Bak.) T.K. Morton		H	+	+	+	+	-	-	+	-	+
Rubiaceae											
Keetia guinzii (Sond.) Bridson	2040	C	+	-	-	-	-	-	-	-	-
Lasianthus kilimandischaricus K. Schum	2100	T	+	-	-	-	-	-	-	-	-
Pauridianthus paucinennis (K. Scum) Brem	2050	T	+	+	+	-	-	-	-	-	-
Parapentas battiscombei Verdc	2000-2200	H	+	+	-	-	-	-	-	-	-
Psychotria fractinervata Pelit	2130	T	+	+	+	+	-	-	-	-	-
Psychotria orophila Pelit	2100	T	+	+	+	-	-	-	-	-	-
Leguminosae											
Parachetus communis D. Don	2030	H	+	+	-	+	-	-	-	-	+

Plants species	Elevation	GF	BEES Ap	La	Hs	Hd	Co	Ad	Me	Xy	He
Leguminosaee											
Senna didymobotrya (Fresen) Irwin & Baarneby	1900	S	+	-	-	-	-	-	-	-	-
Indigofera ? homblei Bak. F. S & Martin	1850-2800	S	+	+	-	-	-	-	-	-	-
Euphorbiaceae											
Croton macrostachyus (Retz.) E.H. Walker	1900-2300	T	+	-	+	-	-	-	-	-	+
Phyllanthus niruroides Muell. Arg	1580-2500	H	-	+	+	+	-	-	-	-	-
Acalpha frucicosa Forsk	1800-2460	S	+	-	-	+	-	-	-	-	+
Amaranthaceae											
Cyathula cylindrica Moq	2000-2100	H	+	-	-	-	-	-	-	-	-
Rosaceae											
Rubus steudneri Schweinf	1900-2100	C	+	+	+	+	+	+	-	-	+
Rubus pinnatus Willd	2100	C	+	+	+	+	+	+	-	+	+
Begoniceae											
Begonia meyeri-johannis Engl	2000-2300	C	+	+	+	+	-	-	-	-	-
Ranunculaceae											
Thalictrum rhynchocarpum Dillon & A. Rich	2080-3200	H	+	+	-	-	-	-	-	-	-
Ranunculus multifidus Forssk			+	+	+	-	-	-	+	-	-
Pytolaceae											
PhytoLacca dodecandra L' Herit	2000-2100	H	-	+	+	-	-	-	-	-	+
Solanaceae											
Nicotina tabacum L.	2000-2200	S	-	+	+	-	-	-	-	-	-
Cestrum elegans (Brough.) Schl	1980	S	-	+	+	+	-	-	+		+
Solanum nigrum L.	2000-2200	S									
Piperaceae											
Piper capense L. F	2150	H	-	+	+	-	-	-	+	-	-
Verbanaceae											
Clerodendrum johnstonii Oliv	2110	S	-	+	+	+	+	-	-	-	-
Gramineae											
Kyllinga sp	1980-2100	H	+	+	+	+	-	-	-	-	-
Sporobolus africana (Poir) Robyrus	2200-3150	H	+	+	+	+	+	+	-	-	-
Cyperaceae											
Cyperus sp	1780-3150	S	-	+	+	-	-	-	-	-	-
Myricaceae											
Myrica sp	1580-2000	S	-	+	+	+	-	-	+	-	-
Myrica salicifolia Hochest & A.Rich	2800	S	-	+	+	+	+	-	-	-	-
Cucurbitaceae											
Momordia sp	2000-2600	H	+	+	+	-	-	-	-	-	-

Plant species	Elevation	GF	Bees Ap	La	Hs	Hd	Co	Ad	Me	Xy	He
Acanthaceae											
Justicia Striata (KL.) Bullock	2360-2800	S	-	+	+	+	-	[illegible]	-	-	-
Isogrossa gregori (S.Moore) Lindau			+	+	+	-	-	-	-	+	-
Lobeliaceae											
Lobelia sp	2080-2800	T	+	+	-	-	-	-	-	-	-
Polygonaceae											
Polygonum ? nepalense Meisn	2120-2560	S	-	+	+	+	-	-	-	-	-
Polygonum pulcherum			-	+	+	+	+	-	-	-	-
Ulmaceae											
Celtis sp	1580-1860	S	+	+	+	+	+	+	-	-	+
Passifloraceae											
Adenia sp	1580-2300	C	+	-	+	-	-	-	-	-	-
Violaceae											
Viola abyssinica Oliv	2000-2100	C	+	+	+	-	-	-	-	-	-
Tiliaceae											
Triumfetta macrophylla K. Schum	1900-2400	S	+	-	-	-	-	-	-	+	-
Campanulaceae											
Lobelia baumanii		H	-	+	-	-	-	-	-	-	-
Myrtaceae											
Eulcalptus saligna SM.	1900-2200	T	+	-	-	-	-	-	-	-	-

4.3 Effects of physical factors on bee foraging activity

Multiple linear regression tests were carried out on whether parameters (temperature, light intensity, wind speed, relative humidity, and time). With multiple regressions, it was not possible to explain the most significant variables due to low explanatory power of jackknife regressions (r^2 = 10 %) to explain a regression variance. Light intensity was the only factor that seemed to have a small linear relationship with bees ($P<0.058$).

4.3.1 Effects of life forms on bee foraging activity

Analysis of variance was carried out to test other growth forms or life forms (tree, shrub and herb) of plants had any effect on bee foraging behaviour. According to the test, no significant difference was found between different life forms or growth forms of plants in different habitats. However, climbers such as *Begonia meyeri* (Plate 11) were more common in open woodland and they were important nectar sources for wild bees especially Halictidae.

Table 6: Means and ± standard error (S.E) of life forms visited by the bees in the southeastern part of Mount Kenya forest

Growth forms	**N**	**Mean ± SE**
Herbs	78	3.4 ± 1.54
Shrubs	45	2.8 ± 0.78
Trees	8	1.62 ± 1.4
Climbers	8	1.31 ± 1.1

Plate 11. ***Begonia meyeri*, a common bee plant in an open woodland of the southeastern part of Mount Kenya forest**

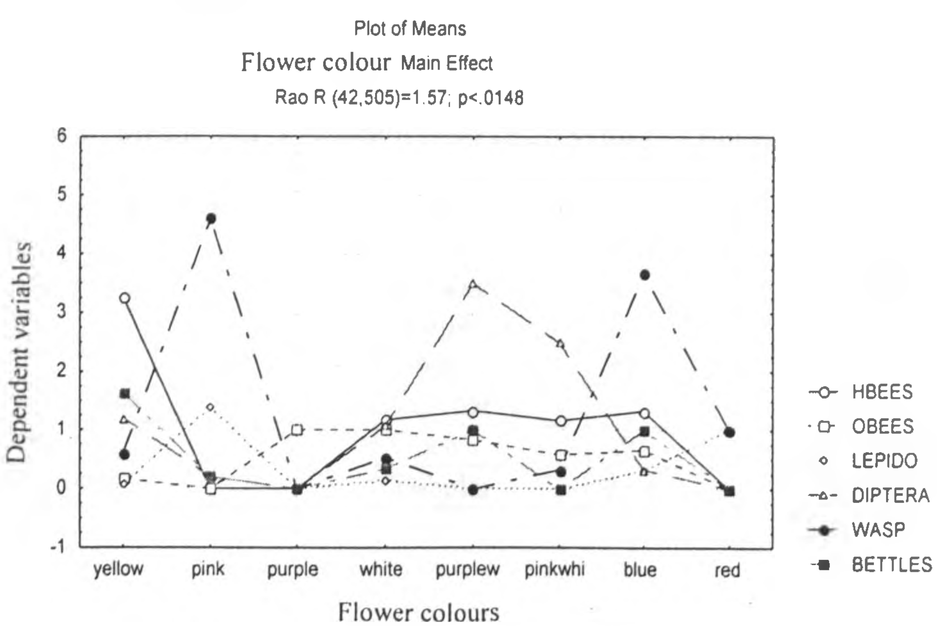
4.3.2 Effects of floral colour on bee foraging activity.

Analysis of variance (ANOVA) and Pearson Chi-square tests were carried out to test whether flower colour had an influence on bee foraging activity. Multivariate analysis of variance (MANOVA) was also performed to test the influence of flower colours on other insect flower visitors and their relationship with bees.

Table 7: Means and standard error (S.E) values of flower colours visited by the bees in the southeastern part of Mount Kenya forest

Flower colours	**N**	**Mean ± S.E (number of flowers)**
White	62	1.17 ± 0.31
Yellow	30	0.11 ± 0.61
Pink-white	12	1.16 ± 0.49
Purple-white	6	1.33 ± 0.49
Pink	5	3.27 ± 0.00
Blue	3	1.33 ± 0.67
Purple	1	0 ± 0
Red	1	0 ± 0

Fig.6. Bee foraging associates in relation to different flower colours in the southeastern part of Mount Kenya forest



Based on Pearson chi-square test (X2=37.82· df = 14, p<0.0005) the analysis revealed that the insect pollinators were dependent on different floral colours (Fcolor) as shown above. Using analysis of variance test, there was a significant difference between yellow and pink (P< 0.009647), Yellow and white (p<0.00003) and yellow and pink-white (P, 0.00183). Therefore bees preferred yellow flowers more than pink, white or pink-white. With the help of multivariate analysis of variance, a significant difference was found on colour was found among bees foraging associates or other insect flower visitors (Rao R (42,505)=1.57; p<0.0148).

4.3.3 Effects of flower morphology on bees foraging activity.

According to analysis of variance test, a significant difference (P< 0.493) was noted on flower shapes. In all habitats tubular flowers were visited less often than open flowers by the bees. Perhaps butterflies, moths and birds pollinate most tubular flowers. This is because moths and butterflies have the ability to uncoil their tongues when sucking the nectar from flowers.

Table 8. Means and ± standard error (S.E) values of flower shapes visited by the bees in the southeastern part of Mount Kenya forest

Bees	Flower shape	N	Means ± SE
Honey bees	Open	99	1.82 ± 0.22
	Tubular	9	0.78 ± 0.32
Wild bees	Open	99	0.74 ± 0.18
	Tubular	9	0.33 ± 0.17

CHAPTER FIVE

5.0. DISCUSSION

The number of bee species recorded in the study site may not be a true representation of the bee populations in Mt Kenya forest. This is because the study was confined only to the forest reserve covering Kirinyaga district, which represents the wettest area of Mount Kenya forest. In addition, the taxonomy of the collected bees during this study was difficult due to lack of local identification keys and reference materials. Very little is known about the taxonomy of wild bees in East Africa and as well as in many countries of Africa.

However, the findings of this study have shown significant difference in bee species distribution in different habitats and perhaps this could be as a result of human disturbances in the forest. Wild bees and honeybees were more frequent in large forested areas. This could have been due to availability of nesting sites and variety of food sources. An observation consistent with that reported by McCall and Primack (1992). However, honeybees were found to be the dominant flower visitors in every habitat and this could be attributed to their large colonies and foraging behaviour as compared to wild bees.

The highest species diversity of bees was recorded in the shrublands, followed by closed woodland and open woodland consequently. The fact that the highest index value was recorded in the shrubland does not mean that species evenness was also high in the same areas. Shrublands were characterized by mass flowering of pioneer plants such as *Crassocephalum muotusum, which* attracted a lot of honeybees because they are known to be floral density dependent. This is one of the weaknesses of Shannon and Weaner Index. It is highly influenced by species unevenness. Species richness of the wild bees was very low in the shrublands as compared to either closed or open woodland. However, wild solitary bees would have avoided foraging in the open shrublands due to fear of predation animals such as birds.

The highest species richness and evenness of bees was recorded in both closed woodlands and open woodland. This could be attributed to habitat heterogeneity, availability of nesting sites and abundance of different types of flowers in the forest gaps. In addition, in open woodlands, there was increased light intensity. Increase in light intensity in the overlying branches of trees and in lower canopies enhances luxuriant growth of shrubs and herbaceous plants which are good sources of pollen and nectar for the bees. Such areas were dominated by pioneer plant species, *Crassocephalum mutuosum* and *plectranthus species,* which were important pollen and nectar sources of bees.

Pine plantations had the lowest diversity of both bees and bee plants. Pine trees are wind pollinated and their dry leaves form a thick mattress layer on the ground which takes very long to decay, thus preventing growth of other herbaceous plants. Destruction of nesting sites by cattle, coupled with lack of herbs could have contributed to the low species diversity there.

Nevertheless, the complete absence of stingless bees remains a major question in the conservation of bees in Mount Kenya forest. According to the report given by the local people, these bees used to be in existence in 1940s. Their current disappearance is not fully understood. One of the major causes of extinction could be logging of indigenous trees, which serve as good nectar/pollen and nesting sites. Studies conducted in Bwindi National Park forest showed that stingless bees prefer nesting in old indigenous trees with about 40 % dry wood (Byarugaba, 1996). Increased charcoal burning and collection of firewood could have led to the loss and reduction of nesting sites and hence bees in the forest.

Distribution of major nectar and pollen sources of bees was found to vary from site to site depending on the elevation, degree of habitat disturbance and plant associations. Habitats with open canopy such as open woodland had the highest diversity of bee plants. Perhaps, this could be attributed to diversity of microhabitats and increased light intensity in the overlying branches and forest floor. However, some plant species were found to be habitat specific. For example, some climbers such *Begonia meyeri* were found only in forested sites while *Crassocephalum mutuosum*, a pioneer plant occurred only in disturbed sites.

A marked decrease of bee plants with increase in elevation was recorded in this study. This could be associated with cold temperatures at higher elevations. Mount Kenya forest is an afromontane forest, which is characterized by nocturnal frosts at elevation 2500 m. Thus, less flowering would be expected in the higher elevations of the forest due to cold temperatures. Again, most bees would also avoid foraging in higher elevation areas where the temperatures are too low and perhaps flowering plants found in such areas are either self, wind or animal pollinated. These findings agree with observations made by Richards (1986) and Regal (1982). However, large bees whose surface area volume ratio is small are good foragers of high montane areas.

Floral characteristics were found to play a major role in the foraging patterns of bees in the study area. The bees frequently visited open flowers compared to tubular ones. This could be associated with ease of collecting nectar from open flowers thus enhancing foraging efficiency. Bees are known to maximize energy net gain per unit time by reducing the time and energy spent while collecting food resources. Observation made by Faegri and Van der Pijl, (1979) showed that long-tongued bees, moths and butterflies visit tubular flowers. The flower color was also found to be significant. Most bees preferred yellow followed by white flowers. The preference of yellow colour to white was also documented by MaCall and Primack (1992).

Most weather parameters (temperature, Time, Relative humidity, wind speed) were not significant on the foraging patterns of bees. Studies have shown that the foraging patterns of bees observed in the field are governed by both extrinsic and intrinsic factors. The statistical tests done on the collected data could not show any significant difference on the above variables. In the four selected habitats, only light intensity was found to be significant. Among the other weather variables, may be light intensity is the most important in a tropical forest. Studies done by Waddington (1983) have shown that bees are known to use the sun as an orientation cue for finding home and food patches, and may also use the sun to orient them while flying between flowers.

5.1 CONCLUSIONS AND RECOMENDATIONS

5.1.1 Conclusions

Both social and solitary wild bees were found to be important pollinators of forest plants. Honeybees were the dominant bees in every habitat of the study area followed by the sweat bees (Halictidae). Both bees and bee-pollinated plants species were highly threatened by human activities in Mount Kenya forest. Solitary bees were found to be more endangered than honey bees because they have small colonies, nest in trees prone to logging and charcoal burning and have shorter foraging ranges. However, distribution of food sources was a major determinant in bee distribution.

The plant-pollinator interactions of Mount Kenya forest need to be conserved in order to save the forest for the bees and bees for the forest. The complete absence of sub-family Melliponinae (stingless bees) is product of forest degradation by man in the forest. Mount Kenya forest can serve as an "important pollinator garden" that needs to be preserved for the well being of man and animals. Animal pollinators enhance seeds set which are very important for forest regeneration.

5.1.2 Recommendations

The following are recommendations of the study:

- Policy makers and the stake holders need to be informed about the threatened ecological relationships and processes such as pollination service.

- There is need to address the reforestation program in the tropical forests of East Africa. Replacement of indigenous trees species with exotic species is driving many pollinator species to extinction. For example, pine plantations were found to be detrimental to pollinators. These trees are wind pollinated and they do not offer either food sources or nesting sites to solitary bees.
- Collection of firewood and charcoal burning by the local people should be controlled. Different bee species nest in different textures of dead wood e.g. the carpenter bees prefer soft dead wood. There is thus an urgent need to research on the nesting sites of bees in Mt Kenya forest in order to save this biota.
- Honey gatherers and beekeepers need to be trained on honey harvesting. Use of power saws to harvest honey should be discouraged. Traditional or modern bee keeping should be encouraged for it is a means of conserving bee fauna.
- An inventory of pollinators of keystone plants species of the forest should be compiled for forest managers and stakeholders. Manuals of important bees and bee plants should be established for forest managers and training institutions. Pollination remains one of the weakest links in our understanding of how ecosystem function. Hence the need to include pollination biology in school curricula at all levels.
- Future research should include more detailed pollination studies of keystone forest plants, assessment of forest fragmentation and restoration of degraded forest areas for pollinator populations.

APPENDIX 1

Appendix 1. Bee keeping in the forest

Very little bee keeping activity was observed in the lower elevation especially in the open woodland where food sources were highly available and diverse. In addition, there were very few beekeepers in the area whose preference for hive placing was the bamboo zone, which starts from elevation 2400 m. Thus they harvest very little honey due to scarcity of bee plants and low temperature in higher elevation. Perhaps this is because in cold temperatures, bees spend most of their time in the hives feeding on the gathered food resources rather than foraging. However, one of the major problems with the bee keeping was the security of their hives in the lower elevation zone.

REFERENCES

Arroyo, M. T. K., J. Armesto and R. Primack (1985). Community studies in pollination ecology in the high Andes of central Chile. Effect of temperature on visitation rates and pollination possibilities. *Plant systematics and Evolution* **149**: 187-203.

Ayala, B., R. T. L. Griswold, and D. Yenega. (1996). Apoidea, pp. 423-464 in J. Liorente B., A.N. Gorcia A., and E. Gonzalez S., eds., Biodiversidad Taxonomia Biogeografia de Artropodos de Mexico. Mexico: Universidad Nacional Autonomo de Mexico.

Bawa, K. S.(1990). Plant-pollinator interactions in the tropical rainy forests. Ann.Rev. *Ecol. Syst.* **21**: 399-422.

Beentje, H. F. (1990). Forests of Mount Kenya vegetation and human uses. In: Winiger, M Wiseman, U. and Rheker, J. R (eds): Mount Kenya area - Differentiation and dynamics of a tropical Mountain ecosystem. Bern: George. Insti. Dev. Universitat, 47-57.

Bohart, G.E. 1972. Management of wild bees for pollination of crops. *Annual review of Entomology* **17**: 287-312.

Braulio, S. F & V. L. Imperatriz-Fonseca. (1999). Report on the Recommendations of the Workshop on the Conservation and sustainable Use of Pollinators in Agriculture with emphasis on Bees. Pp 8

Brewer, J. W. (1984). In: Insects Text Book of Entomology. Pg 252-270.

Buchmann, S. L. and G. P Nabhan.1996. The forgotten pollinators. Island Press, Washington, D.C Shearwater Books, Covelo, California. pp320

Bussmann, R. W. (1994). The forests of Mount Kenya (Kenya). Vegetation, ecology, destruction and management of tropical Mountain ecosystem. PhD thesis, Bayreuth University, Germany.

Byarugaba, D. (1996). Stingless bees and Batwa honey hunters. A study linking indigenous knowledge and bee ecology. MSc Thesis, Zoology Department, Makerere University, Uganda

Carol, T (1997). Bee-keeping. A beginner's guide. Prepared by Association for better land Husbandry. Report no. 30.

Corbet, S. A., Williams, I. H. and Osborne (1991b). Bees and pollination of crops and wild flowers: changes in the European community, Review commissioned by scientific and technical options Assessment, European Parliament.

Eltringham, S. K. (1984). Wildlife resources and economic development. John Willey and Sons, New York.

Faegri, K., and L. Van der Pijl.(1979). The principles of pollination ecology, 3d ed. Pergamon Press, New York, NY.

Frankie, G.W., Vinson,. B, Newstrom, L.E., Barthell, J. F., Haber, W. A., Frankie, J. K., (1990). Plant phenology, pollination ecology, pollinator behaviour and conservation of pollinators in neotropical dry forest. In: Bawa, K. S., Hadley. M.Eds. Reproductive ecology of tropical forest plants. Man and the Biosphere No. 7. Parthenon, Carnforth, UK, pp 37-47.

Frankie, G.W., Vinson,. S. B; Rizzard, T. L; S. O' Keefe and R. R. Snelling. (1997). Diversity and abundance of bees visiting a mass flowering tree species in disturbed seasonal forest, Costa Rica. *Journal of the Kansas Entomological society*, **70:** 281-296.

Friese, H. (1914b). Neue Bienenarten der Orienalischen Region. Deutsche Entomologische Zeitshrift 1914: 320-324.

Gakuu, M. (2000). Kenyans in rush to clear forests across the country. In: Daily Nation News Paper, 7/9/2000. Horizon Team. Pp 21

Gathara, G. (1999). The recent report on destruction of Mount Kenya forest reserve, Ngare Ndare and Imenti forests. Pp 5-9

Gemmill, B. and A. Ochieng. (1999). The role of wild bees in the pollination of Egg plant, *Solanum melongena.* Proceedings of Second International Workshop on Conservation and Utilisation of Commercial Insects, pp 227-235.

Gess, F. W., Gess, S. K. (1983). Effects of increasing land utilization on species representation and diversity of aculeate wasps and bees in the Semi-arid areas of Southern Africa. Pgs 83 – 114 in Lasalle J, Gauld ID, eds. Hymenoptera and Biodiversity. Oxon (UK) : C.A.B International.

Hagerup, O. (1932). On pollination in the extremely hot air in Timbuctu. *Danske Botaniske Archiv* **8** : 1-20

Hedberg, O. (1951). Vegetation belts of East African Mountains, *Svensk Bot Tidskr* **45**: 140-199

Heinrich, B. (1979). Bumble Economics. Harvard University Press, Cambrigde, Massachuttets. Pp 23-57.

Hill, D.B. and Webster, T. C. (1995). Apiculture and Agroforestry (Bees and plants). Agroforestry systems. *Apiculture*. **29**: N0.3 pp 313-320.

Inouye, D. W., and G. H. Pyke. (1988). Pollination biology in the snowy Mountains of Australia: comparisons with montane Colorado, U.S. A. Aust. *J. Ecol.* **13**: 191-210.

Jennersten, O. (1988). Pollination in *Dianthus deltoides* (Caryophalaceae): Effects of habitat fragmentation on visitation and seed set. Conservation Biology. *Bioscience* **47** : 297-307.

Jones, C.E. and R. J. Little (eds).(1983). Handbook of experimental Pollination Biology. Van Nostrand Reinhold, New York.

Kahenya, A.W. and E. M. Gathuru, (1984). Identification of honey plants analysis. *In*: Proceedings of Third International Conference on Apiculture in Tropical climates. Nairobi pp 203-204.

Kearns, C.A. & Inouye, D.W. (1997). Pollinators, flowering plants, and conservation biology. *Bioscience* **47**:297-307.

Kevan, G. K. (1999). Pollinators as bioindicators of the state of the environment: species, activity and diversity. Agriculture, Ecosystem and Environment, pp 373-393.

Kevan, P. G. (1989). How honey bees forage for pollen at skunk cabbage, *Symplocarpus foeticlus* (Araceae). *Apidologie* **20**: 6, 485-490

Kevan, P. G., & H. G. Baker. (1993). Insects as flower visitors and pollinators. *Ann. Rev. Ent.***28**: 407- 453.

Kevan, P. G., and H. G. Baker.(1984). Insects on flowers: pollination and floral visitations. In: C. B. Huffaker and R. C. Rabb (eds). Insect Ecology. J. Wiley, New York, New York. Chapter 21, pp. 607-631.

Kevan, P.G., E.A. Clark and V.G. Thomas. (1990). Insect Pollinators and Sustainable Agriculture 5:13-22.

KIFCON, (1994a). Kenya Indigenous Conservation Programme. Forest inventory Report 6. Mt Kenya and Thunguru Hill pp 1-6.

Kigatiira, I. K. (1984). Some aspects of ecology of African honeybees. University of Cambridge, London. Ph.D. Thesis. Pp 46-57

Kiringe, J. W. (1990). A vegetation and large mammal survey in Hell's Gate National Park, Kenya. Msc. Thesis, University of Nairobi. pp23-40

Krebs, C. J. (1985). Ecology. The experimental Analysis of Distribution and Abundance. Harper and Row, New York.

Lamont, B. B., P. G. L. Klinkhamer, and E. T. F. Witkowski. (1993). Habitat fragmentation may reduce fertility to zero in Banksia: a demonstration of the Alee effect. *Oecologia* 94: 446-450.

Lasalle, J.& I. D. Gauld. (1993). In: Hymenoptera: The diversity, and Their Impact on the Diversity of other organisms. C. A. B. International. Wallingford. UK pp 1-25.

Levin, D. A. (1978). Pollinator behaviour and the breeding structure of plant populations, pp 133-150 in Richards, A.J. (ed).

Levin, D.A. & Kerster, H. W. (1969a). Density-dependent gene dispersal. In: Liatris. Ann. Nat **103**: 69-74.

Levin, D.A. & Kerster, H.W. (1969b). The dependence of bee-mediated pollen and gene dispersal upon density. *Evolution* **23**: 560-571.

Levin, D.A. (1983). Plant parentage: an alternative view of the breeding structure of populations. Pp 171 – 188. In King, C.E, & P. S Dawson (eds). Population biology-retrospect and prospect, New York.

Lockwood, L. (1995a). Mount Kenya under threat. Swara September/October1995 Vol, 18. No 5. Pp 9.

Magurran, A. E. (1983). Ecological Diversity and its measurements. Pp 11-39.

Mbaya, J.K. (1981). Studies of the distribution and some behaviour aspects of African Honey bees in Kenya. Msc. Thesis pp 73-84

McCall, C. & Primack, R.B. (1992). Influence of flora characteristics, weather, time of day, and season on insect visitation rates in plant communities. *American Journal of Botany* 79 (4): 434-442.

McGregor, J. E. (1972). Insect pollination of cultivated crop plants. U.S. Department of Agriculture, Washington DC. Handbook 496.

McGregor, R.E. (1972). *Insect Pollination of cultivated Crop Plants.* U.S. Department of Agriculture, Washington DC. Handbook 496.

Meffe, G. K. (1997). The potential consequences of pollinators declines on the conservation and stability of food crops yields. Conservation Biology. Vol. 12: No, 1 pp 8-17.

Michener, C.D. (1954b). Bees of Panama. Bulletin of American Museum of Natural History 104: 1-176.

Michener, C.D. (1979). Biogeography of the bees. *Annals of the Missouri Botanical Garden* 66: 277-347.

Michener, C.D. (2000). In: The Bees of the world. Pp 3-21. Neff, J.L. & Simpson B.B. (1993). Bees, pollination systems and plant diversity. In: Lasalle J. Gauld I.D. eds. Hymenoptera and Biodiversity. Oxon (UK) : C.A. B International pg 143 – 168.

Michener, C.D., R. J. McGinley and B.N. Danforth. (1994). *The Bee Genera of North and Centrral America (Hymenoptera: Apoidea).* Smithsonian Institution Press, Washington DC.

Neff, H. L. and B. B. Simpson, 1993. Bees, pollination systems and plant diversity. In: J. Lasalle and I. Gauld (eds), Hymenoptera and Biodiversity. Commonwealth Agricultural Bureau International, London.

Ngethe, J. C. (1984).Honey production from natural vegetation in Kitui District, Kenya. *In:* Proceedings of the Third International Conference on Apiculture in Tropical Climates, Nairobi, pp 205-208.

O'Toole, C. (1993). Diversity of native bees and agroecosystems. Pp 169 – 196 *in:* Lasalle J. Gauld I.D. eds. Hymenoptera and Biodiversity. Oxon (UK): C.A.B International.

O'Toole, C. (1994). Who cares for the solitary bees? In: A. Matheson (ed) Forage for bee in an agricultural landscape. International Bee Research Association, Cardiff, UK: pp 47-56.

O'Toole, C. (1986). Bee systematics in Europe: the continuing crisis and some possible cures, In: A. Matheson *et al.* The conservation of bees :227-232. Academic press, London, Linnean society of London and International Bee Research Association-IBRA.

Orim, J. M. C., L. M. Eijnatten and R. S. Pathak (1979). Some factors which encourage the out crossing of Pigeon pea. In: In Proc. 4th Intl. Symp. Pollination, D. Caron (ed.) College Park, Maryland: Maryland Agric Exp. Sta. Misc. Publ. 1. Pp 219-255

Pimental, D. C; C. Wilson; C. Macullum, R. Huang; P. Dwen; J. Flack, Q. Tran; T. Saltman and B. Cliff. (1997). Economics and Environmental Benefits of biodiversity. Bioscience. **47** (11): 747-757.

Prinsloo, G. L. and C. Eardley. (1985). In: Insects of South Africa. Pp 393-400.

Rathcke, P. G. & E. Jules. (1993). Habitat fragmentation and plant-pollinator interactions. Current science 65: 273-278.

Regal, P.J. (1982). Pollination by the wind and animals: ecology of geographic patterns. Ann. Rev. Ecol. Syst. 13, 497-524.

Richards, A. J.(1986). Plant breeding systems. Allen and Unwin, London.

Richards, K.W. (1993). Non-*Apis* bees as crop pollinators. *Revue Suisse de Zoologie* **100**: 807-822.

Roubik, D. W. (1983). Experimental community studies: time-series tests of competition between African and neotropical bees. *Ecology* **64**: 971-78.

Roubik, D. W. (1989). Ecology and Natural History of Tropical Bees. Cambridge University Press, New York, 514 pp.

Roubik, D.W. (1995). Pollination of cultivated plants in the tropics. Food and Agriculture organization, Rome. FAO Agricultural services Bulletin 118: 1-196.

Roubik, D. W. (1998). Pollination of cultivated plants in the tropics. Food and Agriculture Organization, Rome. FAO, Agricultural services Bulletin 118:1-196.

Salt, G. (1987). Insects and other invertebrates animals collected at high altitudes in the Ruwenzori and on Mount Kenya.

Schaal, B.A. (1978). Density dependent foraging in *Liatris pycostachya*. *Evolution* **32**: 452-454.

Schmidt, J. (1983). Density-dependent pollinator foraging, flowering phenology, and temporal pollen disperal patterns in *Linatus bicolor*. *Evolution* **37**: 1247 – 1257.

Selman, B. (1979). In: Insects. An illustrated survey of the most successful animals on earth. Pp 18-20.

Shricker, B. (1965). Die otientierung der Honigbiene in der Dammerung, Zugleich ein Beitrag Zur Frage der ocellenfunktion bei neinen. *Z.Vergy Physiol.* **49**: 420-458.

Stebbins, G. L. (1979). Rare species as examples of plant evolution. Pages 113-118. In Great Britain Basin natralist memoirs nr 3: the endangered species: a symposium; 7-8 Dec, 1978. Provo (UT): Brigham Young University.

Solbrig, O.T. (1996). Biodiversity: Scientific Issues and Collaborative Research Proposals. MAP Digest 9. UNESCO, Paris. Pp 77.

Survey of Kenya. (1959). National atlas of Kenya. Nairobi: Survey of Kenya.

Survey of Kenya. (1966). East African mean monthly rainfall in millimetres. (North sheet: Kenya and Uganda). Nairobi. Survey of Kenya.

Thery, M., A.D.Stevens; J.R. Hoppe; Dominique and K. L. Schchmann. (1998). Angiosperms pollination and seed dispersal. A review. *Ecotropica* 4: 69 - 91.

Torchio, P.F. (1987). Use of non-honeybee species as pollinators of crops. Proceedings of the Entomological society of Canada 118 : 111 – 124.

Torchio, P.F. (1990). Diversification of pollination strategies for U.S. crops. Environmental Entomology 19 (6): 1649-1656.

Torchio, P.F. (1991). Bees as crop pollinators and the role of solitary species in changing environments, In: C. van Heemert and A. de Ruijter (eds.) Sixth International Symposium on Pollination, Wageningen. *Acta Horticulturae* **288**: 49-61.

Trapnell, C. G. & Burnt, M. A. (1987). Vegetation and Climate maps of south western Kenya (8 maps 1;250,000) Surbiton : Survey of Kenya.

Velthuis, H.H. W. (1992). Pollen digestion and evolution of sociality in bees. Bee world Vol. 73 No. 2 pg 21

Waddington, K. D., and Heinrich, B. (1981). Patterns of movement and floral choice by foraging bees. In: "Foraging Behaviour: Ecological, Ethological, and Psychological Approaches" Kamil and T. Sargent, eds.), pp. 215-230. Garland STPM Press, New York.

Waddington, K. D. (1983). Foraging behaviour of pollinators. In: Pollination Biology. Pp 213-239.

Warui, C. M. (1999). Diversity, species composition and some ecological aspects of terrestrial molluscs in Mount Kenya National park, Kenya. Thesis. University of Nairobi.

Wittmann, D. & C. Schlindwein. (1995). Mellittophilous plants, their pollen and flower visiting bees in southern Brazil. *Biociencias, Porto Alegre*.**3**, n.2, p.19-34.