

**BEE DIVERSITY AND THEIR FLORAL RESOURCE UTILIZATION ALONG A
DISTANCE GRADIENT FROM THE ARABUKO SOKOKE FOREST**

By

Kenneth Njoroge Mwangi
(BSc. University of Nairobi)

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DECLARATION

This Thesis is my original work and has not been presented for award of a degree in any other University

Kenneth Njoroge Mwangi

Signed 

Date 21/01/2010 03/07/2009

This thesis has been submitted as original work with our approval as university supervisors

Dr. Paul N. Ndegwa

University of Nairobi

Signed 

Date 03/07/2009

Dr. Evans M. Mwangi

Signed 

Date 03/07/2009

DEDICATION

This work is dedicated to my wonderful, loving, and supportive parents

Joseph and Loise

For their foresight, belief in the power of education and constant inspiration

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ABSTRACT

A study was conducted to assess the change in bee diversity along a distance gradient from the Arabuko Sokoke forest and among the three major vegetation types found in the forest. The floral utilization and resource partitioning among solitary and the honeybees was also studied. Sampling sites were selected from the three main vegetation types of the forest namely, Mixed forest, *Brachystegia* and *Cynometra*. Each vegetation type had four sampling sites; one sampling site at the forest margin and three sampling sites located in farmlands selected along a distance gradient from the forest margin; at 2 km, 4 km, and 6 km respectively. The number of bees and species collected in four 50 x 6 metres sampling plot at each sampling sites from 0800 hrs – 1500 hrs on sunny days with fair weather were recorded. The flower cover was estimated as the number of flowers sampled in ten 1m² quadrat at each plot. Kruskal-Wallis test was used to test for significant difference across the distance gradient and among the vegetation types. Bee diversity was calculated as the Shannon diversity index and similarity in species composition was calculated with Horn's similarity index. Morisita index was used to calculate the overlap between the honeybees and the solitary bees in resource use across the distance gradient.

Sixty three bee species belonging to three families, Apidae, Halictidae, and Megachilidae were found around the Arabuko Sokoke forest. Bee abundance increased significantly across the gradient from the forest margins ($H = 15.055$, $df = 3$, $P < 0.01$), while the number of species declined significantly from the forest margins ($H = 14.203$, $df = 3$, $P < 0.01$). Species diversity decreased significantly across the gradient from the forest margins ($H = 19.39$ $df = 3$, $P < 0.01$). Based on Horn's index, similarity in bee fauna across the distance gradient from the forest margins was high, ranged from $C_H > 0.83 - 0.89$. Significantly more honeybees were found at the farmlands than at the forest margins ($H = 9.93$, $df = 3$, $P = 0.02$).

There was a significant difference in the number of bees and species recorded among the three vegetation types ($H = 37.993$ $df = 2$, $P < 0.01$) and ($H = 10.171$, $df = 2$, $P < 0.01$) respectively. Similarity in bee fauna found between the vegetation types was high, $C_H > 0.80$, with *Cynometra* and the mixed vegetation types having the most similar bee community, $C_H = 0.95$. Significantly more member of the family Apidae were found in the mixed forest vegetation type ($H = 67.07$,

df = 2, P < 0.01), while significantly more members of the family Halictidae were found in the *Brachystegia* vegetation type (H = 11.96, df = 2, P < 0.01).

There was a significant difference in the amount of flower across the distance gradient from the forest margins (H = 22.776, df = 3, P < 0.01), but not in the number of flowering species. However the number of flowering species utilized by bees differed significantly across the distance gradient (H= 22.05, df = 2, P = 0.02). Over 60% of all the bees utilized floral resources from five plant families Polygonaceae, Compositae, Amaranthaceae, Commelinaceae, and Acanthaceae. The honeybees and the solitary bees utilized similar flowering plants across the gradient from the forest. An overlap in floral resource utilization between the social honeybees and the solitary bee species was recorded. Species richness and diversity were found to decline with the increased distance from the forest margins.

CHAPTER ONE

1.0 INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

The Arabuko Sokoke forest is a key biodiversity hotspot that is under threat from extractive utilization by the surrounding local community (Gordon and Ayiemba, 2003). This extractive utilization includes illegal logging, charcoal burning and clearing of valuable vines and medicinal plants. Given the high levels of endemism found in this forest, habitat altering activities pose a great danger to the species with high levels of habitat specificity (Burgess *et al.*, 2000). This forest has a rich biodiversity that provides important ecological services (Burgess *et al.*, 1998). Ecological services are a wide range of conditions and processes within the ecosystems that help to sustain and meet human needs, such as soil nutrient supply, soil carbon storage and biodiversity-related services like pollination, decomposition, natural control of pests and invasive species (Daily, 1997). Some ecosystem services, such as pollination and seed dispersal, are produced at a local scale by mobile organisms foraging within or between habitats (Lundberg and Moberg, 2003). Pollination of both wild and cultivated crops is an important ecosystem service that is highly disregarded (Klein *et al.*, 2003; Rathcke and Jules, 1993).

Kenyan forests exist today as islands surrounded by land under intense cultivation, due to the explosive human population increase resulting in the degradation of existing arable lands and encroachment on forests (Wass, 1995). These indigenous forests are known to be declining in quality and quantity, but the data on the extent to which this is happening are inadequate (Wass, 1995; Younge *et al.*, 2002). The coastal forests are among the most endangered ecosystems in Kenya due to the high poverty levels in surrounding communities (ASFMT, 2002; Gordon and Ayiemba, 2003). The coastal forests of East Africa are a chain of relict forest and thicket patches set within savannah woodlands, wetlands and agricultural land. The forests extend from Southern Somalia to Southern Mozambique. Although the remaining forests scattered throughout this region are typically tiny and fragmented, they contain remarkable levels of biodiversity. These forests also vary greatly in their species composition, particularly among less mobile species. For example, forests that are only 100 kilometers apart may have up to 80 percent differences in their plant species (Burgess, 2000).

In Kenya, the coastal forest mosaic is mostly confined to a narrow strip except along the Tana River where it extends inland to include the forests of the lower Tana River (the northern-most of which occur within the Tana Primate National Reserve). In Tanzania, the Mosaic runs from border to border along the coast, contracting in the Rufiji Delta region (Young *et al.*, 2002). Much of the Mosaic has been converted to subsistence agriculture, interrupted by plantations and human settlements, including the large cities of Mombasa and Dar es Salaam with populations of more than 700,000 and 3 million, respectively (Burgess *et al.*, 2003).

Despite the obvious importance of the coastal forests in terms of biological value and the high levels of threat by deforestation, only 17% of the coastal forests hotspot is formally protected, with just 4% having high levels of protection under the International Union for the Conservation of Nature (IUCN) protected area categories I-IV (Baillie *et al.*, 2004). By the early 1990s, there were about 175 forest patches in the Coastal Forest Mosaic (Kenya 95, Tanzania 66) covering an area of approximately 1,360 km² (Kenya 660 km², Tanzania 700 km²) (Burgess *et al.*, 2000). Mean patch size was 6.7 km² in Kenya and 10.6 km² in Tanzania. Modal patch-size classes were 0 – 1 km² in Kenya and 5-15 km² in Tanzania. The two largest protected coastal forests are both in Kenya (Arabuko-Sokoke, 417 km²; Shimba hills, 63 km²) (Burgess *et al.*, 2003), while in Tanzania there are no coastal forests larger than 40 km² in protected areas (Younge *et al.*, 2002).

The Arabuko-Sokoke forest covers approximately 417 square km close to the Indian Ocean in Kilifi and Malindi Districts of Coast Province, Kenya, about 110 km north of Mombasa (ASFMT, 2002). It is the last remnant of indigenous forests in Kenya, the largest and most intact coastal forest in East Africa (Burgess *et al.*, 2000). The forest contains at least three distinct vegetation types, which provide the habitat for several endangered species, and a high number of species in relation to the area. At least 24 rare or endemic bird, mammals, and butterfly species are restricted to this stretch of coast (Burgess, 2000). This high proportion of endemic species, some known only from Arabuko-Sokoke Forest, makes the forest a key part of the East African coastal forests endemic bird area.

Over the recent decades, coastal forest resources have been impacted negatively by over-exploitation and are still on the decline. The survival of these forests is threatened by the ever

increasing human population and the consequent demand for natural resources and farmland (Maundu *et al.*, 1997). Extreme poverty results in heavy subsistence demands, especially for firewood and building materials, and illegal activities within the forest, such as poaching (of wood and animals). These activities endanger the forest resources that have helped to support local communities, leading to a vicious circle of degradation all too often seen in tropical forests.

In an effort to reduce the extractive utilization of the Arabuko Sokoke forest, the Kipepeo Project was started in 1993 (Ayiemba, 1997; Gordon and Ayiemba, 2003). The Kipepeo Project is mainly involved in the sustainable utilization of the forest butterflies by breeding them for the export market in Britain and the USA. The farmers under the project capture adult butterflies that are kept in breeding cages to lay eggs. On emerging, caterpillars are nurtured until the pupal stage then sold to the Kipepeo project, which in turn sells them to butterfly house dealers (Gordon and Ayiemba, 2003). The project has now expanded to include bee keeping activities, silk moth rearing, and mushroom farming as the new and highly lucrative non-extractive means of utilizing the biologically diverse forest. It is hoped that by involving the local community in forest conservation centered activities, their attitudes towards the Arabuko Sokoke forest will be positive (ASFMT, 2002).

In addition to providing, important ecosystem services to such as nutrient recycling and carbon sequestration, the presence of natural forests close to agricultural farmlands has been known to enhance the abundance and diversity of pollinating vectors available to such farms in many regions. In Australia, Blanche and Cunningham (2005) found that orchards located nearer to the forests had a higher number of native beetles species pollinating custard apples (*Annona reticulata* L.). The higher beetle diversity resulted in higher fruit yields in these orchards than those that were located further away from the forests. Ricketts (2004) and Klein *et al.* (2002; 2003) found that coffee farms that were located closer to the tropical forest had better coffee (*Coffea Arabica* L.) yields due to the availability of a highly diverse pollinating bee community in Costa Rica.

In Sweden, Ockinger and Smith, (2006, 2007), concluded that the species richness in butterflies and bumble bees found in agricultural land was negatively correlated with the distance from

natural habitats. Kremen *et al.* (2002) found that a native bee community was essential in improving pollination of watermelons (*Citrullus lanatus* Thunb.) and that wild ecosystems supported a diverse bee composition in the USA. Winfree *et al.* (2007) also found a positive association between extensive forest cover with bee species. In Kenya, Gikungu (2006) found a large portion of forest-dependent bee species that were rarely found in the surrounding farmlands.

Bees are an important group of pollinators and indispensable in agriculture and in maintaining biological diversity, for they are the most dominant of all pollen vectors (Buchman and Nabhan, 1996). In the afro tropical region, bees have been found to inhabit all the biomes making them, an important reference group for biodiversity studies (Eardly, 2002). Despite their importance as pollinators, there is little scientific understanding of how conversion of habitat to human use affects bee species composition (Buchmann and Nabhan, 1996; Allen-Wardell *et al.*, 1998; Winfree *et al.*, 2007).

Investigations into the pollen vectors held by islands of biodiversity surrounded by extensive farmlands are critical in order to demonstrate to farmers, the importance of these forests to the pollination of their crops and subsequent produce (Klein *et al.*, 2002). One such biodiversity islands is the Arabuko Sokoke forest, due to its highly diverse flora and fauna coupled with high levels of endemism (Gordon and Ayiemba, 2003). The Arabuko Sokoke forest is surrounded by a populous community of peasant farmers who rely heavily on extractive utilization of the forest to earn a living (Maundu *et al.*, 1997; Gordon and Ayiemba, 2003). It is important to investigate the role of the forest as a reservoir of this pool of pollinators to demonstrate to the farmers the benefits of conserving this forest in its pristine condition.

1.2 Literature review

1.2.1 Conservation of Kenyan forests

Forests play a great role in conservation of biodiversity (Wass, 1995; Burgess *et al.*, 1998). Although forests cover less than 2% of Kenya's land area, they contribute over half of the total number of woody species found in the country. Approximately one hundred and four rare woody species found in Kenyan forest are threatened due to habitat loss and degradation by human activity (Wass, 1995). These forests also provide habitat and refuge to about 50% of all the

threatened mammalian species in Kenya. About 30% of all birds found in Kenya, occur in these forests (Bennun and Njoroge, 1999). Forests are home to 26 forest dependent birds and 26 forest generalist species (Burgess *et al.*, 1998). Important forests for biodiversity conservation in Kenya include the Arabuko Sokoke, Shimba hills, Mt Kenya, the Aberdare ranges, Kakamega forest, the Mau forest complex, Taita Hills, Tana River, Mathews Range and Marsabit (Wass, 1995).

With only 18% of arable land in Kenya (Republic of Kenya, 1988), emigration to the semi arid areas and encroachment on conservation areas has been extensive. This has in turn led to many excisions and illegal encroachment of the protected forests. General forest cover has in the period from 2000-2005 continued to decline by an annual rate of 0.03% (Food and Agricultural Organization (FAO), 2007). According to a Kenya Forests Working Group report (KFWG, 2001), the Mau Forest Complex, the largest water catchment area in Kenya, decreased in area by approximately 9% (340 km²) from 1964 to 2000 as plantation forests were replaced by small-scale subsistence agriculture.

The coastal forests in Kenya are characterized by a mosaic of vegetation types including evergreen forest, *Brachystegia* woodland, scrub forest and dry forest. They form a part of the Zanzibar – Inhambane forest zone (Davies *et al.*, 1993), which stretches from southern Somalia to northern Mozambique and into Zimbabwe (Burgess *et al.*, 1998). Due to the exceptional level of plant endemism in the northern part of this regional mosaic, the Zanzibar-Inhambane regional mosaic has recently been reclassified as the Swahilian regional center of endemism and the Swahilian-Maputaland regional transition zone (Clarke, 1998). The total area of these forests is approximately 3165 km², comprising 2 km² along the Jubba River in Somalia, 660 km² in Kenya, 697 km² in Tanzania, 16 km² in Zimbabwe, and 1790 km² in Mozambique (Burgess *et al.*, 1998). These forests that had been in existence for millions of years as a continuous band (Hamilton, 1981) currently exist only as small fragments.

These closed - canopy coastal forests retain high numbers of endemic plant and animal species: 554 plants, five birds, three mammals, 24 reptiles, five amphibians, 86 molluscs, and 75 butterfly species (Burgess *et al.*, 2000). The mosaic of habitats within the hotspot, including forest, woodland, and thicket, contains a greater total number of endemic species: 1750 plant, 11 bird,

11 mammal, 53 reptile, six amphibian, and 32 freshwater fish species. Of these, there are 333 globally threatened (Red listed) species, with 105 species being represented in Kenya and 307 in Tanzania (Burgess *et al.*, 1998; Baillie *et al.*, 2004).

A major threat to these forests is the ever increasing human population and the consequent demand for natural resources and farmland. Other threats include commercial logging, removal of fuel wood, burning of charcoal, replacement of natural forests with plantation, subsistence hunting, and breakdown of traditional land ownership patterns and forest protection practices (McClanahan and Young, 1996). The local communities harbor negative attitudes towards forest conservation due to the perceived loss of agricultural land and crop raiding by wild animals and, the current forest management policies that prevent them from deriving short term benefits.

International interest in the conservation of the coastal forest hotspot has increased over the last three decades as the realization of its biodiversity importance deepened (Kelsey and Langton, 1984). A detailed survey of the sacred Kaya forests highlighted their conservation importance for trees and led to a comprehensive survey of the Kenyan coastal forests commissioned by World Wide Fund (WWF) (Robertson, 1987; Robertson and Luke, 1993). These studies focused on the plant species, status of the forest and made recommendation for their conservation. Recently, a series of workshops to develop an Eastern Africa Coastal Forest Programme covering Kenya, Tanzania, and Mozambique were organized to develop a regional synthesis on coastal forest conservation (Younge *et al.*, 2002). They analysed the threats posed to these forest and their root causes, set country conservation targets and developed action plans for each country to enhance their conservation initiatives.

1.2.2 Plants - Pollinators Interactions

Pollination ecology addresses the mechanisms through which plants donate and receive pollen, including floral phenology, floral adaptation, pollinator behaviour, and plant breeding (Wyatt, 1983; Morgan and Schoen, 1997). A great diversity exists in the way plants have adapted their flowers to insect visitation resulting in diversified pollination mechanisms, breeding systems and co – evolution between plants and their animal visitors (Proctor, 1978; Rodger *et al.*, 2004). Biotic pollination is a mutualistic process involving two parties or communities (plants and animals), that can mutually benefit from each other (Proctor, 1978). Animals actively or passively transfer pollen grains, containing the male gametes, from the stamina to the stigmas of the flowers, where the pollen grains can germinate and fertilize the female gamete in the ovule.

Pollination is vital for the successful reproduction of the majority of the world's higher plants (Kearns *et al.*, 1998). Most plant species rely on the intervention of animal vectors to carry pollen from flower to flower and any disruption of this process may lead to diminished seed production (Bond, 1994). Over 91% of the 240,000 angiosperm species worldwide are insect-pollinated (Bawa *et al.*, 1990; Buchmann and Nabhan, 1996). Animal pollinators have been important since the angiosperms evolved, with evidence indicating that early members of the angiosperms were insect pollinated (Crane *et al.*, 1995). The four largest orders of insects, Hymenoptera, Lepidoptera, Diptera, and Coleoptera, include well known species that pollinate flowering plants (Proctor *et al.*, 1996). The total number of pollinator species is unknown, although estimates vary between 130,000 and 300,000 (Shepherd *et al.*, 2003). On larger scales, pollination is an essential ecosystem service that is central to understanding interactions in pollinator networks and food webs, ecosystem function, conservation and restoration biology (Kremen, 2005).

Mutualism between plants and pollinators is ancient, dating at least back to the Cretaceous period (Kearns and Inouye, 1997). From the perspective of the plant, a successful pollinator is an animal that makes contact with the anthers and stigma, moves quickly between plants, and stays faithful to flowers of that species (Feinsinger, 1983; Arroyo *et al.*, 1985). This ensures that the flowers receive the correct type of pollen ensuring fertilization and seed formation, thereby

maintaining the plant's vigour by enhancing gene flow within a plant community (Thomson and Goodell, 2001).

Most plants and their pollinators are involved in generalised interactions, where plants are pollinated by more than one pollinator, and these pollinators interact with more than one plant species (Waser *et al.*, 1996; Olesen, 2000). Other pollinators and plants appear to be highly specialized resulting in a narrow spectrum of host plants or pollinators. Community composition varies between and among habitats, which support different assemblages of pollinators and relationships between a plant species and a pollinator species may change among communities (Kearns and Inouye, 1997).

Pollinators have a strong influence on the patterns of diversification and distribution of the flowering species they associate with, and as such, they are key contributors to biological diversity (Kremen, 2005). The presence of pollinators is also influenced by the spatial structure of the plant population because plant density and distribution affect their movement (Shmidt, 1983, Roubik *et al.*, 1995). The movement of pollinators through the plant population has profound influences on the breeding and genetic structure of the population. The physical architecture of forests is determined mainly by plants, but reproduction to ensure their continued existence is dependent on pollinators, especially in the tropics where many plants are dioecious (Renner and Feil, 1993). To attract pollinators, angiosperms offer floral rewards such as nectar pollen or oils and produce conspicuous flowers. A number of insects group learned to exploit these floral resources but none of them exploit them to such extent as bees (Velthuis, 1992).

1.2.3 Bees and pollination

Among the available pollinator groups, bees have been identified as the single most important pollen vectors that pollinate about 80% of domesticated crops (Free, 1993; Buchmann and Nabhan, 1996). Bees feed their progeny on pollen and nectar from the flowers they forage upon/visit. This behaviour results in pollination, thereby giving them a major role in enabling seed production and determining patterns of gene flow in populations of many flowering plant species (Bronstein *et al.*, 2004). Thus, bees provide a crucial biodiversity related ecosystem service by pollinating many crops and non crop plants (Corbet *et al.*, 1991; Kremen, 2005). Due

to their importance as pollinators, the loss of bee species could dramatically affect the reproduction or fitness of many crops and wild species (Corbet *et al.*, 1991; Klein *et al.*, 2007).

There is an estimated 25,000 bee species worldwide, all of which are obligate flower visitors (Buchmann and Nabhan, 1996; Weislo and Cane, 1996). Globally, the most species rich bee faunas occur in xeric, warm-temperate regions including the Mediterranean basin, the desert regions of the southwestern United States and northern Mexico, central Chile, central Argentina, and much of Australia (Michener, 1979, 2000). Eardley (2002) found 129 bee genera in the sub-Saharan Africa making up an estimated 3000 species. Bees found in the tropical regions have been found to be ecologically diverse (Roubik, 1989) giving the indication that each species potentially pollinates more plant species and may have a greater part in maintaining fertilization in angiosperms than in other regions (Michener, 2000).

In many parts of the world, farmers rely heavily on the pollination services provided by the managed honeybee, *Apis mellifera*, on their farms. Honeybees are easy to handle and manage as well as important in honey production. However, over the last two decades, a major problem has arisen for the world agricultural production reflecting the dangers of relying on a single pollinator species. Great reduction in honeybee colonies has been reported in North America and South Africa (Allsopps, 2003; Ghazoul, 2005). This has been attributed to the introduced parasitic mites (*Acaparis woodi* and *Varroa jacobsoni*) (Krauss and Page, 1995; Allsopps, 2003), reduction of available floral resources outside agricultural areas (Cane and Tepedino, 2001) and unwise usage of pesticides (Torchio, 1990). The resulting decline has produced awareness on the potential role of wild bees in crop pollination and stimulated interest in learning to manage them. Currently, farmers who manage pollination on farms or in glasshouses rely on about 11 of the 25,000 bee species available worldwide (Parker *et al.*, 1987). The ability of wild bees to compensate for a decline in honeybees is considerable, provided less intensive agricultural practices such as reduced pesticides usage and retention of natural habitat within agricultural landscapes are adopted (Banaszak, 1992).

Bees are directly or indirectly essential for an estimated 30% of world's food production (McGregor, 1976). Examples of wild bees already commercially used are *Osmia comiferous*,

which pollinates fruit trees in Japan, *Megachile rotunda*, which pollinates alfalfa (*Medicago sativa* L.) 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 efficient pollinators of eggplants (*Solanum melongena* L.) (Gemmill and Ochieng, 1999). The value of crop pollination by the most important managed pollinator, the honeybee, is estimated to be \$14 billion per year in the USA, R3.2 billion in South Africa (Southwick and Southwick, 1992; Morse and Calderone, 2000). Globally, this service is estimated to have a value at \$200 billion (Richards, 1993). In the USA, pollination by the wild bee species is estimated to be worth \$6.5 billion annually.

Wild bee communities provide an insurance policy in the event of honeybee shortages and may contribute substantially to crop pollination (Parker *et al.*, 1987; Kearns *et al.*, 1998). Different bee species also differ in their efficiency as pollinators both within and among agricultural crops (Freitas and Paxton, 1998). Wild bees have been found to be more efficient pollinators of some crops (Corbet *et al.*, 1991), such as coffee (*Coffea arabica* L.) (Klein *et al.*, 2002), and cashew nuts (*Anacardium occidentale* L.) (Freitas and Paxton, 1998) compared to the honeybees. A diverse bee community provides stable crop pollination services by buffering against temporal fluctuations in abundance between seasons (Klein *et al.*, 2002; Kremen, *et al.*, 2002). Wild bees are responsible for much of the pollination of agricultural crops in the sub-Saharan Africa (Eardly, 2002). A study carried out in Kenya, Ghana and South Africa found that of twelve agro-ecosystems studied, honeybees were the exclusive pollinators in only one agro-ecosystem (Eardly *et al.*, 2004).

The diversity of wild bees in agricultural systems is enhanced by the presence of natural and semi natural habitats, which provide nesting and continuous diverse foraging resource in agricultural landscapes (Corbet *et al.*, 1995; Dramstad and Fry 1995). Expansion of agriculture both in size and in intensity reduces floral resources and nesting habitats available for wild bees, resulting in their decline in the farmlands (O'Toole, 1993). Pollination services by wild bees declined with increasing distance to natural habitats for watermelon (*Citrullus lanatus* Thunb.) in California (Kremen *et al.*, 2004) and coffee in Indonesia (Klein *et al.*, 2003), Brazil, (De Marco and Coelho, 2004) and Costa Rica (Ricketts, 2004). The diversity of pollen vectors providing

pollination services to important crops such as cashew nuts, *Anacardium occidentale*, (Heard, 1990), macadamia (*Macadamia* spp.) (Blanche *et al.*, 2006) and mango (*Mangifera indica*) (Anderson *et al.*, 1982) is also enhanced by the presence of natural vegetation remnants in agricultural lands. Conserving such natural vegetation fragments in human-dominated landscapes would benefit biodiversity generally and make good economic sense in terms of improved crop productivity (Ricketts *et al.*, 2004). This implies that even loss of a small subset of the pollinator community might have economic ramifications.

Loss of ecological processes is less apparent than species loss as a negative consequence of anthropogenic habitat changes, although the loss of processes such as pollination is at least as destructive as physical changes to a natural ecosystem (Kearns and Inouye, 1997). It is important to understand how organisms that perform particularly important ecosystem functions such as pollination, persist in human dominated ecosystems (Winfree, *et al.*, 2007).

All these findings highlight the complexity of the interactions of the farms with the natural habitats as well as the need for greater attention to how populations and communities perform in different habitats. Landscape level factors, such as the amount and distribution of various habitat types, their resources, and their connectivity are critical for maintaining diverse bee populations (Kremen *et al.*, 2002; Williams and Kremen, 2007). There is a need for more studies on the variation of these important pollinator groups among the different habitats in order to come up with proper management strategies.

1.2.4 Interaction among bee species on the floral resources

Bees are completely dependent on flowers for food and bee diversity within a habitat is linked to the diversity of flowering species (Banaszak, 1996). Pollen nectar and oils are the main floral rewards that are collected by bees. Generally, the females of non parasitic bees collect pollen to provision their brood and they require the nutritional protein for egg production (Michener, 2000; Proctor *et al.*, 1996).

Most bees forage on nectar from a wide range of plant species than they do to meet their pollen needs (Buchmann and Nabhan, 1996; Waser *et al.*, 1996). There are two broad classifications of bees based on their foraging preferences. Oligolectic bees restrict their pollen foraging to plants

within a particular family (Wcislo and Cane 1996). These species are typically solitary and have a relatively short adult lifespan that must be synchronized with the blooming period of floral hosts (Cane 2001). Most social bees are polylectic; they forage on a wide range of unrelated or distantly related plant species and have a long adult life span (Wcislo and Cane, 1996). Social species tend to generalize because maintenance of colony life requires that multiple resources be exploited throughout the active season (Michener, 2000).

The social bees are more generalized in their foraging behavior than the solitary bees and consequently they have a larger foraging range (Diego and Simberloff, 2005). The range of resources utilization influences patterns of diversity among communities as species that utilize a wide range of resources have wider distribution range (Krebs, 1996). While the most common social bee, the honeybee, is known to forage on over 40,000 flowering plant species, little is known of the foraging range and floral preference of the numerous solitary bee species (Crane, 1990). The large numbers of honeybees in some habitats may make them important competitors for a great diversity of wild plant species. Sugden and Pyke, (1991) found that honeybees decreased the foraging success of native pollinators by out competing them for resources. They also found that the number of native bees declined with the introduction of honeybees in Australia.

Bees are affected strongly by interspecific competition for the high quality food resources provided by flowering plants to attract pollinators (Corbet *et al.*, 1995; Sugden *et al.*, 1996). Competition among the bee species disrupts the natural composition of the community and is likely to have negative effects of the reproduction of the native vegetation. The ability of honeybees to out-compete other bee species stems from their ability to locate and dominate food source quickly, presumably because of their large number of workers that can search for food and successfully recruit colony members (Roubik, 1980). Schaffer *et al.* (1983) found that honeybees excluded their rivals from the most productive sites by active interference or by reducing the amount of nectar available in the most productive sites to very low levels. However, even in cases where there is clear indication that honeybees interfere with the foraging behaviour of the wild bees their effect on the population size of the native bees is still ambiguous (Roubik *et al.*, 1986; Aizen and Feinsinger, 1994).

1.2.5 Threats to bee populations

Despite their importance of bees as pollinators, several studies have shown that the numbers of native species are dwindling (Frankie *et al.*, 1997). The fragmentation of large natural habitats into smaller fragments results in the creation of 'ecological traps' from which pollinators cannot escape due to short flight capacities or high predation risks while crossing between two adjacent fragments (Battin, 2004). Habitat alteration by agricultural, grazing and infrastructure development of areas that once supported wild vegetation cause loss of native food plants and nesting sites used by pollinators. With the intensification of agriculture, wild pollinators are increasingly being threatened by human land use practices that result in the loss of their nesting grounds and loss of larval host plants through the introduction of exotic plant species (Kremen and Ricketts, 2000). Bees may depend on native plants because they are not always able to access food rewards from introduced flowers (O'Toole, 1993). The loss natural habitats results in decreased bee diversity due to the depletion of the resources such as nectar pollen and nesting sites (Aizen and Feinsinger, 1994). Extensive usage of pesticides and herbicides on the farmlands causes high bee mortalities as well as reduces the flowering weedy species that provide alternate floral resources to bees after the mass flowering crops are harvested. Kremen *et al.* (2002) and Holzschuh *et al.* (2007) found that the farms that used no pesticides and herbicides had higher bee diversities than those where chemicals were used.

1.3 Justification

As the primary group of pollinators, bees provide valuable environmental services in many natural and agricultural ecosystems. By pollinating over half of the world's flowering plants, bees contribute to habitat preservation, erosion prevention, and carbon storage. In addition, they also pollinate over 30% of the crops grown for human consumption. Despite the role, they play in ecosystem functioning bee populations are declining at an alarming rate in many habitats all over the world. The presence of large natural forests at close proximity to the agricultural lands has been found to provide a diverse pollinator community to the crops on these farms. A diverse bee community improves the quantity and quality of the farms produce, effectively increasing the farmers' earnings. A study of the bee fauna of the Kakamega forest, a key biodiversity hot spot in western Kenya, revealed a highly diverse bee community inside the forest and in the

surrounding farmlands. The forest had a higher diversity of bees than the farmlands (Gikungu, 2006). Little research has been carried out on the bee fauna of the Arabuko Sokoke forest despite the presence of a diverse community of butterflies. The Arabuko Sokoke forest is surrounded by a large community of subsistence farmers whose main income is the proceeds from their crop such as mangoes, cashew nuts, and coconuts. It is important to demonstrate the important role of the forest in provisioning a diverse community of pollinators to their crops to ensure maximum yields. This in turn can result in improved earning from their crops without incurring additional expenses. These services can only be enjoyed through the conservation of the forest. As the local communities are the main custodians of the forest as per current forest bill, a demonstration of how the continued conservation of the forest can enhance their income in terms of improved crop yields, would ensure their cooperation in its preservation.

1.4 Research Hypothesis

The hypotheses of the study were,

1. The forest margins have higher bee diversity than the farms located along a distance gradient from the Arabuko Sokoke forest
2. Overlap in resource utilization between the honeybees and the solitary bees is higher in the farmlands than at the margins of the Arabuko Sokoke forest.

1.5 Objectives

- i) To investigate the change in bee diversity along a distance gradient from the forest margins of the Arabuko Sokoke forest.
- ii) To compare bee diversity among the three vegetation types of the Arabuko Sokoke forest
- iii) To investigate the floral utilization and resource partitioning between the solitary bees and the honeybees along a gradient from the forest margins of the Arabuko Sokoke forest.

CHAPTER TWO

2.0 MATERIALS AND METHODS

2.1 Study Area

2.1.1 Location and Forest Management

The Arabuko Sokoke is the largest single block of indigenous coastal forest (approximately 41,600 hectare) remaining in East Africa. It is situated in coastal province of Kenya and transverses Kilifi and Malindi districts. It lies between 3° 20' S and 39° 50' E (ASFMT, 2002), to the west of Mombasa – Malindi highway between Kilifi and Malindi towns (Figure 1). In 1932, 39,105 ha of forest land were set aside as crown forest and declared a forest reserve managed by forest department in 1943. A further 2,676 hectares were added at the Kararacha area in 1968. A nature reserve of 2,700 hectares was set aside within the forest in 1977 and expanded with a further 1,635 hectares in 1979. The forest is currently managed by a team of five strategic partners; the Arabuko Sokoke Forest Management Team (ASFMT), whose key players are the Kenya Forest Service (KFS), Kenya Wildlife Service (KWS), Nature Kenya (NK), the Kenya Forestry Research Institute (KEFRI) and the National museums of Kenya (NMK). These organizations work closely with the local community in a program termed Participatory Forest Management (PFM), which is proving to be highly effective.

2.1.2 Rainfall and Temperature

The annual rainfall varies from less than 600 mm in the North West part of the forest to over 1000 mm at Gede in the east. Rainfall is bimodal in pattern, beginning from April to June, with a second period of rainfall during the months of November and December. January and February are the driest months. Temperatures remain high for the most part of the year with a daily mean of 25°C, with little monthly variation. March is usually the hottest month. Humidity remains high all year round due to the proximity to the Indian Ocean (ASMT, 2002).

2.1.3 Topography and Soils

The eastern part of the forest lies on a flat coastal plain with land rising gradually from sea level to peak at an altitude of 210 metres (Robertson and Luke, 1993) in the central and western parts of the forest. The soils predominantly sandy with low carbon content and are slightly acidic (pH

= 5.1 ± 0.8) (Robertson and Luke, 1993). On the eastern side of the forest, soils are whitish, light and airy- the “sosoni” soils. The western side has dark red, well drained, and relatively infertile soils – the “magarini” soils. There are no permanent water sources in the forest. A series of temporary pools run along the divide of the two soil types with a few other pools scattered mainly in areas of the “sosoni” soils. Two rivers flow close to the forest boundaries: Dida – Rare to the south west and Sabaki to the north.

2.1.4 Flora

At least 585 plant species are found in the forest (Robertson, 1999) including 50 globally or nationally rare plants. The forest is divided into three vegetation types (Figure 1), related to various factors such as soils type and rainfall distribution as one moves inland.

i) Mixed Forest — this is a dense forest covering about 7,000 ha on the wetter coastal sands at the eastern side of the Arabuko Sokoke forest. It has a diverse tree flora including *Azelia quanzensis* Welw., *Hymenaea verrucosa* Guertn. *Combretum schumannii* Engl. and *Manilkara sansibarensis* Engl. and *Lannea stuhlmanni* Engl.

ii) Brachystegia Forest — this is a more open forest covering about 7,700 ha and is dominated by *Brachystegia spiciformis* Benth, *Teclea trichocarpa* Engl., *Azelia quanzensis* Welw., and *Manilkara sansibarensis* Engl., on the drier and infertile white sands through the centre of the forest

iii) Cynometra Forest — this is a dense forest or thicket on the north-west side of Arabuko-Sokoke, covering about 23,500 ha on the red “magarini” sands towards the western side of the forest. It is dominated mainly by *Cynometra webberi* Bak. f. and *Manilkara sulcata* Engl. *Brachylaena huillensis* O. Hoffin., was quite abundant in this zone, but its numbers have been severely reduced by extraction. (Ayiemba, 1997; Chira, 1993; ASFMT, 2002)

2.1.5 Fauna

The forest supports a diverse assemblage of fauna. There are at least 234 bird species (Britton and Zimmerman, 1979). Six bird species of conservation interest are Clarke’s weaver (*Ploceus golandi*) (endemic to the forest and its neighbourhood) Amani Sunbird (*Anthrepetes pallidigaster*), Sokoke Pipit (*Anthus sokokensis*) (all of which occur in this forest and a few forest patches in Tanzania) Sokoke Scops owl (*Otus ireneae*), the Spotted Ground Thrush (*Turdus fischeri*) (a rare non-breeding visitor) and the East Coast Akalat (*Sheppardia gunningi*).

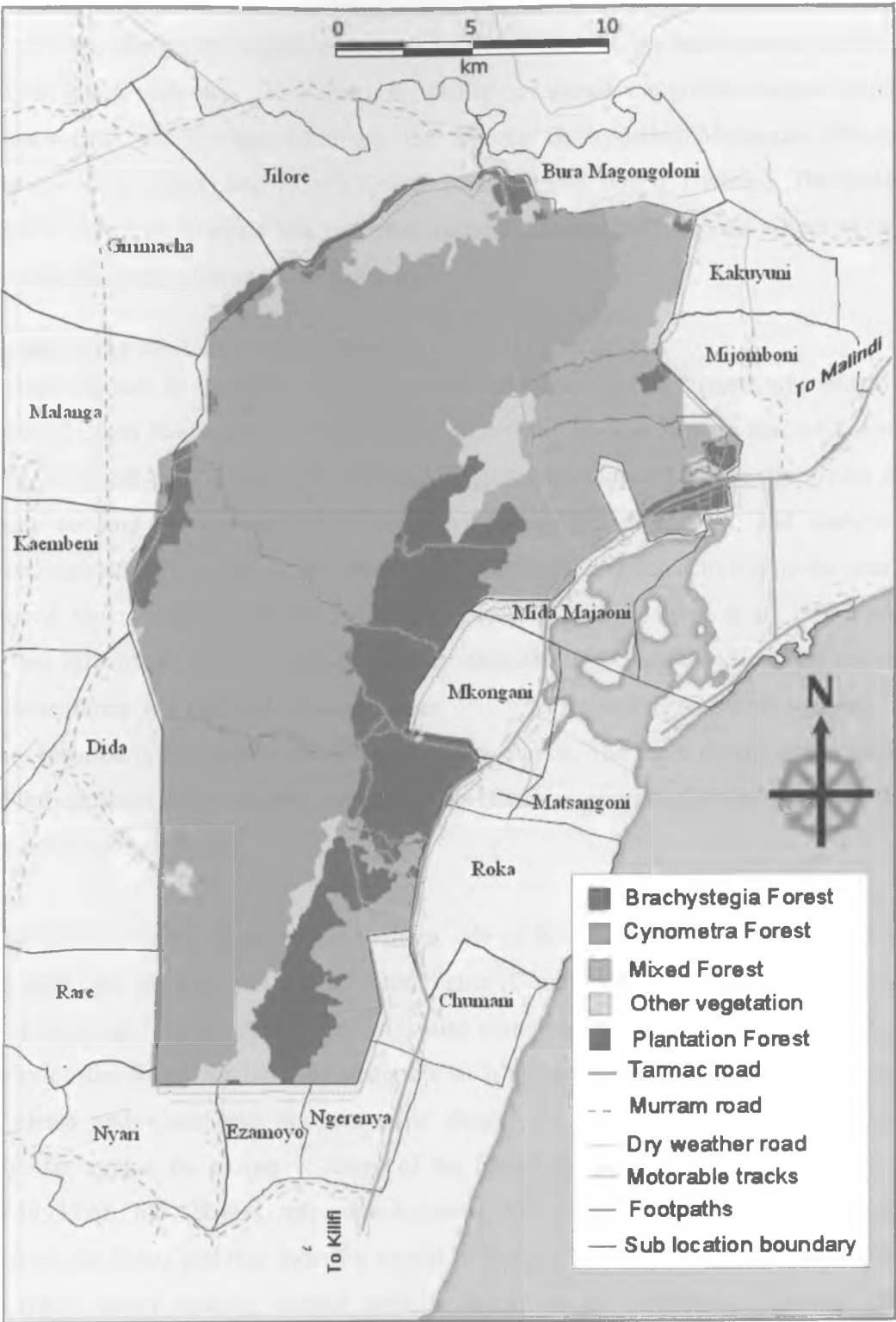


Figure 1 Vegetation types found within the Arabuko Sokoke forest.

In addition 17 birds species are endemic the coast region. Fifty-two mammal species have been recorded in the forest, including 3 taxa that are globally threatened: the golden-rumped elephant shrew (*Rhynchocyon chrysopygus* Gunther), the Sokoke Bushy-tailed Mongoose (*Bleogale crassicauda omnivora* Heller) and Ader's Duiker (*Cephalophus adersi* Thomas). The forest is also a refuge for some of Kenya's less common mammal species and supports a herd of about 100 elephants (*Loxodonta Africana* Blumenbach).

2.1.6 Threats to the Arabuko Sokoke Forest

The population adjacent to the forest is mostly small scale subsistence farmers who utilise the forest for some of their livelihood (ASFMT, 2002). The main crops grown are maize (*Zea mays* L.), cassava (*Maniholt esculentum*), and cowpeas (*Vigna unguiculata* L.). Locally grown cash crops include coconut (*cocos nucifera* L.), mango (*Mangifera indica* L.), and cashew-nut (*Anacardium occidentale* L.). Due to low rainfall and poor soils, farming activities in the area are greatly reduced. Most of the households own 12 acre pieces of land (Maundu *et al.*, 1997), which are largely left fallow and used as pasture for their animals. The mango and cashew nut trees found on these farms are old and disease ridden owing to neglect (Pers. Observation). This therefore has resulted in heavy reliance on the forest resources. The main threats include illegal logging of the commercially valuable trees such as *Azalia quazensis*, *Brachylaena huillensis*, and *Manilkara sansibarensis*.

Charcoal burning is a great threat on the western side of the forest where there are relatively fewer trees on private land and poverty level are higher (Gordon and Ayiemba, 2003). Poaching of smaller animals such as the Ader's duiker is also commonplace. The local community also relies heavily on the forest for building materials such as poles. Illegal extraction of valuable medicinal plants and vines also poses a great danger to the conservation of the forest's biodiversity. To combat the extractive usage of the forest resources, the Kipepeo project was initiated in 1993 (ASFMT, 2002; Gordon and Ayiemba, 2003). Farmers under this project collect butterflies from the forest and rear them for export in Europe. Though the project has expanded to include other money making venture such as apiculture and mushroom farming, illegal extractive uses of the forest is still a major setback in its conservation.

2.1.7 Farmland Characteristics

The acreage of the farmlands used in this study ranged from 6 to 12 hectares. Due to the prevailing dry conditions at the coastal region little or no farming activities was going on in the farmlands. The main crops in the farmlands selected along a gradient from the *Cynometra* forest margins were mango and cashew nut trees. No tilling activities occurred in these farmlands and sheep and goats were left to roam free on a daily basis. The farmland selected at 2 km from the mixed forest margins was an abandoned mango orchard that served as pastureland for goats and sheep. Cowpeas and cassava were the main crops grown in the other two farmlands and they did not serve as pasture lands. Cowpea was the main crop grown in the farmland located 2 km from the *Brachystegia* forest and cows were occasionally grazed after harvesting, the farm was tilled towards the end of the study and maize planted. No tilling took place in the other two farmlands, which were dominated by old cashew nut trees. The flowering weedy species found in all the farmlands provided a rich source of food for all the bees and other agents of pollination such as the butterflies, flies, butterflies, and beetles.

2.2 The study design

The three main vegetation types found within the Arabuko Sokoke forest namely the *Brachystegia*, *Cynometra* and the mixed forests were selected for the study. Each vegetation type had four sampling sites, one sampling site at the forest margin and three sampling sites located in farmlands selected along a distance gradient from the forest margin at 2 km, 4 km, and 6 km respectively (Figure 2). All the distances were measured with a global positions system unit (GPS).

2.2.1 Sampling bees

Field observations took place between 0800 and 1500 hrs, the period of maximum bee activity. Sampling sessions were blocked into four 2-hour sessions: 0800 - 0900, 1000 - 1100, 1200 - 1300, and 1400 - 1500 hrs. At each site, ten flowering patches were conveniently identified in open areas with little or no canopy cover and assigned numbers 1-10. A table of random numbers was used to select four patches on which sampling was carried out. Each flowering patch was used only once during a sampling session. Areas with large trees were avoided as light intensity influence the presence of some bee species (Klein *et al.*, 2002). Each of the four sites within each vegetation block was sampled for four consecutive days in a factorial experimental design in which only the main effects i.e distance from the forest margins, the vegetation type, and time.

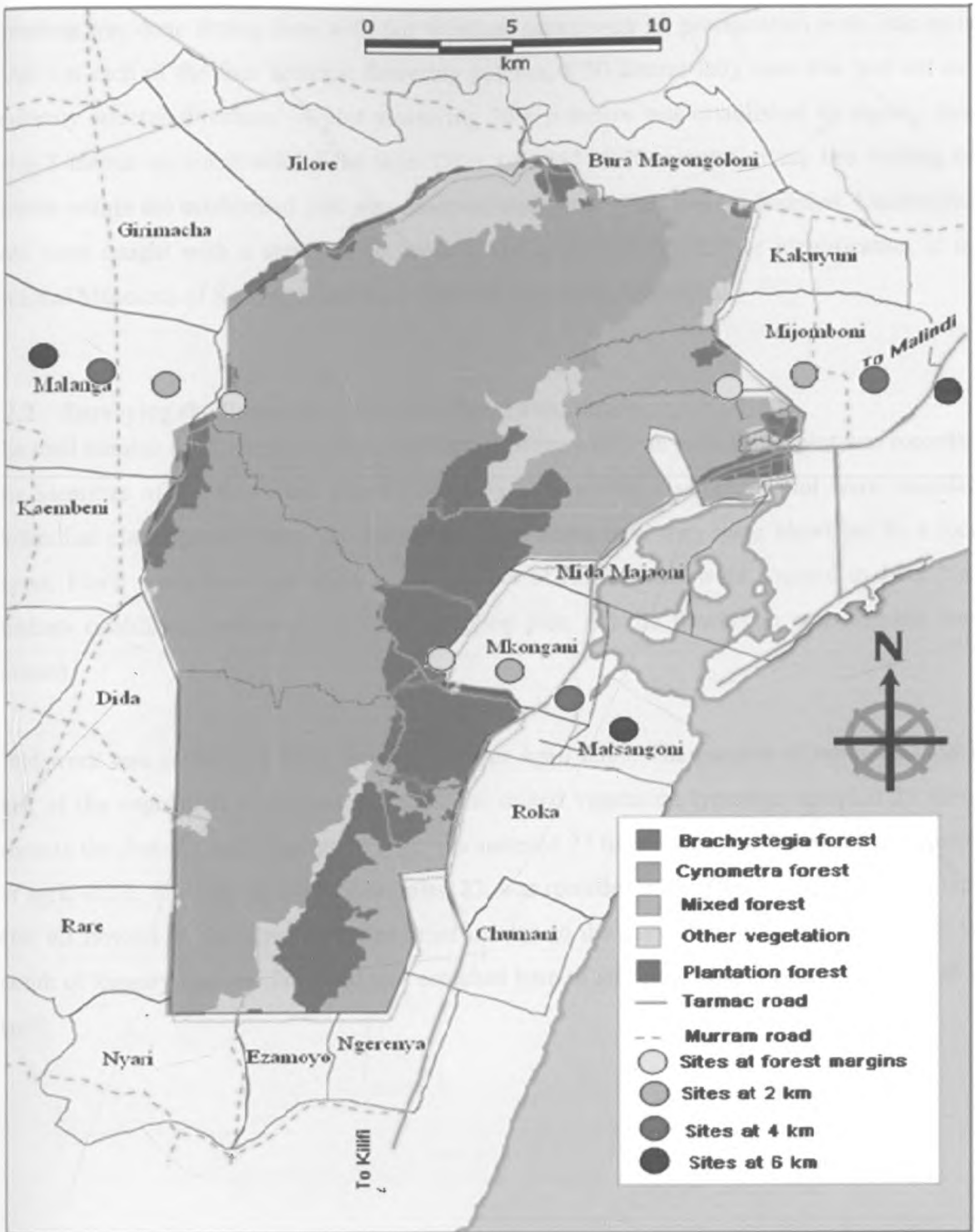


Figure 2 Location of the sampling sites along a distance gradient from the Arabuko Sokoke forest

Sampling was done during days with fair weather, sunny with no precipitation with little or no wind. On each of the four selected flowering patches, a 50 metres long tape was laid out in a randomly selected direction. A plot measuring 50 x 6 metres was established by staking short poles 3 metres on either side of the tape. Over a period of 20 minutes, every bee visiting the flowers within the established plot was observed and listed when easily identified. Unidentified bees were caught with a standard net, coded, and preserved for further identification at the National Museums of Kenya, where the collection is currently deposited.

2.2.2 Surveying the flowering plants and floral abundance

The total number of flowering species and their identity within an established plot was recorded. The identities of the flowering plants visited by bees within a sampling plot were recorded. Unfamiliar plant species were also assigned a code name until they were identified by a local expert. Floral cover was quantified as the number of flowers that were counted in 10 x 1 m² quadrats established randomly within a sampling plot. All the flowers in each quadrat were counted.

Field work was carried out from October 2007 to April 2008. The number of sampling days in each of the vegetation types was unequal. The mixed vegetation type was sampled 28 times, whereas the *Brachystegia* vegetation type was sampled 27 times, after one farmland was cleared for agriculture. The least number of samples, 23, was recorded in the *Cynometra* vegetation type, after all flowers in the forest margins dried up due to the prevailing dry conditions from the month of January and one farmland was scotched bare of any flowering species in the month of April.

2.3 Data Analysis

In this study, data were analysed with SPSS 11.5 for Windows. Data were tested for normality using the Kolmogorov – Smirnov goodness of fit (Zar, 1984) and were found to be non-normally distributed. The number of bee species and abundance occurring in each sampling plot were subjected to Kruskal-Wallis test to reveal any significant differences across the distance gradient from the forest margins and among the three vegetation types. The number of flowers in 10 m² quadrat in each sampling plot was tested for variation across the distance gradient from the forest margin and among the three vegetation types using kruskal-Wallis test. The numbers of honeybees, solitary species, and abundance of each of the bee family in each sampling plot were also tested for variation along the distance gradient from the forest and among the vegetation types using the Kruskal - Wallis test

Bee diversity in each sampling plot was calculated using Shannon index (Magurran, 1988). Kruskal Wallis was then used to test for variation across the distance gradient from the forest margins and amongst the vegetation types.

The Shannon diversity index, was calculated as,

$$H' = -\sum p_i \ln p_i,$$

Where,

$$p_i = \text{the proportional abundance of the } i\text{th species } (p_i = n_i / N)$$

Pair-wise comparison of similarities in bee species composition between the farmlands and the forest margins was calculated using Horn's index, R_o , (Horn, 1966). Pair-wise comparison of bee species composition was also carried out between the three vegetation types. This index calculates the probability that specimens drawn from two sites will be of the same species, relative to the probability that specimens randomly drawn from the same site will be of the same species. Horn's index is relatively little affected by sample size (Krebs, 1996). Whereas R_o values were defined as follows: No similarity (0), Low similarity (0.55 – 0.60), moderately similar (0.6 – 0.75), highly similar (0.75 - 0.99), and equal (1.0).

Horn's index formula:

$$R_o = \frac{\sum [(X_{ij} + X_{ik}) \log (X_{ij} X_{ik})] - \sum (X_{ij} \log X_{ij}) - (X_{ik} \log X_{ik})}{[(N_j + N_k) \log (N_j + N_k)] - (N_j \log N_j) - (N_k \log N_k)}$$

Where,

R_o = Horn's index of similarity for samples j and k

X_{ij}, X_{ik} = Number of individuals of species i in sample j and sample k respectively.

$N_j = \sum X_{ij}$ = Total number of individuals in sample j

$N_k = \sum X_{ik}$ = Total number of individuals in sample k

Family visitation index was calculated on a 10 point scale. The plant species visited by bees in each site were grouped in accordance to their families and the family visited by the most number of individuals was assigned a score of 10 points, 9 points for the second most visited family, and so on. Addition of the rank point per plant family across all the sampling sites gave the visitation index.

Trophic niche overlap (NO) was calculated using Morisita Index (Krebs, 1996), this index is one of the most commonly used measures of niche overlap.

$$C_H = \frac{2 \sum_i P_{ij} P_{ik}}{\sum_i P_{ij}^2 + P_{ik}^2}$$

Where,

C_H = Morisita index of overlap between bee species j and species k

P_{ij} = Proportion of resource i is of the total resources used by species j

P_{ik} = Proportion of resource i is of the total resources used by species k

n = Total number of resources states (i = 1, 2, 3,n)

CHAPTER THREE

3.0 RESULTS

3.1 Bee abundance and diversity

Overall, 6,350 bees from 63 species belonging to three families: Apidae, Halictidae and Megachilidae, were recorded in this seven-month study (Appendix 1). The Apidae family was the most dominant (77%), whereas Halictidae and Megachilidae comprised 18% and 5%, respectively. The Apidae family also had a higher number of species collected (32), compared with Halictidae (17) and Megachilidae (14) (Appendix 2-4). The honeybee (*A. mellifera*), was the only social species recorded and was the most dominant species. When all the samples were pooled, a Shannon diversity index of 2.96 was obtained. There was a significant monthly variation in the number of bees and species collected per sampling plot during the study ($H = 13.18$, $df = 6$, $P = 0.04$) and ($H = 30.34$, $df = 6$, $P < 0.01$), respectively. The least number of species and bee abundance per plot were recorded in the month of April (Table 1).

Table 1 Mean number of bee and species per sampling plot (\pm SE) in the seven months of the study around the Arabuko-Sokoke forest (October 2007–April 2008)

Month	Mean \pm S.E		n
	No. of bees	No. of bee species	
October	26 \pm 3.1 ^a	8 \pm 0.8 ^a	48
November	23 \pm 2.6 ^a	7 \pm 0.6 ^a	48
December	23 \pm 2.5 ^a	6 \pm 0.6 ^a	48
January	21 \pm 2.4 ^a	7 \pm 0.6 ^a	44
February	17 \pm 2.0 ^b	5 \pm 0.6 ^b	44
March	16 \pm 2.4 ^b	5 \pm 0.6 ^b	44
April	15 \pm 2.6 ^b	4 \pm 0.5 ^c	36

3.2 Bee abundance and diversity across a distance gradient from the forest margins

There was significant difference in bee abundance across a distance gradient from the forest margins ($H = 15.06$, $df = 3$, $P < 0.01$). The number of bee species also differed significantly across the distance gradient from the forest margins ($H = 14.20$, $df = 3$, $P < 0.01$). The forest

margins had low mean number of bees recorded per sampling plot, while the least number of species was recorded in the farmlands that were furthest from the forest margins (Table 2).

Table 2 Mean number of bees and species per sampling plot (\pm S.E) across a distance gradient from the Arabuko-Sokoke forest margins (October 2007–April 2008).

Site	Mean \pm S.E		
	No. of bees	No. of species	n
Forest margin	15 \pm 1.9 ^b	6 \pm 0.6 ^a	68
2 km	21 \pm 1.5 ^a	7 \pm 0.4 ^a	76
4 km	25 \pm 2.0 ^a	7 \pm 0.4 ^a	84
6 km	20 \pm 2.2 ^a	5 \pm 0.4 ^b	84

There was a significant change in species diversity across the distance gradient from the forest margins ($H = 19.39$, $df = 3$, $P < 0.01$). The farmlands that were located furthest from the forest margins had lower bee diversity (Table 3).

Table 3 Mean bee diversity per sampling plot along the distance gradient from the Arabuko Sokoke forest margins.

Site	Mean Shannon index
Forest margin	1.13
2 km	1.53
4 km	1.42
6 km	1.05

3.2.1 Bee composition along a distance gradient from the forest margins

Pair-wise comparison of the forest margins and the farmlands using Horn's index revealed a high similarity in the bee fauna across a distance gradient from the Arabuko Sokoke forest. The farmlands located furthest from the forest had a lower similarity index with the forest margins than the farmlands that were located nearer to the forest (Table 4). The similarity index was higher between the farmlands.

Table 4 Similarity in species composition along the distance gradient from the Arabuko Sokoke forest, based on Horn's similarity index.

	Forest Margin	2 km	4 km	6 km
Forest Margin	1	0.87	0.89	0.83
2 km		1	0.92	0.91
4 km			1	0.94
6 km				1

To reveal further variation in bee composition along the distance gradient, bees were separated on the basis of their social organization. A significant difference in the abundance of the social honeybees and solitary bees occurred across a distance gradient from the forest margins ($H = 9.93$, $df = 3$, $P = 0.02$), and ($H = 15.70$, $df = 3$, $P < 0.01$) respectively. A higher number of both honeybees and the solitary bees were found at the farmlands except those located at 2 km from the forest margins (Table 5).

Table 5 Mean number of honeybees and solitary bees per sampling plot (\pm S.E) along a distance gradient from the Arabuko-Sokoke forest margins (October 2007–April 2008).

Site	Mean \pm S.E		n
	Honeybees	Solitary bees	
Forest margin	4 ± 0.9^a	11 ± 1.4^a	68
2 km	4 ± 0.7^a	7 ± 1.2^b	76
4 km	9 ± 1.3^b	16 ± 1.1^a	84
6 km	5 ± 1.3^a	15 ± 1.4^a	84

At the genus level, four of the five major bee genera encountered were had a very low abundance at the farmlands that were furthest from the forest margins (Figure 3).

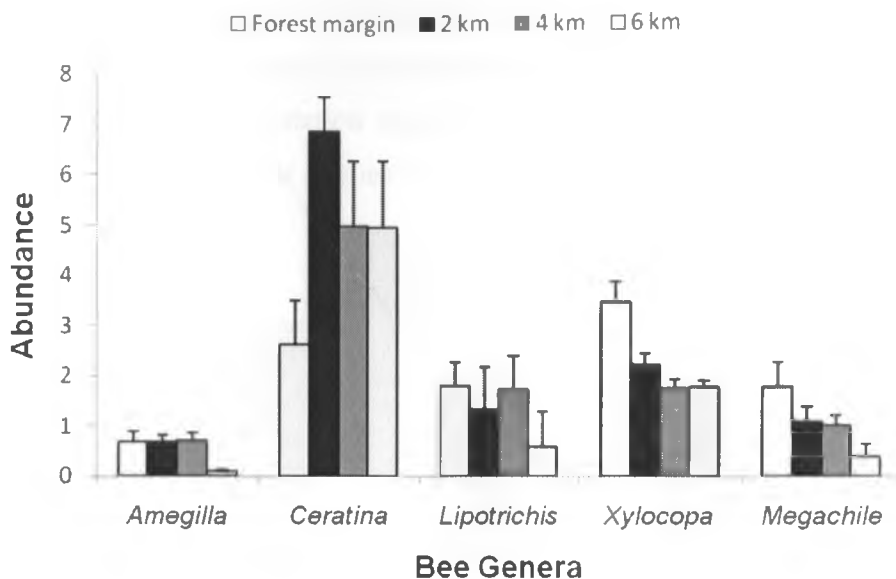


Figure 3 Mean abundance (\pm SE) of five bee genera across a distance gradient from the Arabuko Sokoke forest

3.3 Bee abundance and diversity among the three vegetation types

Among the three vegetation types, there was a significant difference in the number of bee species ($H = 10.171$, $df = 2$, $P < 0.01$). Each vegetation type constituted of the forest margin sites and the adjacent farmlands along a distance gradient. There was also a significant difference in bee abundance among the three vegetation types ($H = 37.993$ $df = 2$, $P < 0.01$). The *Brachystegia* vegetation type had low number of bees per sampling plot (Table 6), compared to the other vegetation types, while the *Cynometra* vegetation type had the least number of species.

Table 6 Mean number of bees and species per sampling plot (\pm S.E) in the three vegetation types of the Arabuko-Sokoke forest (October 2007–April 2008)

Vegetation type	Mean \pm S.E		
	No. of bees	No. of species	n
Mixed	29 \pm 1.9	7 \pm 0.4	112
<i>Brachystegia</i>	15 \pm 1.2	6 \pm 0.5	108
<i>Cynometra</i>	16 \pm 1.4	5 \pm 0.4	92

There was no significant variation in species diversity among the three vegetation zones ($H = 2.97$, $df = 2$, $P = 0.22$). The mixed vegetation type however, had a high mean bee diversity compared to the other two vegetation types (Figure 3). The *Cynometra* and *Brachystegia* vegetation types had almost similar species diversity index.

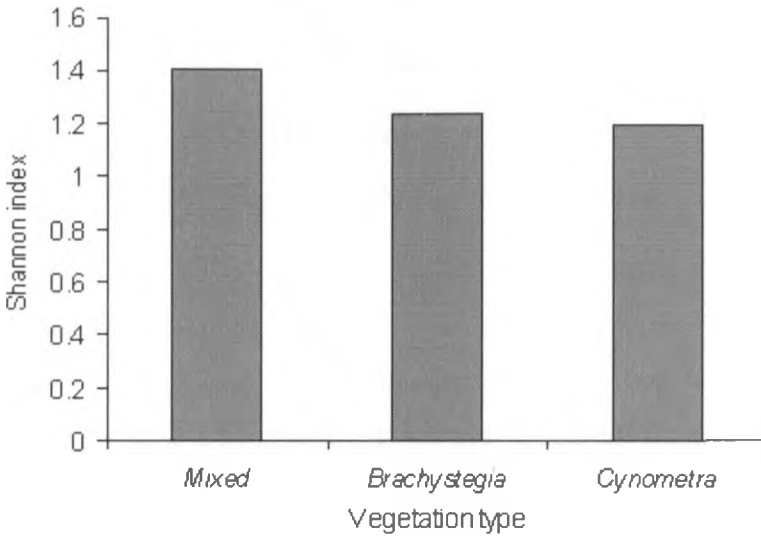


Figure 4 Mean bee species diversity among the three vegetation types of the Arabuko Sokoke forest (October 2007 – April 2008).

3.3.1 Bee composition among the three vegetation types

Pair-wise comparison of the vegetation types using Horn's similarity index revealed a high similarity in their bee fauna composition, the highest similarity occurred between the mixed and *Cynometra* vegetation zones (Table 7).

Table 7 Similarity in species composition among the three vegetation types of the Arabuko Sokoke forest, based on Horn's similarity index.

	<i>Brachystegia</i>	Mixed	<i>Cynometra</i>
<i>Brachystegia</i>	1	0.82	0.85
Mixed		1	0.95
<i>Cynometra</i>			1

Separation of the bees into the honeybees and solitary bees revealed a significant difference in their abundance among the three vegetation types, honeybees ($H = 38.52$, $df = 2$, $P < 0.01$) and

solitary bees ($H = 20.79$, $df = 2$, $P = 0.01$). Both the honeybees and the solitary bees were more abundant in the mixed vegetation type compared to the other vegetation types (Table 8).

Table 8 Mean number of honeybees and solitary bees per sampling plot (\pm S.E) in the three vegetation types of the Arabuko-Sokoke forest (October 2007–April 2008).

Vegetation type	Mean \pm S.E		n
	Honeybees	Solitary bees	
Mixed	10 ± 1.2^c	19 ± 1.2^b	112
<i>Brachystegia</i>	1 ± 0.4^a	13 ± 1.1^a	108
<i>Cynometra</i>	5 ± 1.0^b	11 ± 0.8^a	96

There was a significant difference in the abundance of two bee families among the three vegetation types, Apidae ($H = 67.07$, $df = 2$, $P < 0.01$), Halictidae ($H = 11.96$, $df = 2$, $P < 0.01$), but the abundance of the family Megachilidae did not differ significantly among the vegetation types ($H = 4.73$, $df = 2$, $P = 0.1$). Low abundance of family Apidae bees was found per sampling plot in the *Brachystegia* vegetation type, while there was a low abundance of family Halictidae bees in both *Cynometra* and mixed vegetation types (Table 9). The abundance of megachilid bees did not vary among the vegetation types.

Table 9 Mean number of individuals in the three bee families per sampling plot (\pm S.E) in the three vegetation types of the Arabuko-Sokoke forest (October 2007–April 2008).

Vegetation Type	Mean \pm S.E		
	Apidae bees	Halictidae bees	Megachilidae bees
<i>Brachystegia</i>	8 ± 0.8^a	5 ± 0.6	1 ± 0.2
<i>Cynometra</i>	13 ± 1.2^b	3 ± 0.4	1 ± 0.1
Mixed	25 ± 1.7^c	3 ± 0.3	1 ± 0.1

3.4 Floral resource utilization across a distance gradient from the forest margins

The number of flowers, quantified in 10 m^2 quadrant per sampling plot, differed significantly across the distance gradient from the forest margins ($H = 22.78$, $df = 3$, $P < 0.01$), while the

number of flowering species did not differ significantly across the distance gradient from the forest margins ($H = 6.17$, $df = 3$, $P = 0.104$). However the number of flowering species utilized by bees differed significantly across the distance gradient ($H = 22.05$, $df = 2$, $P = 0.02$). The forest margins had low mean number of flowers and flowering species per sampling plot (Table 10).

Table 10 Mean flower abundance and the number of flowering species per plot (\pm S.E) along a distance gradient from the Arabuko-Sokoke forest margins (October 2007 – April 2008).

Site	Mean \pm S.E		
	Flowers/10 m ²	Plant species	Utilized species
Forest margin	396 \pm 44.7 ^a	7 \pm 0.4	5 \pm 0.9 ^a
2 km	496 \pm 35.5 ^b	8 \pm 0.4	4 \pm 0.6 ^a
4 km	694 \pm 62.2 ^b	8 \pm 0.4	6 \pm 0.5 ^a
6 km	541 \pm 48.9 ^b	8 \pm 0.5	7 \pm 0.7 ^b

The number of flowers and flowering species also differed significantly among the three vegetation types ($H = 22.22$, $df = 2$, $P < 0.01$) and ($H = 62.29$, $df = 2$, $P < 0.01$). The *Brachystegia* vegetation type had low number of flowers and flowering species recorded per sampling plot compared to the other vegetation types (Table 11).

Table 11 Mean number of flowers and flowering species per sampling plot (\pm SE) in the three vegetation types of the Arabuko-Sokoke forest (October 2007–April 2008)

Vegetation block	Mean \pm S.E	
	Flowers /10 m ²	Flowering species
Mixed	795 \pm 56.1 ^b	9 \pm 0.3 ^b
<i>Brachystegia</i>	342 \pm 22.3 ^a	7 \pm 0.3 ^a
<i>Cynometra</i>	464 \pm 28.7 ^a	7 \pm 0.4 ^a

There was a significant monthly variation in the number of flowers and flowering species available during the study, ($H = 51.626$, $df = 6$, $P < 0.01$) and ($H = 34.935$, $df = 6$, $P < 0.01$),

respectively. The month of April had the lowest number of flowers as well as the number of flowering species available (Table 12).

Table 12 Mean flower abundance and flowering species (\pm SE) per sampling plot in the seven months of the study around the Arabuko-Sokoke forest (October 2007–April 2008)

Month	Mean \pm S.E	
	Flowers /10 m ²	Flowering species
October	702 \pm 82.6 ^b	9 \pm 0.4 ^c
November	628 \pm 62.6 ^b	9 \pm 0.5 ^c
December	563 \pm 46.0 ^b	8 \pm 0.5 ^c
January	561 \pm 78.2 ^b	9 \pm 0.6 ^c
February	554 \pm 36.2 ^b	7 \pm 0.5 ^b
March	538 \pm 43.5 ^b	6 \pm 0.4 ^a
April	405 \pm 86.5 ^a	5 \pm 0.5 ^a

There was a variation in the number of bees visiting different plants families. The main plant families utilized were, Polygonaceae, Compositae, Amaranthaceae, Commelinaceae, and Acanthaceae (Figure 4). These five plant families were visited by over 75% of all the bees encountered during the study. A summary of bee visitation on all plant families is presented in Appendix 5.

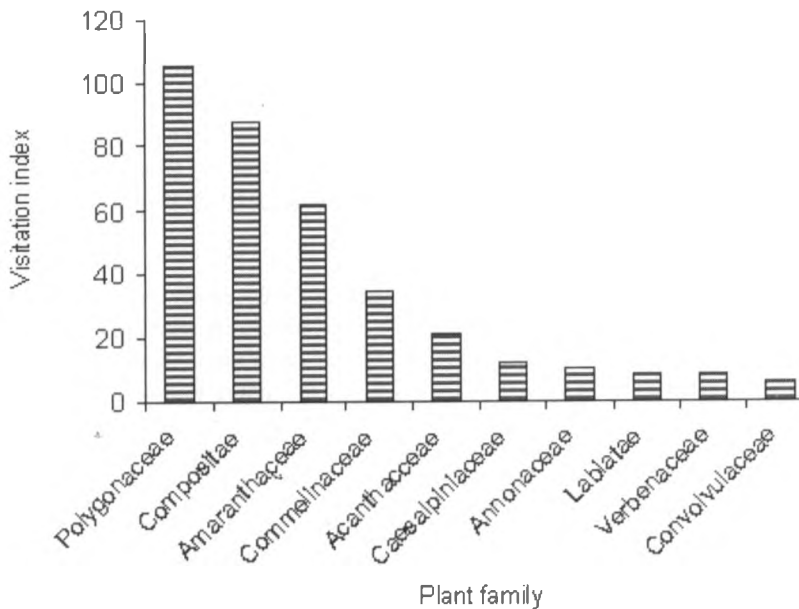


Figure 5 Ranking of plant families according by their utilization by bees species around the Arabuko Sokoke forest

Bees were observed to collect nectar or pollen from 60 of the 114 flowering plant species around the Arabuko Sokoke forest margins and the adjacent farmlands. Shrubs and herbs were the most frequently visited plants at the farmlands. *Oxygonum sinautum*, *Hermennia exappandeculata*, *Polygonum aviculare*, *Tridax procumbens*, and *Erlangea cordifolia* were the five most heavily utilized weedy species. These weedy species were well established in the untilled farmlands as well as in the forest margins. Other important plants visited by bees included *Blepharis maderaspatensis*, *Cassia* sp., and some woody species such as *Uvaria lucida*, *Grewia plagiophylla*, *Manilkara sansibarensis*, and *Cynometra webberi* at the forest margins. Though honeybees and solitary bee species exploited the similar flowering species at the forest margins and at the farmlands, the proportion of these bees on each flowering species varied (Table 13).

Table 13 The proportion of honeybees and the solitary bees foraging on the five most utilized plant species across a distance gradient from the forest margin

Forest margin	Species	Honeybees %	Solitary bees %
	<i>Cassia</i> sp	0.0	21.7
	<i>Uvaria lucida</i>	25.3	4.5
	<i>Blepharis maderaspatensis</i>	10.9	6.9
	<i>Polygonum aviculare</i>	4.2	8.7
	<i>Hermennia exappandeculata</i>	6.3	6.3
2 km	<i>Hermennia exappandeculata</i>	21.0	11.6
	<i>Oxygonum sinautum</i>	16.2	38.0
	<i>Tridax procumbens</i>	13.8	8.8
	<i>Erlangea cordifolia</i>	21.4	23.3
	<i>Polygonum aviculare</i>	3.4	4.3
4 km	<i>Hermennia exappandeculata</i>	8.5	20.9
	<i>Oxygonum sinautum</i>	31.3	10.4
	<i>Tridax procumbens</i>	9.1	13.2
	<i>Polygonum aviculare</i>	36.1	18.0
	<i>Commelina benghalensis</i>	5.4	5.8
6 km	<i>Hermennia exappandeculata</i>	7.1	34.4
	<i>Oxygonum sinautum</i>	60.9	6.1
	<i>Tridax procumbens</i>	4.5	9.6
	<i>Polygonum aviculare</i>	0.2	7.4
	<i>Commelina benghalensis</i>	0.0	8.5

The total number of plant species visited by both bee groups varied across the distance gradient from the forest margins (Table 14). Of the 60 flowering species that utilized by all the bees, the honeybees visited 36 species. Some of the solitary bees that visited a high number of flowering species included the large carpenter, *Xylocopa senior*, 26 flowering species, *X. flavacolis*, and *X. somalica*, 25 and 21 flowering species respectively. A detailed list of all the bee species visiting each plant species is presented in appendix 7.

Table 14 The number of flowering plant species utilized by both the honeybees and the solitary bees along a distance gradient from the Arabuko Sokoke forest.

	Forest margins	2 km	4 km	6 km
Honeybees	16	13	18	13
Solitary bees	35	22	29	32
No. of all flowering species utilized	36	22	31	33
Total no. of flowering species	54	51	56	46

3.4.1 Trophic niche overlap across a distance gradient from the forest margins

The niche overlap was calculated between the honeybees and the ten most common solitary bees along the distance gradient from the forest margins. There was a low niche overlap between the honeybees and solitary bee at the forest margins with niche overlap values ranging from 0.08 to 0.42 (Table 15). Niche overlap was high between the honeybees and five solitary bee species in the farmlands located 2 km from the forest margins, with overlap values ranging from 0.39 – 0.9 (Table 16). A high niche overlap between the honeybees and seven solitary bee species was also recorded at the farmlands located 4 km from the forest margins, ranging from 0.14 – 0.84 (Table 17). Niche overlap was low between the honeybees and the solitary bees in the farms that were located 6 km from the forest margins, ranged from 0.05 – 0.39 (Table 18).

Table 15 Niche overlap between the honeybees and the ten most common solitary bees at the forest margins of the Arabuko Sokoke forest (October 2007 – April 2008).

	<i>Apis mellifera</i>	<i>Psuedapsis sp1</i>	<i>Macrogalea candida</i>	<i>Ceratina sp 1</i>	<i>Ceratina sp 2</i>	<i>Ceratina sp 3</i>	<i>Ceratina sp 4</i>	<i>Seladonia sp1</i>	<i>Xylocopa caffra</i>	<i>Megachile Ciastacombusta</i>	<i>Xylocopa flavocolis</i>
<i>Apis mellifera</i>	1	0.28	0.18	0.16	0.24	0.16	0.39	0.35	0.05	0.2	0.12
<i>Psuedapsis sp1</i>		1	0.62	0.65	0.64	0.59	0.65	0.6	0.27	0.67	0.34
<i>Macrogalea candida</i>			1	0.8	0.95	0.88	0.88	0.97	0.28	0.93	0.32
<i>Ceratina sp 1</i>				1	0.82	0.8	0.85	0.75	0.21	0.78	0.3
<i>Ceratina sp 2</i>					1	0.91	0.93	0.94	0.22	0.9	0.31
<i>Ceratina sp 3</i>						1	0.89	0.82	0.29	0.85	0.45
<i>Ceratina sp 4</i>							1	0.91	0.21	0.8	0.38
<i>Seladonia sp1</i>								1	0.2	0.86	0.27
<i>Xylocopa caffra</i>									1	0.28	0.88
<i>Megachile ciastacombusta</i>										1	0.28
<i>Xylocopa flavocolis</i>											1

Table 16 Niche overlap between the honeybees and the ten most common solitary bees at the farmlands located 2 km from the Arabuko Sokoke forest (October 2007 – April 2008).

	<i>Apis mellifera</i>	<i>Ceratina sp 1</i>	<i>Ceratina sp 2</i>	<i>Ceratina sp 3</i>	<i>Macrogalea candida</i>	<i>Ceratina sp 4</i>	<i>Psuedapsis sp</i>	<i>Megachile Ciastacombust</i>	<i>Xylocopa senior</i>	<i>Seladonia sp1</i>	<i>Xylocopa flavocolis</i>
<i>Apis mellifera</i>	1	0.53	0.51	0.39	0.9	0.41	0.79	0.7	0.72	0.52	0.67
<i>Ceratina sp 1</i>		1	0.99	0.96	0.65	0.97	0.71	0.34	0.23	0.34	0.23
<i>Ceratina sp 2</i>			1	0.97	0.63	0.97	0.69	0.34	0.21	0.33	0.21
<i>Ceratina sp 3</i>				1	0.5	0.99	0.57	0.17	0.11	0.32	0.12
<i>Macrogalea candida</i>					1	0.54	0.84	0.76	0.73	0.68	0.67
<i>Ceratina sp 4</i>						1	0.59	0.19	0.14	0.32	0.15
<i>Psuedapsis sp</i>							1	0.77	0.49	0.36	0.43
<i>Megachile ciastacombusta</i>								1	0.53	0.46	0.41
<i>Xylocopa senior</i>									1	0.45	0.92
<i>Seladonia sp1</i>										1	0.42
<i>Xylocopa flavocolis</i>											1

Table 17 Niche overlap between the honeybees and the ten most common solitary bees at the farmlands located 4 km from the Arabuko Sokoke forest (October 2007 – April 2008).

	<i>Apis mellifera</i>	<i>Psuedapsis sp1</i>	<i>Macrogalea candida</i>	<i>Ceratina sp 1</i>	<i>Ceratina sp 2</i>	<i>Ceratina sp 3</i>	<i>Ceratina sp 4</i>	<i>Seladonia sp1</i>	<i>Xylocopa caffra</i>	<i>Megachile Ckastacombusta</i>	<i>Xylocopa flavocolis</i>
<i>Apis mellifera</i>	1	0.28	0.18	0.16	0.24	0.16	0.39	0.35	0.05	0.2	0.12
<i>Psuedapsis sp1</i>		1	0.62	0.65	0.64	0.59	0.65	0.6	0.27	0.67	0.34
<i>Macrogalea candida</i>			1	0.8	0.95	0.88	0.88	0.97	0.28	0.93	0.32
<i>Ceratina sp 1</i>				1	0.82	0.8	0.85	0.75	0.21	0.78	0.3
<i>Ceratina sp 2</i>					1	0.91	0.93	0.94	0.22	0.9	0.31
<i>Ceratina sp 3</i>						1	0.89	0.82	0.29	0.85	0.45
<i>Ceratina sp 4</i>							1	0.91	0.21	0.8	0.38
<i>Seladonia sp1</i>								1	0.2	0.86	0.27
<i>Xylocopa caffra</i>									1	0.28	0.88
<i>Megachile ciastacombusta</i>										1	0.28
<i>Xylocopa flavocolis</i>											1

Table 18 Niche overlap between the honeybees and the ten common solitary bees at the farmlands located 6 km from the Arabuko Sokoke forest (October 2007 – April 2008).

	<i>Apis mellifera</i>	<i>Macrogalea candida</i>	<i>Ceratina sp 1</i>	<i>Psuedapsis sp</i>	<i>Ceratina sp 2</i>	<i>Seladonia sp1</i>	<i>Ceratina sp 3</i>	<i>Ceratina sp 4</i>	<i>Xylocopa flavocolis</i>	<i>Lipotrichis sp 1</i>	<i>Xylocopa senior</i>
<i>Apis mellifera</i>	1	0.5	0.84	0.65	0.68	0.7	0.82	0.79	0.14	0.73	0.09
<i>Macrogalea candida</i>		1	0.81	0.69	0.89	0.47	0.61	0.37	0.45	0.41	0.46
<i>Ceratina sp 1</i>			1	0.82	0.89	0.68	0.9	0.72	0.42	0.65	0.42
<i>Psuedapsis sp</i>				1	0.74	0.65	0.81	0.64	0.27	0.7	0.26
<i>Ceratina sp 2</i>					1	0.58	0.84	0.6	0.38	0.46	0.39
<i>Seladonia sp1</i>						1	0.75	0.9	0.19	0.6	0.06
<i>Ceratina sp 3</i>							1	0.88	0.22	0.58	0.22
<i>Ceratina sp 4</i>								1	0.12	0.56	0.05
<i>Xylocopa flavocolis</i>									1	0.19	0.94
<i>Lipotrichis sp 1</i>										1	0.1
<i>Xylocopa senior</i>											1

CHAPTER FOUR

4.0 DISCUSSION, CONCLUSIONS, AND RECOMENDATIONS

4.1 Discussion

4.1.1 Spatial Variation in Pollinator Community

A diverse bee community was found in the understory of the Arabuko Sokoke forest and the adjacent farmlands. Analysis showed there were more bees in the fallow farmlands than in the forest margins. Poor soils and low rainfall results in low agricultural yields for the farmers, and as a result, many of the farms are left fallow. Consequently, these farmlands are highly attractive to bees due to the abundance of weedy species. These results mirror the findings of Hagen (2008), who found higher bee abundance in the farmlands than the interior of the Kakamega forest or its margins. Similarly, Tylianakis *et al.* (2005) found that agricultural habitats had the greatest abundance of both bees and wasps compared to the nearby forests in Ecuador. Banaszak (1996) also found a decline in bee density from cultivated farmlands to natural forests in Europe.

Though the highest number of bee species was not found in the forest margins, the least number of bee species were found at the farmlands located furthest away from the forest margins. More species were found in the farms that were nearer to the forest margins. The low farming intensity probably accounts for the results of this study differing slightly from other studies that were carried out on farms with intensive management regimes (e.g. Klein *et al.*, 2002, 2006; Ricketts, 2004). They found higher bee diversity and abundance in the forests than in the farmlands that had low floral diversity. Results from this study show that, though some bee species are able to persist in managed farmlands, as the distance from natural habitats increases fewer species are able to forage in such isolated farmlands. The degree to which bee diversity between the natural habitats and the proximate farmlands varies is dependent on the amount of resources present (Ricketts, 2004). Bees may move between the forest margins and the adjacent farmlands depending on the availability of floral resources. Gikungu (2006) found that more bee species in the farms adjacent to the Kakamega forest when there was floral dearth inside the forest. The forest margins may have had a higher number of bee species foraging on the high canopy trees that could have been missed in this study that focused on the understory bee community.

The presence of bees was highly dependent on the amount of floral resources available; the least number of bees was recorded at the forest margins, which had the least number of flowers per sampling unit. The open and sunny areas in the previously cleared agricultural areas allowed for luxuriant establishment of weed species that provided large floral resources that were easily accessible to all bee species. There was a monthly variation in bee abundance, which could be explained by the variation in floral resources. A decline in bee abundance was evident in the last three months of the study; these months were marked by low floral abundance especially in the *Brachystegia* and *Cynometra* sampling sites. Floral density and diversity are believed to promote bee diversity because heterogeneity in the resource base supports a greater number of foraging niches (Tepedino and Stanton, 1981).

The farmlands that were located furthest from the forest margins had the lower bee diversity compared to the forest margins. These findings are concomitant with the findings of Liow *et al.* (2001) and Klein *et al.* (2003) who found a decrease in species diversity with the increased isolation of the farmlands to the forests in South East Asia and Costa Rica respectively. Some bee species have high specificity in their nesting sites and materials and thus prefer the undisturbed forest margins to the farmlands (Michener, 2000). The forest provides a wide range of nesting sites such as burrows, tree cavities, and young pithy plants that are favored by some solitary bee species (Gikungu, 2006). The findings of this study contrast those of Brosi *et al.* (2007) who did not find a change in bee abundance or diversity with increased distance from the forest, but found a variation in bee community composition.

The bee fauna of the forest margins and the adjacent farmlands was highly similar, because there were many common species between them. However, some bee genera such as *Amegilla*, *Lipotrichis*, *Megachile* and *Xylocopa* were more abundant at the forest margins compared to the farmlands. The *Amegilla* bees declined from 3% of samples in the forest margins to < 0.5% in the furthest farmlands, while *Lipotrichis* bees decline from 12% in the forest margins to 2% in the furthest farmlands. The megachilid bees declined from 4% at the forest margins to 2% in the furthest farmlands. The large carpenter bees of the *Xylocopa* genera, declined from 23% at the forest margins to 8% in the farmlands that were located furthest away from the forest. This agrees with other study findings from other parts of the world, Costa Rica (Klein *et al.*, 2001;

Brosi *et al.*, 2007) and Germany (Ockinger and Smith, 2007), which found a strong change in bee community composition with the increased isolation from the forests. Though other biotic and abiotic factors could have influenced the distribution of bee species along the distance gradient, differences in the vegetation structure, availability of nesting sites as well as short foraging ranges could have limited bee movement between the forest and the farmlands.

More honeybees were found at the farmlands, over 30%, thus contributing to higher bee abundance in the farmlands compared to the forest margins. These results, however, differ from the findings of Klein *et al.* (2003) who found a decline in the number of the social bees with the increased isolation of the farmlands from the forest. Honeybees have a large foraging range and the ability to nest within farms and thus are less sensitive to the amount of nearby natural habitats than many solitary species (Steffan-Dewenter and Kuhn, 2003).

The solitary bees were also more abundant in the farmlands compared to the forest margins; the low tilling frequencies may have provided ideal nesting sites for some ground nesting bee species. These results differed with Hagen (2008) who found a higher abundance of solitary bees at the forest margins of the Kakamega forest than in the adjacent farmlands. Grazing activities at the farmlands also influenced the abundance of both the honeybees and solitary bees. The farmlands that served as pastureland for sheep and goats had a lower bee abundance and species richness, such as the farmlands situated at 2 km from the forest margins. Kruess and Tschardt (2001) found that regularly grazed pasturelands had lower bee density and diversity compared to ungrazed pastures due to the reduction of vegetation heterogeneity.

Bee fauna between neighbouring farmlands was probably similar because of the capacity of bees to disperse and locate fragrances compensating for possible negative effects of forest isolation (Tonhasca *et al.*, 2002). Some bees that were commonly found at the farmlands included *Apis mellifera*, *Ceratina* spp., *Macrogalea candida*, and the *Seladonia* sp 1. The high degree of similarity in bee fauna composition in the farmlands indicates that the communities are composed of generalist species that are able to utilize a wide range of floral resources and had similar nesting requirements.

4.1.2 Influence of Habitat Diversity

The mixed vegetation had higher bee abundance, species richness, and diversity than the other two vegetation types. This was as expected due to its structurally more diverse vegetation cover; resultant of higher rainfall and better soils (Robertson and Luke, 1993). Heterogeneous environments are expected to accommodate more species due to greater variety of nesting sites and adequate floral resources (Kremen, 2005). Due to dry and infertile soils, *Brachystegia* vegetation type had the least number of flowers and flowering species and consequently the least bee abundance. The *Cynometra* vegetation type had the least number of bee species recorded. This can be attributed to the poor soil condition in this zone, which results in low vegetation cover as well as flowering species. Only a few bees were observed at the *Cynometra* forest margins, which had a complete dearth of flowers for most part of the study. There is hardly any under growth in the forest and even the deciduous trees die back early due to the relatively little rainfall (Ayiemba, 1997).

Bee fauna in the three vegetation types was highly similar, indicating they shared many common species. The *Cynometra* and the mixed vegetation types had almost similar bee community as evidenced by a high Horn's index value. The honeybees comprised more than 30% of all bees recorded in the two vegetation types. Other bee species that were common in the two vegetation types included the *Ceratina*, *Macrogalea candida*, *Psuedapsis*, *Seladonia*, and *Xylocopa* with the exception of *X. terminata*, which occurred only in the mixed vegetation type. Similarity in bee fauna was also high between the mixed and *Brachystegia* vegetation types. Solitary bees, especially *Lipotrichis* and *Psuedapsis* species, were however more abundant in the *Brachystegia* vegetation type, while the mixed vegetation type had the highest number of the social honeybees. The *Cynometra* and *Brachystegia* vegetation types also had a high similarity in their bee fauna. A lower abundance of *Amegilla* and *Xylocopa* spp. was however, found in the *Cynometra* vegetation type, while a low abundance in the honeybees was evident in the *Brachystegia* vegetation type.

While the least number of honeybees were found at the *Brachystegia* vegetation type, they were most abundant in the mixed vegetation type in which had more flower abundance. The low presence of honeybees in the *Brachystegia* vegetation type seemed to favour the presence of

solitary bee species of the genus *Lipotrichis*. The family Apidae was most dominant in the mixed vegetation type while the family Halictidae was more abundant in the *Brachystegia* vegetation type. This concurs with the findings of Thorp (1996) who found that the abundance of the Halictidae bees was negatively correlated with the honeybee abundance.

4.1.3 Effects of Plant Phenology and Season

Of the 114 flowering species available in the Arabuko Sokoke forest margins and the adjacent farmlands, over 50% were utilized as food resources by the bee community. Of the 36 flowering plant families encountered, five families, Polygonaceae, Compositae, Amaranthaceae, Commelinaceae, and Acanthaceae, were the most heavily utilized. These families included mass flowering weedy species such as *O. sinautum*, *H. exappandeculata*, *P. aviculare*, *T. procumbens*, *E. cordifolia*, and *C. benghalensis*, which had easily accessible flowers and were very common in the fallow farmlands and open areas at the forest margins. They were also found to be flowering through out the study period. Two species of the Polygonum family, *O. sinautum* and *P. aviculare* were the most abundant weedy species on the farmlands.

Different proportions of honeybees and solitary bees were found utilizing each flowering species along the distance gradient. When the proportion of honeybees utilizing a particular flowering species was high, the proportion of solitary bees utilizing that particular species was lower. This suggests that there was competitive exclusion of solitary bees from some flowering patches by the highly competitive honeybees. Steffan – Dewenter and Tschardtke (1999) found a similar trend in central Europe, whereby honeybees were commonly found foraging on the blooming coffee plants while the solitary species foraged on the ground cover.

The honeybees utilized about a third of all the flowering species available at the farmlands and in the forest margins. This compares well with the results of Buchmann (1996) who found honeybees utilizing 25% of flowering species in the Sonoran desert of North America. These findings also concur with the results from the Kakamega forest (Gikungu, 2006; Hagen, 2008), that found the honeybees to have the highest interactions with the flowering species. Combined, all the solitary species visited more than 50% of all the flowering species at the forest margins and in the farmlands. This also compares well with Buchman (1996), who found solitary bees to

exploit floral resources from over 50% of all the flowering species, and were the only visitors on 25 flowering plant species. A diverse bee community thus increases the chances of a flowering plant being pollinated thereby improving the reproductive success of a plant community (Kremen, 2005)

On finding a large source of floral resources, the honeybees are able to communicate to the other members of their colonies and thus direct them towards the food sources (Roubik, 1989). Over 70% of the honeybees recorded during the study were found foraging on six mass flowering plant species namely *O. sinautum*, *H. exappandeculata*, *P. aviculare*, *T. procumbens*, *E. cordifolia*, and *C. benghalensis*. Faced with the pressure to sustain large perennial colonies, honeybees cannot specialize on particular plant species. They are more advantaged than the other bees because they have special galleries to store the rapidly harvested foods unlike the solitary bees that collect just enough to provision their larvae (Roubik, 1989).

This study demonstrated that overlap in resource utilization between the social honeybees and the solitary species at the forest margins is quite low. The honeybees were commonly found foraging on larger mass flowering species such as *Grewia plagiophylla*, *Manilkara sansbarensis* and *Cynometra webberi*, which were not utilized as heavily by the solitary bees. The flowering plant community across all the farmlands was highly similar and highly attractive to all bee species. The niche overlap between the honeybees and the solitary bees indicated that both groups intensively used identical flowering species and their preferences tended to coincide. While honeybees were commonly observed on large floral patches, the solitary bee species could be found foraging on patches that had lower floral density. No aggression was observed between the honeybees and any other bee species when they were foraging on the same flowering patches. Some solitary bee species that foraged in large numbers included, *Macrogalea candida*, *Ceratina* spp. and *psuedapsis* species. The *Ceratina* spp. are small bodied and several individuals could be found foraging simultaneously on the same flower.

However, the high overlaps in resource use documented between some bees species did not necessarily mean competition for plant resources existed among the studied species. High overlap measure does not imply competition if resources are abundant (Abrams 1980).

Honeybees have the ability to locate and dominate floral resources quickly presumably because of the large number of workers that can search for food and successfully direct other colony members using a dance language to communicate direction and distance (Roubik, 1980). Overall bee abundance was highly influenced by the abundance of flowers in a particular sampling site, such that sites with abundant flowers had greater possibilities for partitioning of available resources.

4.2 Conclusions

This study established that bee species richness and diversity declined with the distance to the forest. It is therefore clear that preserving the diverse pollinator community found in the farmlands around the Arabuko Sokoke forest, requires the conservation of this forest. Though the forest margins and the farmlands shared many common bee species, it is imperative to conserve the forest in its pristine condition to preserve these highly diverse pollinating species. In addition to acting as a reservoir for some bee species, the Arabuko Sokoke forest provides nesting sites, which might not be readily available in the farmlands. The low farming activities in the surrounding farmlands resulted in rich bee community thriving on these farmlands and this diluted any negative effects that may have resulted from the increased distance of the farmland from the forest. Most farmlands had great numbers of feral honeybees indicating that there is a high bee keeping potential.

The study also established that the three vegetation types found in the Arabuko Sokoke forest differed in their bee community composition. The different conditions provided by the three major vegetation types of the Arabuko Sokoke favoured the establishment of different bee families especially in the mixed and *Brachystegia* forests. Thus to maintain this diverse bee community in each of the vegetation type, conservation of these different sections of the forest is paramount. Degradation of these forested habitats would result in selective loss of some bee species or families that were prevalent in the different sections of the forest. Solitary bee species are more prone to habitat degradation as they have smaller colonies, nest on trees or in the ground and have shorter foraging ranges compared to the honeybees (Steffan-Dewenter and Tsharntke, 1999).

An overlap in utilization of flowering species in the understory at the farmlands and the forest margins by the solitary bees and the honeybees was recorded. The bee fauna around the Arabuko Sokoke forest is composed of species with high level of generalization in their floral resource utilization. The honeybees are super generalist feeders that visit a high number of flowering species both at the forest margins and in the adjacent farmlands. The solitary bees are also very important flower visitors as they were less specific on the flowering species they visited. The honeybees had a higher preference for mass flowering species than the solitary bee species. Bee preference of flowering species was based on their availability and the amount of floral resources they offered. The honeybees were able to exclude the solitary bees from the floral rich patches by foraging in large numbers on such patches.

4.3 Recommendations

- **Actions for Improving Livelihoods and Economy**

As the high poverty level in the local community is the single most dangerous threat to the continued existence of the forest, efforts should be made to help the local community diversify economic activities based on the sustainable usage of the forest resources. This would go a long way in eliminating the threat that is the extractive utilization of the forest in form of poaching, illegal logging, and charcoal burning. A larger export market for the butterfly pupae reared by the Kipepeo butterfly project farmers would ensure induction of more farmers into the project as well as secure good income for all the participants. Despite the high bee keeping potential, only a few farmers participate in this highly lucrative venture. This is based largely on ignorance and mortal fear of bee stings. There is urgent need to educate the community on the most productive methods of bee farming to ensure that they reap maximum returns for their efforts. After successful trials, the local community should now be highly encouraged to take up mushroom farming. The availability of a ready market and marketing channel through the Kipepeo project market place should prove to be a great incentive to the farmers. The rearing of silk moths (*Argema mimosae*), a newly started project should be expanded and farmers encouraged to participate. Technical assistance and start up resources assistance should be availed to the farmers as an incentive to get them to participate in this highly lucrative type of farming.

- **Conservation actions/Knowledge Transfer**

In order for the farmers to appreciate the importance of pollinators, effort should be made to revive the once lucrative farming of cashew nut and mangoes in the farms surrounding the Arabuko Sokoke forest. The farmers should be encouraged to plant the new hybrid species of coconuts, cashew nut, and mango trees, which are drought resistant and not susceptible to pest and diseases. Research should be undertaken to demonstrate the role of key pollinators in increasing quality and quantity of crops yields. Improved yields resulting from sufficient pollination services by the bees found in the forests would result in higher economic earnings for the farmers. This would go along way in improving their livelihood, reducing their over reliance on the extractive uses of the forest and improve their conservation efforts.

- **Land and Forest Management Actions**

Management strategies to conserve pollinators in the forest should be developed to involve all levels of forest management, district administrators, and policy makers at national level, as well as local community who are the custodian of biodiversity. Further studies are therefore needed for the establishment of bee reserves, both inside and outside the forested areas. This would enhance the knowledge of the available bee species found in and around the forest there by providing the farmers with a resource base of the available pollinator species for their crops.

- **Further Research/Study**

There is urgent need to increase capacity building in bee taxonomy and pollination biology in order to make pollination a more conducive field of study. With a team of experts on bee biology, it would be easier to carry out research studies and disseminate the finding to the local communities. Based on their findings workshops should be held in order to sensitize the local community on the importance of forest and pollinator conservation on the overall well being of the environment and the benefit it confers to their farms in terms of ecological services.

Regular bio-monitoring of bee fauna should be conducted after every three years, given that Arabuko Sokoke forest is faced with anthropogenic factors like any other natural

habitat in the world. Findings based on these surveys would be important in assessing the status of the forest, as some of the bee species can be useful as bio – indicators. Other pollen vectors such as the wasps, flies, butterflies, and beetles should also be thoroughly investigated and the research findings made available to the local community This would provide insights of pollinator population status and would also highlight the presence of some parasitoid species that could be useful in biological control of pests in the adjacent farms.

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APPENDICES

Appendix 1 A checklist of the bee species found in the three vegetation types of the Arabuko Sokoke forest (October 2007 – April 2008).

Apidae Family	Halictidae Family	Megachilidae Family
<i>Amegilla (megamegilla sp1)</i>	<i>Lipotrichis sp 1</i>	<i>Coelioxysis sp</i>
<i>Amegilla aff langi</i>	<i>Lipotrichis sp 2</i>	<i>Megachile felina</i>
<i>Amegilla mimadvena</i>	<i>Lipotrichis sp 3</i>	<i>Megachile ciastacombusta</i>
<i>Amegilla sp 1</i>	<i>Lipotrichis sp 4</i>	<i>Megachile daviensis</i>
<i>Amegilla sp 2</i>	<i>Lipotrichis sp 5</i>	<i>Megachile sp 1</i>
<i>Amegilla terminata</i>	<i>Lipotrichis sp 6</i>	<i>Megachile sp 2</i>
<i>Apis mellifera</i>	<i>Lipotrichis sp 7</i>	<i>Megachile sp 3</i>
<i>Bruanapis sp</i>	<i>Lipotrichis sp 8</i>	<i>Megachile sp 4</i>
<i>Ceratina sp 1</i>	<i>Lipotrichis sp 9</i>	<i>Megachile sp 5</i>
<i>Ceratina sp 2</i>	<i>Lipotrichis sp10</i>	<i>Megachile sp 6</i>
<i>Ceratina sp 3</i>	<i>Lipotrichis sp11</i>	<i>Megachile sp 7</i>
<i>Ceratina sp 4</i>	<i>Nomia ambile</i>	<i>Pachyanthidium sp1</i>
<i>Ceratina viridis</i>	<i>Nomia sp</i>	<i>Pachyanthidium trichanthidium</i>
<i>Ctenoplectra albolimbata</i>	<i>Psuedapsis sp1</i>	<i>Pseudoanthidium sp1</i>
<i>Macrogalea candida</i>	<i>Seladonia sp1</i>	<i>Serapista sp</i>
<i>Pachymelus conspicuus</i>	<i>Stegnomus</i>	
<i>Thyreus pictus</i>	<i>Tertaloniella sp</i>	
<i>Thyreus sp 1</i>	<i>Thrinchostoma torridium</i>	
<i>Thyreus sp 2</i>		
<i>Thyreus sp 3</i>		
<i>Xylocopa a</i>		
<i>Xylocopa b</i>		
<i>Xylocopa c</i>		
<i>Xylocopa caffra</i>		
<i>Xylocopa flavocolis</i>		
<i>Xylocopa flavonifa</i>		
<i>Xylocopa lottentota</i>		
<i>Xylocopa nigrita</i>		
<i>Xylocopa senoir</i>		
<i>Xylocopa somalica</i>		

Appendix 2 A distribution list of bee species in the Apidae family in the different vegetation types of the Arabuko Sokoke forest (October 2007 and April 2008).

Family	Species	Vegetation Type		
		<i>Brachystegia</i>	Mixed	<i>Cynometra</i>
Apidae	<i>Amegilla (megamegilla sp1)</i>	6	6	5
	<i>Amegilla aff langi</i>	22	6	3
	<i>Amegilla mimadvena</i>	12	5	4
	<i>Amegilla sp 1</i>	19	13	13
	<i>Amegilla sp 2</i>	17	14	4
	<i>Amegilla terminata</i>	0	1	0
	<i>Apis mellifera</i>	131	1145	475
	<i>Bruanapis sp</i>	11	11	3
	<i>Ceratina sp 1</i>	102	353	112
	<i>Ceratina sp 2</i>	74	232	85
	<i>Ceratina sp 3</i>	56	191	86
	<i>Ceratina sp 4</i>	57	125	73
	<i>Ceratina viridis</i>	10	9	0
	<i>Ctenoplectra albolimbata</i>	3	0	0
	<i>Macrogalea candida</i>	152	366	108
	<i>Pachymelus conspicuus</i>	0	0	2
	<i>Thyreus pictus</i>	3	6	1
	<i>Thyreus sp 1</i>	6	2	0
	<i>Thyreus sp 2</i>	12	4	0
	<i>Thyreus sp 3</i>	2	6	0
	<i>Xylocopa a</i>	5	20	4
	<i>Xylocopa b</i>	6	26	20
	<i>Xylocopa c</i>	0	4	0
	<i>Xylocopa caffra</i>	20	39	40
	<i>Xylocopa flavocolis</i>	35	61	42
	<i>Xylocopa flavonifa</i>	21	26	14
	<i>Xylocopa lottentota</i>	11	28	23
	<i>Xylocopa nigrata</i>	0	2	0
	<i>Xylocopa senoir</i>	43	88	25
	<i>Xylocopa somalica</i>	20	48	30

Appendix 3 A distribution list of bee species in the Halictidae family in the different vegetation types of the Arabuko Sokoke forest (October 2007 and April 2008).

Family	Species	Vegetation Type		
		<i>Brachystegia</i>	Mixed	<i>Cynometra</i>
Halictidae	<i>Lipotrichis sp 1</i>	32	33	20
	<i>Lipotrichis sp 2</i>	28	15	6
	<i>Lipotrichis sp 3</i>	20	2	5
	<i>Lipotrichis sp 4</i>	13	5	5
	<i>Lipotrichis sp 5</i>	18	6	0
	<i>Lipotrichis sp 6</i>	13	9	9
	<i>Lipotrichis sp 7</i>	12	4	8
	<i>Lipotrichis sp 8</i>	8	5	5
	<i>Lipotrichis sp 9</i>	23	11	40
	<i>Lipotrichis sp10</i>	13	14	7
	<i>Lipotrichis sp11</i>	4	3	19
	<i>Nomia ambile</i>	1	6	0
	<i>Nomia sp</i>	5	5	0
	<i>Psuedapsis sp1</i>	297	113	95
	<i>Seladonia sp1</i>	78	66	59
	<i>Stegnomus</i>	1	1	0
	<i>Tertaloniella sp</i>	4	9	0
	<i>Thrinchostoma torridium</i>	8	5	3

Appendix 4 A distribution list of bee species in the Megachilidae family in the different vegetation types of the Arabuko Sokoke forest (October 2007 and April 2008)

Family	Species	Vegetation Type		
		<i>Brachystegia</i>	Mixed	<i>Cynometra</i>
Megachilidae	<i>Coelioxysis sp</i>	0	2	7
	<i>Megachile felina</i>	4	8	0
	<i>Megachile ciastacombusta</i>	70	25	10
	<i>Megachile daviensis</i>	0	1	0
	<i>Megachile sp 1</i>	22	20	14
	<i>Megachile sp 2</i>	0	22	2
	<i>Megachile sp 3</i>	0	9	0
	<i>Megachile sp 4</i>	2	6	0
	<i>Megachile sp 5</i>	2	6	8
	<i>Megachile sp 6</i>	1	11	6
	<i>Megachile sp 7</i>	3	1	2
	<i>Pachyanthidium sp1</i>	1	1	0
	<i>Pachyanthidium trichanthidium sp1</i>	0	1	0
	<i>Pseudoanthidium sp1</i>	24	12	8
	<i>Serapista sp</i>	0	2	1

Appendix 5 A Summary of bee visitation on different plant families

Plant family	No. of flowering species	Bee abundance	No. of bee species
Compositae	8	1030	53
Polygonaceae	3	2042	51
Amaranthaceae	2	1117	47
Caesalpiaceae	4	181	39
Labiatae	8	273	37
Commelinaceae	4	386	35
Acanthaceae	5	278	34
Tiliaceae	2	100	28
Papilionaceae	12	102	21
Flacourtiaceae	1	79	15
Annonaceae	3	105	14
Nyctaginaceae	1	92	14
Solanaceae	2	95	13
Verbenaceae	2	82	11
Euphorbiaceae	7	111	10
Malvaceae	5	32	10
Convolvulaceae	2	36	9
Capparaceae	4	23	8
Rubiceae	10	33	8
Ochnaceae	3	31	7
Fabaceae	1	18	6
Meliaceae	1	23	6
Anacardiaceae	3	10	5
Sapotaceae	1	25	5
Mimosaceae	2	9	2
Sterculiaceae	3	37	2
Apocynaceae	1	0	0
Asclepiadaceae	1	0	0
Boraginaceae	1	0	0
Combretaceae	1	0	0
Loganiaceae	1	0	0
Mimisoides	1	0	0
Oleaceae	2	0	0
Portulacaceae	2	0	0
Rhamnaceae	2	0	0
Sapindaceae	1	0	0
Vitaceae	1	0	0

Appendix 6 Floral utilization by bee species around the Arabuko Sokoke forest and the adjacent farmlands. Grouped by the plant families and species. (October 2007 – April 2008)

ACANTHACEAE

Asystersia anelloides

Amegilla (megamegilla sp1)

Amegilla mimadvena

Amegilla sp 1

Apis mellifera

Ceratina sp 1

Ceratina sp 2

Ceratina sp 3

Ceratina sp 4

Coelioxysis sp

Lipotrichis sp 1

Lipotrichis sp 2

Lipotrichis sp 3

Lipotrichis sp 4

Lipotrichis sp 5

Lipotrichis sp 8

Lipotrichis sp 9

Lipotrichis sp11

Macrogalea candida

Megachile ciastacombusta

Pseudoanthidium sp

Psuedapsis sp

Psuedapsis sp 1

Seladonia sp 1

Xylocopa a

Xylocopa flavocolis

Xylocopa flavonifa

Xylocopa senoir

Xylocopa somalica

Blepharis maderaspatensis

Amegilla sp 1

Amegilla sp 2

Apis mellifera

Ceratina sp 1

Ceratina sp 2

Ceratina sp 3

Ceratina sp 4

Lipotrichis sp 1

Lipotrichis sp 3

Lipotrichis sp 5

Macrogalea candida

Megachile ciastacombusta

Megachile sp 1

Megachile sp 2

Megachile sp 4

Megachile sp 6

Psuedapsis sp 1

Xylocopa a

Xylocopa b

Xylocopa caffra

Xylocopa flavocolis

Xylocopa flavonifa

Xylocopa lottentota

Justicia flava

Ceratina sp 1

Macrogalea candida

Lipotrichis sp 1

Lipotrichis sp 2

Lipotrichis sp 4

Sclerochiton vogelii

Xylocopa b

Xylocopa caffra

Xylocopa flavocolis

Xylocopa senoir

Xylocopa somalica

AMARANTHACEAE

Hermenia exappandeculata

Amegilla (megamegilla sp1)

Amegilla aff langi

Amegilla mimadvena

Amegilla sp 1

Amegilla sp 2

Apis mellifera

Bruanapis sp

Ceratina viridis

Ceratina sp 1

Ceratina sp 2

Ceratina sp 3

Ceratina sp 4

Ceratina viridis

Coelioxysis sp

Lipotrichis sp 1

Lipotrichis sp 2

Lipotrichis sp 4

Lipotrichis sp 5

Lipotrichis sp 6

Lipotrichis sp 8
Lipotrichis sp 9
Lipotrichis sp10
Lipotrichis sp11
Megachile felina
Macrogalea candida
Megachile ciastacombusta
Megachile sp 1
Megachile sp 2
Megachile sp 3
Megachile sp 4
Megachile sp 6
Nomia sp
Pseudoanthidium sp
Psuedapsis sp 1
Seladonia sp 1
Thyreus pictus
Thyreus sp 1
Thyreus sp 2
Thyreus sp 3
Xylocopa a
Xylocopa b
Xylocopa c
Xylocopa caffra
Xylocopa flavocolis
Xylocopa flavonifa
Xylocopa lottentota
Xylocopa senoir
Xylocopa somalica

ANACARDIACEAE

Mangifera indica

Apis mellifera
Ceratina sp 1

Ozoroa obovata

Megachile ciastacombusta
Xylocopa a
Xylocopa caffra

ANNONACEAE

Uvaria lucida

Apis mellifera
Ceratina sp 1
Ceratina sp 2
Ceratina sp 3
Ceratina sp 4
Lipotrichis sp 1

Lipotrichis sp 2
Xylocopa a
Xylocopa b
Xylocopa caffra
Xylocopa flavocolis
Xylocopa flavonifa
Xylocopa lottentota
Xylocopa senoir

CAPPARACEAE

Capparis tomentosa

Apis mellifera
Ceratina sp 2
Lipotrichis sp 2
Macrogalea candida
Xylocopa flavonifa
Xylocopa senoir
Xylocopa somalica

Gynandropsis gynada

Lipotrichis sp 2
Thyreus pictus

COMMELINACEAE

Anelemia petersei

Xylocopa a
Xylocopa b
Xylocopa caffra
Xylocopa flavocolis
Xylocopa lottentota
Xylocopa senoir
Xylocopa somalica

Commelina benghalensis

Amegilla (megamegilla) p1)
Amegilla mimadvena
Amegilla sp 1
Apis mellifera
Bruanapis sp
Ceratina sp 1
Ceratina sp 2
Ceratina sp 3
Ceratina sp 4
Lipotrichis sp 1
Lipotrichis sp 2
Lipotrichis sp 3
Lipotrichis sp 4
Lipotrichis sp 5
Lipotrichis sp 6
Lipotrichis sp 7

Lipotrichis sp 9
Lipotrichis sp11
Macrogalea candida
Megachile ciastacombusta
Megachile sp 1
Pseudoanthidium sp
Psuedapsis sp
Psuedapsis sp 1
Seladonia sp 1
Thyreus sp 2
Xylocopa flavocolis
Xylocopa flavonifa
Xylocopa lottentota
Xylocopa senoir

Commelina latifolia

Apis mellifera
Ceratina sp 1
Ceratina sp 2
Ceratina sp 3
Ceratina sp 4
Coelioxysis sp
Lipotrichis sp 1
Lipotrichis sp 2
Lipotrichis sp 3
Lipotrichis sp 8
Macrogalea candida
Pseudoanthidium sp
Psuedapsis sp 1
Seladonia sp 1
Xylocopa flavocolis
Xylocopa lottentota

COMPOSITAE

Bidens pilosa

Ceratina sp 1

Erlangea cordifolia

Amegilla (megamegilla) sp1
Amegilla aff langi
Amegilla mimadvena
Amegilla sp 1
Amegilla sp 2
Amegilla terminata
Apis mellifera
Bruanapis sp
Ceratina sp 1
Ceratina sp 2

Ceratina sp 3
Ceratina sp 4
Ceratina viridis
Ctenoplectra albolimbata
Lipotrichis 9
Lipotrichis sp 1
Lipotrichis sp 2
Lipotrichis sp 3
Lipotrichis sp 4
Lipotrichis sp 5
Lipotrichis sp 6
Lipotrichis sp 7
Lipotrichis sp 8
Lipotrichis sp 9
Lipotrichis sp10
Megachile felina

Macrogalea candida

Megachile ciastacombusta
Megachile sp 1
Megachile sp 3
Megachile sp 5
Megachile sp 6
Megachile sp 7

Pachyanthidium Trichanthidium sp

Pseudoanthidium sp
Psuedapsis sp
Psuedapsis sp 1
Seladonia sp 1
Serapista sp
Stegnomus
Tertalonella sp

Thrinchostoma torridum

Thyreus pictus
Thyreus sp 1
Thyreus sp 2
Xylocopa a
Xylocopa b
Xylocopa caffra
Xylocopa flavocolis
Xylocopa flavonifa
Xylocopa senoir
Xylocopa somalica

Laurnea cornuta

Macrogalea candida

Tridax procumbens

Amegilla aff langi

Amegilla mimadvena

Amegilla sp 1

Amegilla sp 2

Apis mellifera

Bruanapis sp

Ceratina sp 1

Ceratina sp 2

Ceratina sp 3

Ceratina sp 4

Coelioxysis sp

Lipotrichis sp 1

Lipotrichis sp 2

Lipotrichis sp 3

Lipotrichis sp 5

Lipotrichis sp 6

Lipotrichis sp 7

Lipotrichis sp 8

Lipotrichis sp 9

Lipotrichis sp11

Macrogalea candida

Megachile ciastacombusta

Megachile sp 1

Megachile sp 6

Megachile sp 7

Pseudoanthidium sp

Psuedapsis sp

Psuedapsis sp 1

Seladonia sp 1

Thrinchostoma torridium

Xylocopa a

Xylocopa b

Xylocopa caffra

Xylocopa flavocolis

Xylocopa flavonifa

Xylocopa lottentota

Xylocopa senior

Xylocopa senoir

Xylocopa somalica

CONVULVALACEAE

Hewittia sublobata

Apis mellifera

Ceratina sp 1

Lipotrichis sp 3

Lipotrichis sp 6

Lipotrichis sp 7

Macrogalea candida

Megachile sp 3

Seladonia sp 1

Xylocopa flavonifa

EUPHORBIACEAE

Maniholt esculentum

Apis mellifera

Phyllanthus reticulatus

Apis mellifera

Lipotrichis sp 6

Xylocopa a

Xylocopa b

Xylocopa c

Xylocopa flavocolis

Xylocopa lottentota

Xylocopa senoir

Xylocopa somalica

Ricinus communis

Apis mellifera

Xylocopa a

Xylocopa b

Xylocopa caffra

Xylocopa flavocolis

Xylocopa senoir

Xylocopa somalica

FABACEAE

Vigna unguiculata

Apis mellifera

Xylocopa caffra

Xylocopa flavocolis

Xylocopa flavonifa

Xylocopa senoir

Xylocopa somalica

FLACOURTIACEAE

Dovyalis Sp

Amegilla sp 1
Apis mellifera
Bruanapis sp
Ceratina sp 1
Megachile sp 2
Megachile sp 4
Megachile sp 6
Xylocopa lottentota
Xylocopa a
Xylocopa b
Xylocopa caffra
Xylocopa flavocolis
Xylocopa flavonifa
Xylocopa lottentota
Xylocopa senoir
Xylocopa somalica

LABIATAE

Becium filamentosum

Ceratina sp 1
Ceratina sp 2

Husuludia opposita

Apis mellifera
Ceratina sp 1
Ceratina sp 2
Ceratina sp 3
Psuedapsis sp 1
Xylocopa senoir

Leucas tsavoensis

Amegilla (megamegilla sp1)
Amegilla aff langi
Amegilla mimadvena
Amegilla sp 1
Amegilla sp 2
Apis mellifera
Ceratina sp 2
Lipotrichis sp 7
Macrogalea candida
Megachile ciastacombusta
Megachile sp 6
Xylocopa b
Xylocopa caffra
Xylocopa flavonifa
Xylocopa lottentota
Xylocopa senior

Xylocopa somalica

Labiata sp 1

Amegilla (megamegilla sp1)
Amegilla aff langi
Amegilla sp 1
Ceratina sp 1
Ceratina sp 2
Ceratina sp 3
Ceratina sp 4
Ceratina viridis
Coelioxysis sp
Lipotrichis sp 1
Lipotrichis sp 2
Lipotrichis sp 6
Lipotrichis sp 9
Lipotrichis sp10
Macrogalea candida
Megachile ciastacombusta
Megachile sp 4
Megachile sp 5
Pachyanthidium sp
Pachymelus conspicuus
Pseudoanthidium sp
Psuedapsis sp 1
Xylocopa caffra
Xylocopa flavocolis
Xylocopa lottentota
Xylocopa somalica

Ocimum gratissimum

Amegilla (megamegilla sp1)
Amegilla aff langi
Amegilla mimadvena
Apis mellifera
Ceratina sp 1
Ceratina sp 2
Ceratina sp 3
Ceratina sp 4
Lipotrichis sp 1
Lipotrichis sp 3
Lipotrichis sp 6
Lipotrichis sp 7
Macrogalea candida
Megachile ciastacombusta
Pseudoanthidium sp
Psuedapsis sp 1
Seladonia sp 1

Ocimum suave

Apis mellifera
Ceratina sp 1
Ceratina sp 2
Ceratina sp 3
Lipotrichis sp 9
Megachile ciastacombusta

Plecteranthus flaccidus

Amegilla mimadvena
Amegilla sp 1
Lipotrichis sp 6
Lipotrichis sp 8

MALVACEAE

Hibiscus micranthus

Apis mellifera
Xylocopa caffra
Xylocopa flavocolis
Xylocopa flavonifa
Xylocopa lottentota
Xylocopa senior
Xylocopa somalica

Sida cordifolia

Apis mellifera
Macrogalea candida
Psuedapsis sp 1
Xylocopa a
Xylocopa flavonifa
Xylocopa lottentota
Xylocopa caffra

MELIACEAE

Azardachta indica

Apis mellifera
Ceratina sp 3
Ceratina sp 4
Lipotrichis sp 4
Megachile felina
Thyreus sp 3

MIMOSACEAE

Dichrostachs cinerea

Xylocopa b
Xylocopa senoir

NYTCTAGINACEAE

Boerhavia diffusa

Apis mellifera
Ceratina sp 1
Ceratina sp 3
Ceratina sp 4
Lipotrichis sp 1
Lipotrichis sp 10
Macrogalea candida
Megachile sp 2
Megachile sp 5
Megachile sp 6
Psuedapsis sp
Psuedapsis sp 1
Thyreus sp 1
Thyreus sp 3
Xylocopa senoir

OCHNACEAE

Ochna holt

Apis mellifera

Ochna mossambiensis

Ceratina sp 2
Macrogalea candida
Psuedapsis sp
Xylocopa senoir

Ochna thomasiana

Apis mellifera
Ceratina sp 3
Ceratina sp 4

PAPILIONACEAE

Crotalaria retusa

Megachile felina
Megachile ciastacombusta

Indigofera spicata

Ceratina sp 1
Ceratina sp 2
Lipotrichis sp 5
Megachile ciastacombusta
Xylocopa a
Xylocopa lottentota
Xylocopa somalica

Indigofera trita

Ceratina sp 1
Ceratina sp 2
Lipotrichis sp 6
Lipotrichis sp 7
Lipotrichis sp 9
Psuedapsis sp 1
Xylocopa caffra
Xylocopa flavocolis
Xylocopa lottentota
Xylocopa senoir

Indigofera vohamarensis

Amegilla mimadvena
Apis mellifera
Ceratina sp 1
Lipotrichis sp 8
Lipotrichis sp10
Lipotrichis sp11

***Tephrosia* sp 1**

Ceratina sp 3

***Tephrosia* sp 2**

Ceratina sp 3

***Tephrosia* sp 3**

Ceratina sp 3

POLYGONACEAE

Oxygonum salicifolium

Amegilla sp 2
Lipotrichis sp 1
Lipotrichis sp 2
Lipotrichis sp 3
Lipotrichis sp 4
Lipotrichis sp 5
Lipotrichis sp 7
Lipotrichis sp11

Oxygonum sinautum

Amegilla mimadvena
Amegilla sp 1
Amegilla sp 2
Apis mellifera
Bruanapis sp
Ceratina viridis
Ceratina sp 1
Ceratina sp 2
Ceratina sp 3
Ceratina sp 4

Coelioxysis sp

Lipotrichis sp 1

Lipotrichis sp 2

Lipotrichis sp 3

Lipotrichis sp 4

Lipotrichis sp 5

Lipotrichis sp 6

Lipotrichis sp 7

Lipotrichis sp 8

Lipotrichis sp 9

Lipotrichis sp10

Macrogalea candida

Megachile ciastacombusta

Megachile daviensis

Megachile sp 1

Megachile sp 2

Megachile sp 3

Megachile sp 4

Megachile sp 5

Megachile sp 7

Nomia ambile

Nomia sp

Pachyanthidium sp

Pseudoanthidium sp1

Psuedapsis sp

Seladonia sp 1

Thyreus pictus

Thyreus sp 3

Xylocopa flavocolis

Xylocopa flavonifa

Xylocopa senior

Xylocopa senoir

Xylocopa somalica

Polygonum aviculare

Amegilla (megamegilla) sp1)

Apis mellifera

Bruanapis sp

Ceratina sp 1

Ceratina sp 2

Ceratina sp 3

Ceratina sp 4

Ceratina viridis

Lipotrichis sp 1

Lipotrichis sp 2

Lipotrichis sp 3

Lipotrichis sp 4
Lipotrichis sp 5
Lipotrichis sp 7
Lipotrichis sp 8
Lipotrichis sp 9
Lipotrichis sp10
Lipotrichis sp11
Macrogalea candida
Megachile ciastacombusta
Megachile sp 1
Megachile sp 2
Megachile sp 5
Megachile sp 6
Nomia ambile
Pachymelus conspicuus
Pseudoanthidium sp
Pseudoanthidium sp
Psuedapsis sp
Seladonia sp 1
Serapista sp
Thrinchostoma torridium
Thyreus pictus
Thyreus sp 2
Xylocopa caffra
Xylocopa flavocolis
Xylocopa lottentota
Xylocopa somalica

RUBICEAE

Oldenlandia sp
Ceratina sp 1
Parvetta crebifolia
Apis mellifera
Ceratina sp 1
Ceratina sp 2
Ceratina sp 3
Macrogalea candida
Megachile sp 1
Megachile sp 2
Psuedapsis sp 1

SAPOTACEAE

Manilkara sansibarensis
Apis mellifera
Lipotrichis sp 1
Xylocopa flavocolis

Xylocopa flavonifa
Xylocopa lottentota

SOLANACEAE

Solanum incanum

Ceratina sp 3
Ceratina sp 4
Lipotrichis sp 6
Macrogalea candida
Psuedapsis sp 1
Xylocopa a
Xylocopa b
Xylocopa caffra
Xylocopa flavocolis
Xylocopa flavonifa
Xylocopa lottentota
Xylocopa senoir
Xylocopa somalica

STERCULIACEAE

Melhanianthus parviflora

Psuedapsis sp

Waltheria indica

Apis mellifera

TILIACEAE

Grewia plagiophylla

Ceratina sp 1
Lipotrichis sp 1
Lipotrichis sp 2
Lipotrichis sp 8
Lipotrichis sp10
Megachile sp 1
Megachile sp 2
Psuedapsis sp 1
Serapista sp
Stegnomus
Xylocopa a
Xylocopa b
Xylocopa caffra
Xylocopa flavocolis
Xylocopa lottentota
Xylocopa nigrita
Xylocopa senoir
Xylocopa somalica

Truimfetta rhomboidea

Apis mellifera
Ceratina sp 1
Ceratina sp 2
Ceratina sp 4
Lipotrichis sp 1
Lipotrichis sp 6
Lipotrichis sp 9
Lipotrichis sp10
Megachile sp 6
Pseudoanthidium sp
Psuedapsis sp 1
Seladonia sp 1
Tertaloniella sp
Thrinchostoma torridium
Xylocopa caffra

Xylocopa flavocolis
Xylocopa senoir

VERBENACEAE

Clerodendron insisum

Apis mellifera
Ceratina sp 1
Ceratina sp 2
Ceratina sp 3
Ceratina sp 4
Macrogalea candida
Megachile sp 1
Megachile sp 2
Megachile sp 5
Psuedapsis sp 1
Seladonia sp1