

BEE DIVERSITY AND FLORAL RESOURCES ALONG A DISTURBANCE GRADIENT IN KAYA MUHAKA FOREST AND SURROUNDING FARMLANDS OF COASTAL KENYA

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Abstract—Bees provide important pollination services that maintain native plant populations and ecosystem resilience, which is critical to the conservation of the rich and endemic biodiversity of Kaya forests along the Kenyan Coast. This study examined bee composition and floral resources from the forest core to the surrounding farmlands around Kaya Muhaka forest. In total, 755 individual bees, representing 41 species from three families were recorded: Apidae, Halictidae and Megachilidae. Overall, Apidae were the most abundant with a proportion of 76% of the total bee individuals, Halictidae at 14% and Megachilidae at 10%. Bee composition was similar between forest edge and crop fields as compared to forest core and fallow farmlands. We found a significant decrease in bee diversity with increasing distance from the forest to the surrounding farming area. A high abundance of bees was recorded in fallow farmland, which could be explained by the high abundance of floral resources in the habitat. We found floral resources richness to significantly affect bee species richness. These findings are important for understanding the effects of land use change on insect pollinators and their degree of resilience in disturbed habitats.

Keywords: Bee diversity; conservation; habitat disturbance; Kaya Muhaka forest; pollinator abundance

INTRODUCTION

There is evidence that pollinators are declining in some parts of the world (Keams et al. 1998; Kremen & Ricketts 2000), due to habitat destruction and land use intensification (Steffan-Dewenter & Westphal 2008). A strategic pollinator conservation plan should include their associated floral resources because the community structure of insect pollinators is related to their host plants (Potts et al. 2003; São Paulo Declaration 1999). Past studies have revealed positive relationships between bee abundance and floral abundance as well as between bee diversity and floral diversity (Banaszak 1996; Banaszak 2000; Potts et al. 2003). Kremen et al. (2007) explains that pollination services are provided by a variety of wild, free-living organisms but chiefly bees. Bees are the primary pollinators of rare and endangered plants, maintaining the biodiversity of most terrestrial eco-systems (LaSalle & Gould 1993; Stubbs et al. 1997). However, pollination services by wild bees are likely reduced in many areas and pollination-related problems within natural and agricultural ecosystems are becoming more common (Baude et al. 2016; Koh et al. 2016). Habitat fragmentation and isolation due to land use may reduce bee species richness and abundance and change their foraging behaviour (Didham et al. 1996). The decline may be

aggravated at the Kenyan coast due to agricultural encroachment, timber extraction and charcoal production (CEPF 2005). Moreover, commercially managed colonies of *Apis mellifera* have also declined in many parts of the world (Kremen et al. 2007). However, some bee communities appear to have some degree of resilience to land-use change (Banaszak 1992). Approaching such issues by documenting which species are involved is a key step to facilitating their conservation and management (Danks 1994).

Despite the ongoing concerns and controversy, there is little information on the response of bees to land-use change (Brosi et al. 2008) and only a few studies in Kenya have been published (Eardley et al. 2009; Gikungu 2006; Gikungu 2002; Gikungu et al. 2011). In agricultural regions, bees (Hymenoptera: Apoidea) are vital for successful fruit production (O'Toole 1993; Sheffield et al. 2003). Data on their relative abundance and diversity gives an indication of pollinator activities (Kevan 1999). Such data are missing in many forest ecosystems in Africa especially along the coastal region of East Africa. This study documents for the first time bees and their floral resources in Kaya Muhaka Forest and surrounding farmland in the coastal region of Kenya.

MATERIALS AND METHODS

Study area

The study was conducted at Kaya Muhaka forest (KMF) on the coastal plains of Kenya (Fig. 1), East Africa at a geographical location of 04° 18' S; 39° 33' E to 04° 38' S;

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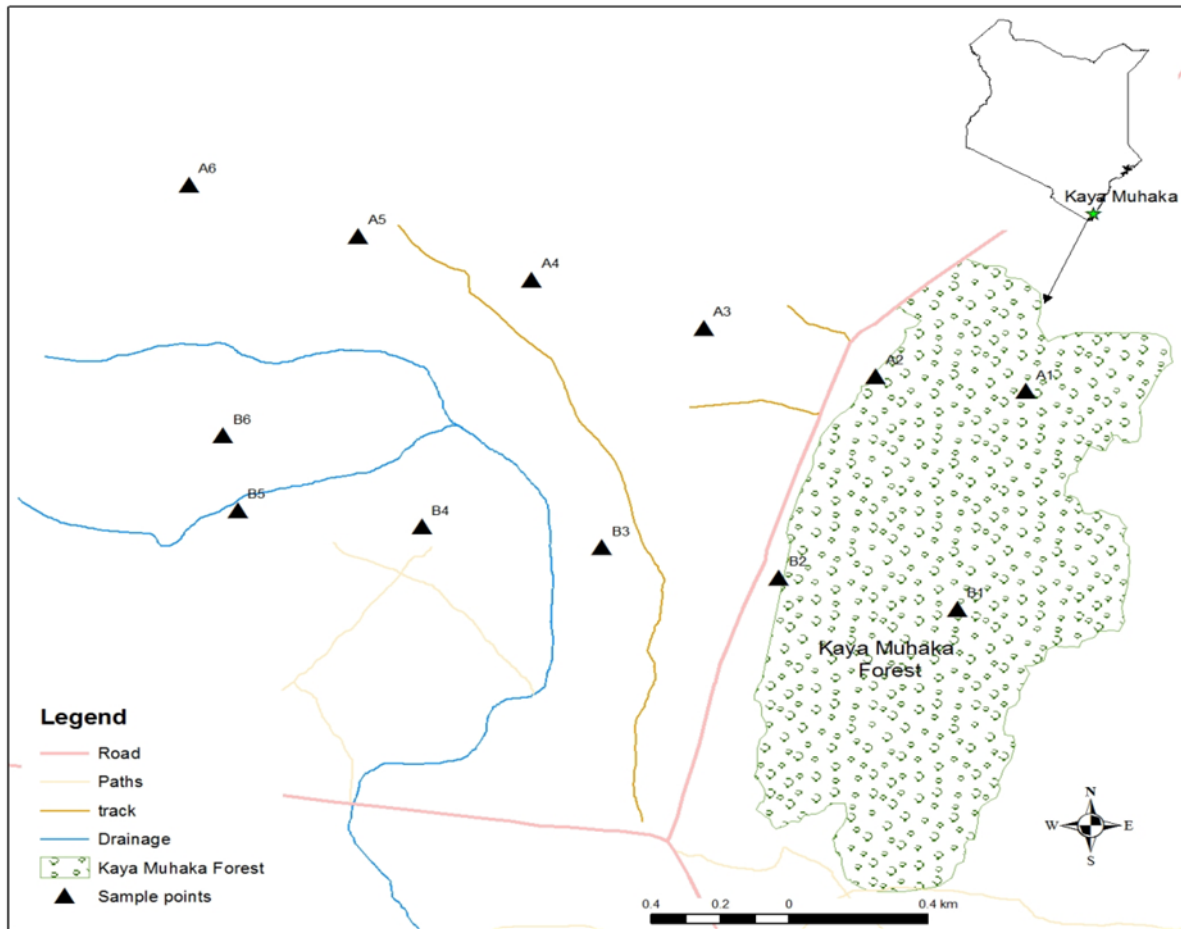


FIGURE I: Study area and satellite map of sampling points.

39° 53' E and surrounding farmlands. Kaya forests are residual patches of once extensive diverse lowland forest of Eastern Africa. It is a protected area and managed by Coastal Forest Conservation Unit (CFCU) of National Museums of Kenya (NMK) in conjunction with the local community. KMF covers about 130-150 ha and is located 32 km South of Mombasa town at an altitude of 20 - 40 m ASL.

Biodiversity of the coastal forests

The coastal forest stretches from Kenya to Tanzania and Islands of Zanzibar and Pemba, hosting more than 4,500 plant species and 1,050 plant genera with around 3,000 species and 750 genera occurring in the forest. At least 400 plant species are endemic to the forest patches and about another 500 are endemic to the intervening habitats that make up 99 percent of the eco-region area (WWF-US, 2003). They are botanically diverse with a high conservation value, consisting of regionally endemic climbers, shrubs, herbs, grasses and sedges (Burgess et al. 2000). The coastal forests are also known for high endemism of invertebrate groups such as millipedes, molluscs and forest butterflies (Burgess et al. 2000). KMF is known for a high Lepidoptera diversity and endemism (Lehmann & Kioko 2005). More than half of Kenya's rare plants occur in the coastal region, many in the Kayas. The flora of the forest is either vulnerable or endangered (TFCG 2007).

Farmlands

The surrounding farmlands are characterised by small-scale farming of subsistence crops, mainly cassava, cowpea, maize and rice. Also pigeon pea is sparsely distributed in these farms. Major commercial crops include coconut, citrus, cashew nut and mangoes. Cashew nuts and mangoes occupy major parts of the fallow farmlands. The latter is characterised by a mix of open grasslands, shrubs, mango and cashew nut trees. Farmlands close to settlements are dominated by coconut plantations.

Data collection

Data was collected in four habitat types, forest core, forest edge, fallow farmlands and crop fields. The forest core of Kaya Muhaka Forest was characterised by dense tree cover and a thick canopy. Forest edge was the transition from forest vegetation to fallow farmland. Fallow farmland was characterized by uncultivated land with wild herbaceous plants, stands of mango trees and cashew nuts while farmlands were cultivated areas. Two main transects, each 2.5 km long, were established from the forest core through the forest edge, fallow farmland to crop fields. Increasing distance from the forest to crop field was characterised by increased disturbance including uncontrolled habitat burning, human settlement, un-planned access routes and

TABLE I: GPS coordinates of sampling points of bees in Kaya Muhaka Forest and surrounding farmlands.

	N	E		N	E
AI	4.1972°	39.3159°	BI	4.2016°	39.3144°
A2	4.1968°	39.3141°	B2	4.2008°	39.3130°
A3	4.1965°	39.3117°	B3	4.2002°	39.3102°
A4	4.1957°	39.3091°	B4	4.1997°	39.3075°
A5	4.1948°	39.3064°	B5	4.1993°	39.3045°
A6	4.1940°	39.3036°	B6	4.1990°	39.3018°

planting of some crops with no floral benefit to the pollinators. Six sampling points were located along each transect at intervals of 0.5 km. A set of 3 parallel belt transects, 50 m long and 2 m wide (50 m × 2 m) were laid at each sampling point across the main transects. Belt transects are most effective active sampling methods for bees (Banaszak 1996). A total of 12 sampling points (Tab. I and Fig. 1) and 36 belt transects were established and surveyed. Each belt transect was surveyed three times per month from April to September 2010 covering the wet and the dry period. To adequately sample species with different diurnal patterns, sampling was done between 8.30 a.m. – 12.30 a.m. and 2.00 p.m. – 4.00 p.m. during sunny and partly cloudy days.

All foraging bees encountered along the 50 m × 2 m belt transects were collected using sweep nets (hand netting) within a standard 20 minute sampling time per belt for diversity and abundance data as described by Potts et al. (2003) and Banaszak (1996). The total number of bee individuals collected during the sampling period was considered as an estimate of bee abundance at each sampling point (Diego & Simberloff 2002). Individual bee samples were coded to be able to associate them with their habitats and floral resources. Bee collections for each day were pinned and later identified at NMK. To assess floral richness at each site, the number of understory plant species with open flowers was recorded at each sampling point. Samples of plants visited by bees were pressed and given the same code as the corresponding bee to correctly document bee-plant association (Gikungu 2006; Gikungu et al. 2011). Plant materials were taken to NMK Herbarium for expert identification.

Data analysis

Diversity was determined based on number of individual species; α Shannon's diversity index. Evenness index (J) was used to measure the relative abundance of bees in the study area. Renyi diversity profiles were used to visually compare bee diversity of the habitats, a higher profile along the entire range from ($\alpha = 0$) to ($\alpha = \text{Inf.}$) is considered to be more diverse (Kindt & Coe 2005). Renyi evenness profiles were used to visually compare bee evenness of the habitats, a profile higher than others along the entire range is considered more even.

Cluster analysis was used to analyse the ecological distance among the habitats to depict their similarity in bee

species composition. One-way ANOVA was used to compare the diversity and relative abundance of insects among habitats (forest core, forest edge, fallow farmland and crop fields). The relationship between bee species richness and floral resources richness was tested using simple linear regression analysis. Simple linear regression was also used to test the effect of increasing distance from forest core to crop fields on bee species diversity, richness and abundance. Analysis was done using R (R Development Core Team 2011).

RESULTS

Bee richness and abundance

A total of 755 bee individuals were collected on 60 days of the 6 months sampling period. About 41 bee species from 3 families (Apidae 76%, Halictidae 14% and Megachilidae 10%) were recorded (Tab. 2). Bee species richness decreased gradually from crop fields, forest edge, fallow farmland, to forest core (Fig. 2). Fallow farmlands had the highest overall bee abundance followed by crop fields then forest edge. Forest core recorded the least number of bee individuals (Fig. 3).

Effect of increasing distance from forest core on bee diversity and abundance

We recorded high bee species diversity at 0.5 km and 1.5 km from the centre of the forest. Bee diversity increased gradually with decreasing distance to forest core which was considered a no disturbance area. Bee diversity was measured by Shannon diversity index (H'). Bee diversity in fallow farmland at 1 km distance from the forest core was $H' = 2.673$, while at 1.5 km it was $H' = 2.668$, at 2 km $H' = 2.300$, and at 2.5 km in crop field it was $H' = 1.883$. The lowest diversity was recorded at 0 km (forest core), with $H' = 1.571$. Distance away from forest had significant effect on bee diversity ($F_{1,4} = 10.705$, $P < 0.05$). The highest bee abundance was recorded at 0.5 km (forest edge) and 1 km (fallow farmland) from the forest core. There was a marked reduction in bee abundance beyond 1 km from the forest core. Increasing distance from forest core had no significant effect on total bee abundance ($F_{1,4} = 0.389$, $P > 0.05$).

Effect of habitat and floral resources on bee composition

Crop fields and forest edge had similar bee species' composition. Fallow farmland shared more species with crop fields and forest edge than forest core, as shown by the cluster analysis (Fig. 4). Several floral resources, common in fallow farmlands and crop fields were visited by many bee species and were considered important flora for bees in the area, e.g. *Agathisanthemum bojeri*, *Crotalaria emarginata*, *Truinfetta rhomboidea*, *Cajanus cajan*, *Rhynchosia velutina*, *Julbernardia magnistipulata*, *Hyptis suaveolens*, *Eriosema glomeratum* and *Waltheria indica* (Tab. 2). The most abundant floral resource was *Agathisanthemum bojeri*; it was abundant at the forest edge. Floral richness declined gradually from the forest edge to crop fields. The highest richness was recorded at the forest edge followed by fallow farmlands then crop fields. The lowest floral resource

TABLE 2: Bee species and associated floral resources in Kaya Muhaka Forest and surrounding farmland collected in the period April 2010 to September 2010.

Bee Family	Bee species	Number of individuals encountered	Floral resources
Apidae	<i>Amegilla mimadvena</i>	4	<i>Hibiscus surattensis</i>
	<i>Amegilla</i> sp. 1	39	<i>Agathisanthemum bojeri</i> <i>Julbernardia magnistipulata</i> <i>Rhynchosia velutina</i> <i>Vernonia cinerea</i>
	<i>Apis mellifera</i>	59	<i>Abutilon zanzibaricum</i> <i>Agathisanthemum bojeri</i> <i>Julbernardia magnistipulata</i> <i>Ludwigia</i> sp. <i>Nesaea radicans</i> <i>Sorindeia madagascariensis</i> <i>Tridax procumbens</i>
	<i>Braunsapis</i> sp.	33	<i>Cocos nucifera</i> <i>Crotalaria emarginata</i> Benth <i>Hoslundia opposita</i> <i>Paulinia pinata</i>
	<i>Ceratina</i> sp. 1	22	<i>Allophylus rubifolius</i> <i>Hoslundia opposita</i>
	<i>Ceratina</i> sp. 2	7	<i>Agathisanthemum bojeri</i> <i>Tridax procumbens</i>
	<i>Ceratina</i> sp. 3	163	<i>Allophylus rubifolius</i> <i>Eriosema glomeratum</i> <i>Gossypioides kirkii</i> <i>Paulinia pinata</i> <i>Waltheria indica</i>
	<i>Ceratina</i> sp. 4	19	<i>Agathisanthemum bojeri</i>
	<i>Ceratina</i> sp. 5	1	<i>Waltheria indica</i>
	<i>Ceratina</i> sp. 6	4	<i>Agathisanthemum bojeri</i>
	<i>Ceratina</i> sp. 7	15	<i>Agathisanthemum bojeri</i> <i>Waltheria indica</i>
	<i>Dactylurina schmidtii</i>	19	<i>Cajanus cajan</i> <i>Urena lobata</i>
	<i>Hypotrigona</i> sp. 1	15	<i>Cajanus cajan</i>
	<i>Hypotrigona</i> sp. 2	4	<i>Cajanus cajan</i>
	<i>Macrogalea candida</i>	30	<i>Agathisanthemum bojeri</i> <i>Hewittia malabarica</i> <i>Waltheria indica</i>
	<i>Meliponula ferruginea</i>	8	<i>Agathisanthemum bojeri</i> <i>Cocos nucifera</i>
	<i>Xylocopa caffra</i>	33	<i>Abutilon zanzibaricum</i> <i>Agathisanthemum bojeri</i> <i>Cajanus cajan</i> <i>Rhynchosia velutina</i> <i>Rhynchosia velutina</i> <i>Vernonia cinerea</i>
	<i>Xylocopa flavicollis</i>	38	<i>Abutilon zanzibaricum</i> <i>Rhynchosia velutina</i> <i>Vernonia cinerea</i>
	<i>Xylocopa hottentota</i>	20	<i>Julbernardia magnistipulata</i> <i>Rhynchosia velutina</i> <i>Vernonia cinerea</i> <i>Waltheria indica</i>
	<i>Xylocopa nigrita</i>	4	<i>Cajanus cajan</i>

TABLE 2 continued

Bee Family	Bee species	Number of individuals encountered	Floral resources
	<i>Xylocopa scioensis</i>	21	<i>Rhynchosia velutina</i>
Halictidae	<i>Lasioglossum</i> sp.	4	<i>Allophylus rubifolius</i> <i>Eriosema glomeratum</i> <i>Truimfetta rhomboidea</i>
	<i>Lipotriches</i> sp. 1	39	<i>Pupalia lappalea</i>
	<i>Lipotriches</i> sp. 2	6	<i>Pupalia lappalea</i>
	<i>Lipotriches</i> sp. 3	12	<i>Agathisanthemum bojeri</i>
	<i>Lipotriches</i> sp. 4	11	<i>Hoslundia opposita</i>
	<i>Nomia</i> sp.	4	<i>Julbernardia magnistipulata</i>
	<i>Pseudapis</i> sp.	24	<i>Agathisanthemum bojeri</i> <i>Allophylus rubifolius</i> <i>Chamaecrista mimosoides</i> <i>Eriosema glomeratum</i> <i>Pupalia lappalea</i>
	<i>Pseudapis</i> sp. 2	8	<i>Chamaecrista mimosoides</i>
	<i>Steganomus</i> sp.	11	<i>Crotalaria emarginata Benth</i>
	Megachilidae	<i>Euaspis abdominalis</i>	3
<i>Heriades</i> sp.		18	<i>Truimfetta rhomboidea</i>
<i>Megachile discolour</i>		4	<i>Crotalaria emarginata Benth</i> <i>Crotalaria emarginata Benth</i>
<i>Megachile felina</i>		7	<i>Crotalaria emarginata Benth</i>
<i>Megachile</i> sp. 2		19	<i>Cajanus cajan</i> <i>Crotalaria emarginata Benth</i> <i>Hyptis suaveolens</i> <i>Indigofera paniculata</i> <i>Indigofera paniculata</i> <i>Julbernardia magnistipulata</i> <i>Tephrosia villosa</i> <i>Truimfetta rhomboidea</i>
<i>Megachile</i> sp. 3		10	<i>Hyptis suaveolens</i> <i>Truimfetta rhomboidea</i>
<i>Megachile</i> sp. 5		1	<i>Hyptis suaveolens</i>
<i>Megachile</i> sp. 7		4	<i>Philenoptera bussei</i>
<i>Megachile</i> sp. 8		4	<i>Hyptis suaveolens</i>
<i>Megachille</i> sp. 6		1	<i>Agathisanthemum bojeri</i>
<i>Pachyanthidium</i> sp.		7	<i>Rhynchosia velutina</i>

richness was noticed in the forest core at 0 km. Increasing distance from forest core had no significant effect on floral richness ($F_{1,4} = 0.0005$, $P = 0.983$). Floral richness had a significant positive effect on bee species richness ($F_{1,10} = 34.5$, $P < 0.0002$, $R^2 = 0.775$) (Fig. 5).

Bee relative abundance

Overall, there was uneven distribution of bee species in the survey area, the evenness index was $J = 0.427$. However, evenness was generally higher in the forest core than in other habitats followed by fallow farmlands. Forest edge and crop fields were largely uneven as indicated by their low profiles (Fig. 6). High abundance of *Ceratina* sp. 3, *Apis mellifera*, *Amegilla* sp. 1, *Lipotriches* sp. 1, *Xylocopa flavicollis*,

Braunsapis sp., *Macrogalea candida*, and *Xylocopa caffra*, affected mainly the evenness of bee distribution.

DISCUSSION

Effect of habitat type on bee diversity and abundance

Overall bee abundance is a positive function of the abundance of flowers in a habitat (Banaszak 1996; Potts et al. 2003). This fact could explain the high overall diversity and abundance of bees in fallow farmland recorded in the study area. The key floral resources supporting high bee diversity in fallow farmlands were mainly annual plants. Bee diversity is known to be strongly correlated with the species

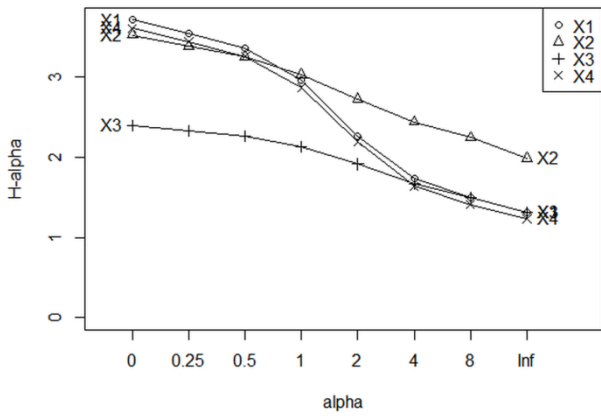


FIGURE 2: Rényi diversity profiles for separate habitats; alpha = 0 indicates species richness; marked points along each profile represent randomly selected sampling points for each habitat: X1-Crop fields, X2-Fallow farmland, X3-Forest core, X4-Forest edge.

richness of annuals (Potts et al. 2003) and overall floral diversity (Banaszak 1996). Our results finding agree with Gikungu et al. (2011) in Kakamega forest, where the overall bee abundance was high in fallow farmlands as well. Apart from a high richness of floral resources, fallow farmland was constantly very heterogeneous, consisting of woody and herbaceous plants offering nesting and feeding requirements for a large diversity of bee species. The heterogeneity attributed to a mix of large cashew nut trees, mango trees and associated woody shrubs, annual flowering plants and grassland patches.

At the forest edge, high abundance of *Agathesanthemum bojeri*, *Tridax procumbens* and *Waltheria indica* probably

attracted foraging bees contributing to an important bee abundance. Bee abundance in crop fields was similar to that of the forest edge due to low-level land use and limited or no use of agrochemicals. After crop harvest, abundant weedy plants flowered on the fields attracting foraging bee species. Crop fields were also characterised by unmanaged hedgerows, which appeared advantageous for the survival of wild flowers that attracted bees. Also Potts et al. (2003) showed that open habitats with abundant floral resources attract numerous foraging bee species. Such disturbed habitats have favourable environmental conditions that are correlated with high bee abundance including temperature, light intensity and humidity (Liow et al. 2001). The low bee diversity and abundance observed in the forest core could thus be attributed to low temperatures, higher humidity and low light intensity associated with a closed forest canopy. Furthermore, the forest core had the lowest abundance and richness of floral resources, explaining the relatively low bee diversity we recorded. However, we considered only the understory community where very few plants were flowering.

Surprisingly, crop fields had the greatest absolute bee species richness. Besides floral resource abundance this could further be attributed to the high attraction of ‘tourist’ bee species to such disturbed habitats. These do not reside within them and have potentially large foraging ranges like *Amegilla* and *Xylocopa* sp. (Liow et al. 2001). If managed properly, crop fields may thus offer supplementary conservation sites for bee species. Carefully designed wild flower and crop mixtures in crop fields could supply important floral resources to bee species in farmlands and support bee conservation in farmlands. Highly abundant bee species included *Ceratina* sp, *Apis mellifera*, *Lipotriches* sp,

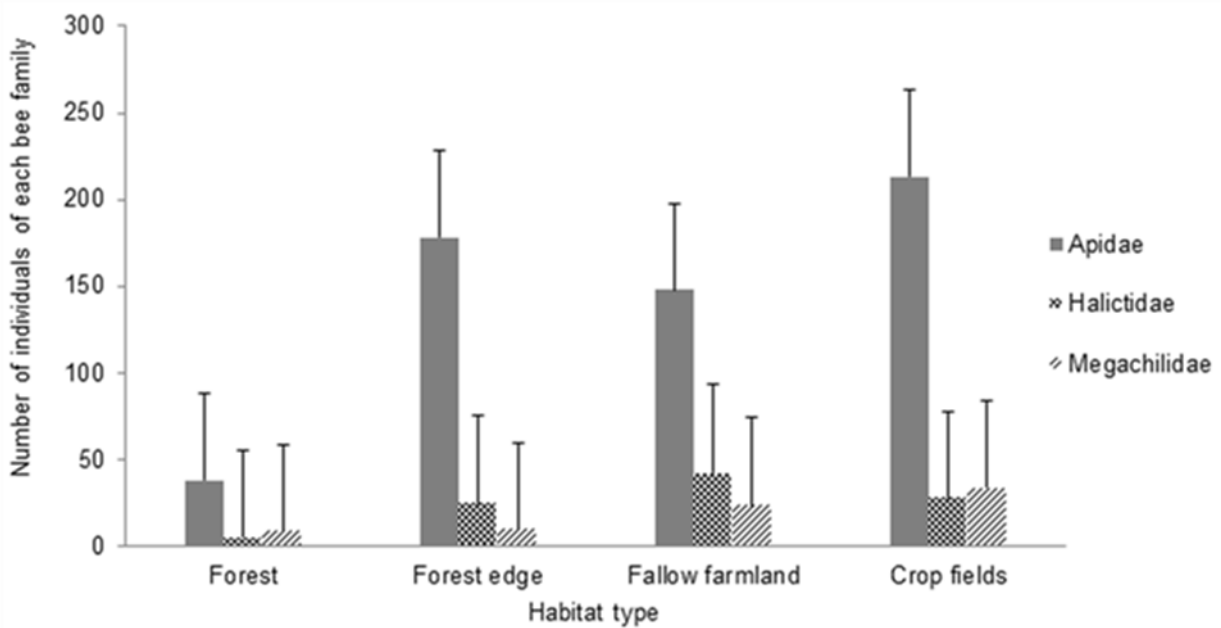


FIGURE 3: Abundance of each bee family per habitat. Bars represent number of individuals with standard error.

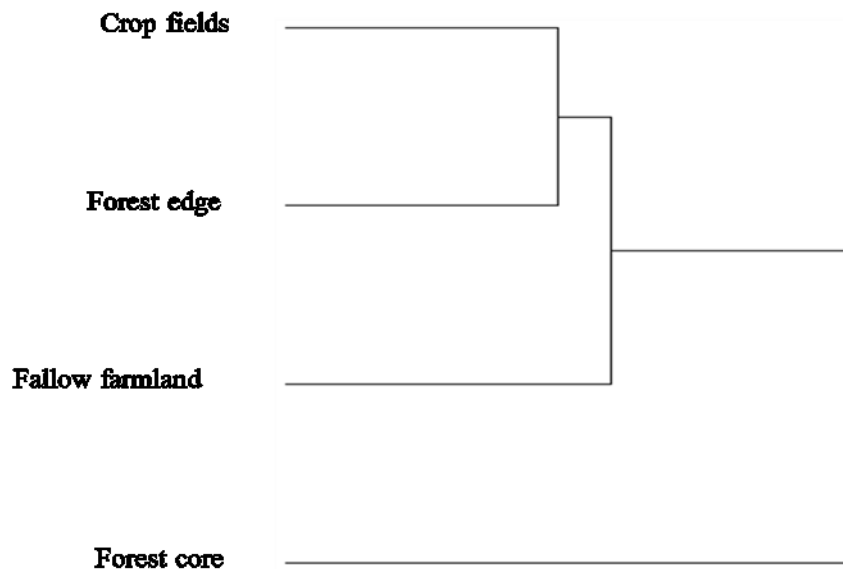


FIGURE 4: Cluster analysis of bee species composition in Kaya Muhaka Forest and surrounding farmland: X1-Crop fields, X2-Fallow farmland, X3-Forest core, X4-Forest edge.

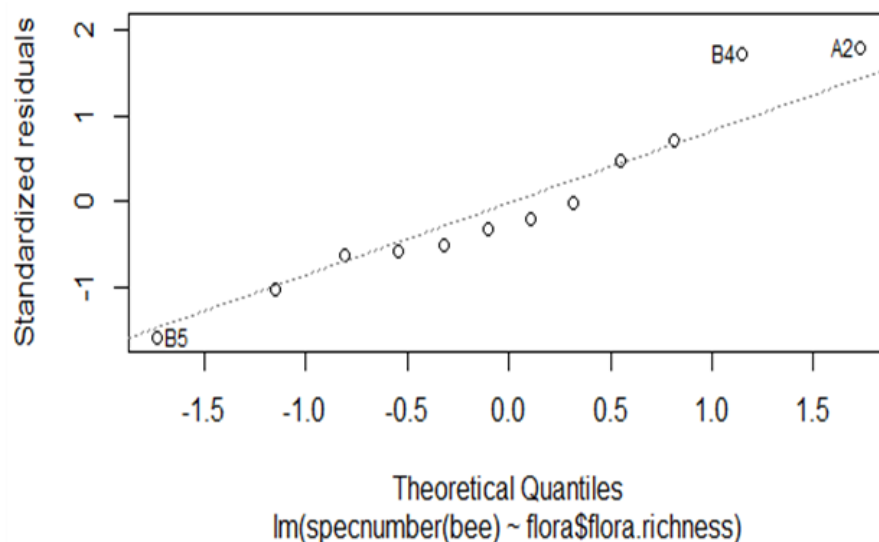


FIGURE 5: Effect of floral resources richness on bee species richness.

Xylocopa flavicollis, *Braunsapis* sp, *Macrogalea candida* and *Xylocopa caffra*. However, low abundance of some bee species, especially solitary bees, could be attributed to a limitation or absence of their preferred host plants. Possibly rare bee species, which were recorded in low numbers were i.a. *Euasapis* sp., *Lasioglossum* sp., *Amegilla mimadvena*, and *Xylocopa nigrita*. Future studies should focus on such rare species and their habitat requirements.

Halictidae were most abundant in fallow farmland where relatively stable habitat conditions with a mix of grasses and shrubs in this habitat could provide favourable nesting sites. Apidae was the dominant bee family across all habitats, similar to a study at Mt. Carmel (Potts et al. 2003). Most Apidae species are long distance foragers and can explore

diverse nectariferous flowers across many habitats. They are less affected by differences in habitats and abundant in diverse habitat types. High abundance of *Ceratina* sp. and honey bees (*Apis mellifera*) contributed largely to the dominance of the family.

Megachilidae were more common in crop fields, attributable to the presence of their important floral resources, Leguminaceae plants e.g *Cajanus cajan* and *Crotalaria emarginata*. The distribution of Megachilidae appeared to be linked to pollen resources as in the case of leguminous plants, see also Potts et al. (2003). It is evident that different groups of bees show contrasting responses to land use change, likely driven by differences in their foraging and nesting biology (Brosi et al. 2008).

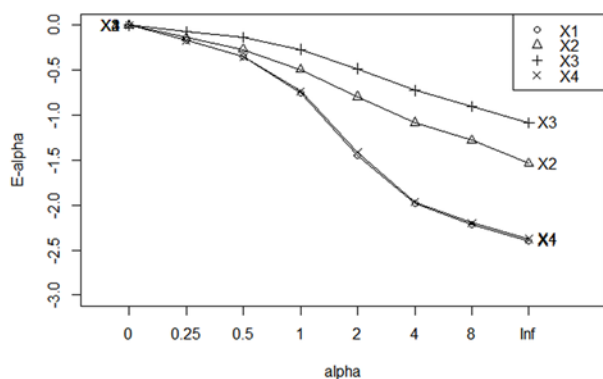


FIGURE 6: Rényi evenness profiles of bees for separate habitats; marked points along each profile represent randomly selected sampling points for each habitat: X1-Crop fields, X2-Fallow farmland, X3-Forest core, X4-Forest edge

Effect of increasing distance from forest on bee diversity and abundance

In contrast to Brosi et al. 2007 and Klein et al. (2007), we found a significant negative effect of distance from the forest core on bee diversity. The results provide evidence that distance from natural habitats may strongly determine spatial distribution of bees. This finding conforms to the pattern found by Ricketts et al. (2008) which reported that native pollinator visitation rate drops to 50 % away from natural habitats. The result is also consistent with the findings of similar research (e.g., Morandin & Winson 2005; Chacoff & Aizen 2006; Bailey et al. 2014). However, overall bee abundance did not vary significantly with distance from the forest implying that most bees are dependent on habitat quality rather than proximity to primary forests and some occur in high abundance away from the natural forest. Kaya Muhaka forest and forest edge probably act as buffers for conservation of bees where they may seek refuge for nesting and foraging when the farmlands are extensively impoverished and indiscriminately disturbed. Though the level of habitat heterogeneity in the habitats was not the same, it was observed across all habitats. This could have been the most important factor influencing the diversity and abundance of bees. Regional habitat heterogeneity could be a more important factor than farming practice in determining the diversity and abundance of pollinators in agricultural landscapes (Brosi et al. 2008).

This study reveals that habitat heterogeneity, presence of natural habitats and land use practices are key factors in determining bee diversity and abundance in a given region. Natural habitats and sites with high heterogeneity have the highest capacity to provide diverse ecological requirements for insect pollinators including shelter, foraging, mating and breeding sites (Kremen et al. 2007). Open and heterogeneous habitats support high bee diversity and overall pollinator abundance. Forest core, forest edge, fallow farmlands and crop fields are important and complement each other in the conservation of insect pollinators. Contrary to traditional opinion, farmlands can be important conservation areas when properly managed to maintain habitat quality, a fact emphasised by Klein et al. (2007). Kaya Muhaka forest and surrounding farmlands have the

potential to support diverse bee communities. However, current human activities may lead to habitat change and degradation and will need to be controlled to further threaten bee populations. Forest edge is an important foraging site for insect pollinators and needs to be conserved. An ecosystem approach to farming in the Muhaka area, along with careful management including wildflowers and crop mixtures, could help to make the farmlands important conservation sites for bees and other pollinators. Our findings echo the need for an ecosystem approach for the management of agro-ecosystems to support sustainable pollination services and contribute to our understanding of the effects of land use change on insect pollinators and their degree of resilience in disturbed habitats.

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