ORIGINAL RESEARCH ARTICLE

Assessment of abundance and diversity of bee species in various agroecological zones in Loitokitok Sub County, Kenya

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ABSTRACT
The bee community is prone to great threats, especially from agronomic activities and climate change. Understanding how bee species vary in abundance and diversity in various agroecological zones is significant towards the development of effective measures to ensure that the environment is protected and conserved. Thus, this study sought to assess the abundance and diversity of bee species in various agroecological zones in Loitokitok sub-county, Kenya. An experimental research design comprising three different habitats was conducted. The study area was stratified into three habitats: (1) cultivated farm, (2) rangeland, and (3) natural forest. A survey of the study area was done, and the habitats were identified. A sample area of 1 × 1 km square was picked at random from each of the three study areas. The selected areas were further subdivided into 0.5 × 0.5 km smaller study areas, and a total of 3 belts were laid down randomly within the small study areas. Sampling of the bees was done for 3 months using a sweep net and pan traps to collect the bee species. The Shannon Weiner diversity index was used to compute the diversity and richness of honey bee species. A one-way ANOVA was used to compute the statistical significance of bee species abundance across the three habitats. A total of 1,106 bee specimens from 2 families and 7 species were collected from the three study habitats. *Apis mellifera* was the most abundant bee species, followed by *Pseudapis spp.*, *Lasioglossum spp., Xylocopa spp., Braunsapis spp., and Ceratina spp.,* while *Heriades spp.* was the least abundant bee species. Natural edge habitat had the highest bee species abundance, followed by rangeland, while cultivated habitat had the least bee species abundance. Cultivated habitat recorded the highest diversity index, $H^{/}$= 1.511 followed by rangeland with $H^{/}$= 1.424 while natural habitat had the least at $H^{/}$= 1.351. However, the overall diversity index was $H^{/}$= 1.43. This study reveals that agronomic activities had an influence on bee species abundance and diversity. Therefore, the findings from this study can be used to devise policies for adoption in sensitising farmers, the public, and relevant stakeholders on the importance of bees, their contribution to livelihood, and their role in enhancing food security and the maintenance of forest cover.

Key words: Abundance, Diversity, Agronomic, Apis, Loitokitok

1.0 Introduction
Globally, human activities in an ecosystem that can result in habitat modifications will disturb bee life, which will decrease their abundance (Beyene and Verschuur, 2014). Bee resources such as nesting, sites, mating, and food will also diminish. Large-scale livestock rearing has the potential to result in overstocking, hence overgrazing, deforestation for crop production,

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monoculture, and the establishment of irrigation schemes for some crop routine management practices such as smoking and pesticide sprays, which will kill or repel foraging bees during visitation during flowering periods (Ali et al., 2014).

The emergence of industries, coupled with numerous industrial operations such as cultivation, irrigation, and deforestation, damages nesting locations of pollinators (Kremen et al., 2007; Biesmeijer et al., 2006). Variations in industrial practices can impact bee abundance and diversity and thus lower their ecological efficiency (Gray et al., 2019). Intensive farming usually results in increased use of agrochemicals such as pesticides, which have negative impacts on the bee community (Nayak et al., 2015). Furthermore, organic farming, which is less embraced than the use of agrochemicals, has proven to be of great significance for the bee population, as observed by Power *et al.* (2012).

Intensive agricultural activities compounded with irrigation systems and deforestation for farming can result in homogenization of the bee community (Ekroos et al., 2010), with a loss of habitat specialists and poor dispersers leaving only common taxa. Thus, any alteration in agricultural areas that leads to changes in land use, spatial configuration, or intensity of management has the potential to affect the abundance and diversity of the bee community (Oliver et al., 2010).

The cultivated area of bee-dependent crops has increased worldwide, raising demand for insect pollination three-fold since 1961 (Aizen and Harder, 2009). This demand is unlikely to be met by managed honey bees alone, given that their activity is often insufficient to deliver adequate quantity and quality pollen at the appropriate time and place (Garibaldi et al., 2011). It has been established that the definite role of pesticides in bees' health is further complicated because places where pesticide use is intense often also correspond with places with low availability of both flower resources and nesting sites (Whittaker, 1972; Kremen et al., 2007).

Insecticides have an impact that reduces bee foraging efficiency and also may affect the health of the bees if they are exposed at a time when their food resources have been contaminated by the application of such herbicides (Brittain et al., 2010). Intensive herbicide utilization severely lowers non-crop plant diversity and abundance, compromising food accessibility for bees (Krupke et al., 2017). Chemical devastation of environments through the substantial use of herbicides generates long-term concerns, especially the occurrence of pollinators in agro-habitats (UNEP, 2010).

Any agronomic practice that can decrease bee populations leads to inadequate pollination in crops since their population size is greatly affected (Karanja et al., 2013). Nevertheless, some plants may not be at a losing end and produce optimally since the dominant bee may not be their pollinator (Kasina, 2018). However, bee community destruction can also be enhanced by natural calamities such as fire, floods, drought, pests, and diseases, which also lower their population size (Goulson et al., 2015). Thus, humans should manage the effects of such calamities by providing survival options to the insects and protecting them against pests and diseases (Kasina, 2007).

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Habitat loss and pesticide application can contribute to the decline of the bee community (Mutuku et al., 2013). The pesticide risk assessment carried out has generated information related to only a few bee species, such as *A. mellifera*. Usually, pesticides are used injudiciously without clear direction, hence negatively impacting non-target organisms such as honeybees; hence, cross-pollination (Aizen et al., 2009). This in turn lowers crop yields, threatening livelihoods (Magembe et al., 2014). The use of pesticides is a common practice in farming with detrimental effects on mortality or transformed foraging capabilities for bees, as observed by Mutuku *et al*. (2013).

Several studies have revealed that excessive use of chemicals lowers the immune system of insects, rendering them susceptible to diseases, parasites, and pathogens. Muli *et al*. (2014) showed that the combined effects of imidacloprid and parasite infestation significantly weakened honeybees, causing high mortality and high levels of stress, blocking the ability of bees to sterilise the colony and their food, and thus weakening the colony as a whole.

Loitokitok Sub-County is an agro-pastoral area with intensive agronomic practices, including farming activities (Magembe et al., 2014). Further, it has varied edaphic and climatic conditions ideal for a range of plant vegetation with nectar and pollen to sustain a large number of honeybee colonies (Muli et al., 2014). Continuous use of monocropping systems leads to a decline in biodiversity, particularly in terms of genomic diversity, plant diversity, and farmlands surrounded by croplands, restricting the quantity of food to be accessed by pollinators in a given space and period (Oliver et al., 2010). Additionally, Biesmeijer *et al*. (2006) conducted an investigation on the degeneration of plant diversity in parallel with the drop in bees and other insect pollinators.

Moreover, in Loitokitok sub-county, Kenya, studies on the assessment of the abundance and diversity of bee species in various agroecological zones have not been established yet. However, a few studies on bees, particularly pollination, have been carried out on some crops, such as pollination of C. arabica (coffee) in Kiambu County carried out by Karanja et al. (2013), bee abundance, diversity, and pollination by Gikungu (2002, 2018), pollination of indigenous crops in Mwingi by Njoroge et al. (2006), pollination of C. lanatus (water melon) at Yatta (Njoroge, 2005) and bottle guard (Lagenaria sicerana) (Morimoto et al., 2004), and studies done in Kakamega on the economic value of pollinators for crop pollination (Kasina, 2018). Kiatoko *et al*. (2014) have done a study on enhancement of fruit quality in *Capsicum annum* through pollination by *Hypotrigona gribodoi* in Kakamega, Western Kenya, and Kioko *et al*. (2017) have carried out a study on bee diversity and floral resources along a disturbance gradient in Kaya Muhaka Forest and surrounding farmlands of coastal Kenya. All these studies did not look at the effects of anthropogenic activities on abundance, diversity, and the state of indigenous knowledge in the bee community. Therefore, this study assessed the abundance and diversity of bee species in various agroecological zones in Loitokitok Sub-County, Kenya.

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2.0 Materials and methods

2.1 Description of the study area

Loitokitok sub-county is found in Kajiado County, Kenya. It is situated in the Rift Valley and borders Narok and Kiambu counties to the west, Nairobi and Machakos counties to the north, Makueni and Taita/Taveta counties to the east, and Tanzania to the south (Figure 1). The subcounty lies between latitudes 10° 10´ and 30° 10´ south and longitudes 2° 36´ and 37° 53´ east. The Sub County covers an area of about 6300 km^2 with six group ranges, namely: Rombo, Kuku A and B, Kimana, Olgulului, Imbirikani, Ensenkei, and some privately owned ranges. The area is mainly composed of *Themeda* grassland, dwarf shrubs, *Acacia drapanolopium* grassland, *Croton* bushes, and other woody species interspersed with grassland (Okello et al., 2011a).

There are several types of soils in the Loitokitok ecosystem: luvisols, cambisols, volcanics, saline and sodic lacustrine, and pleistocene volcanics. The Pleistocene volcanic soils favour agricultural production, especially maize production at the foot of Mt. Kilimanjaro (Burnsilver et al., 2008). In addition, alluvial clays accumulate in seasonal runoff, which traps nutrients and supports grass growth for a while after the rains (Kimana Integrated Wetland Management Plans, 2008–2013).

The vast Loitokitok Ecosystem has been subject to considerable vegetation changes, including the domination of dense woodlands and thickets in the Loitokitok Plains due to the effects of agronomic activities, a change in climate, low fire frequency due to recurrent droughts, and low animal numbers (Okello et al., 2011b). The annual temperature ranges from 18.4 °C to 22.3 °C. The sub-county receives a bimodal form of precipitation, with short rains from October to December and long rains from March to May. The average annual rainfall is 500mm around Lake Amboseli and Magadi and 1250mm on the slopes of Mt. Kilimanjaro. The Loitokitok naturally supports a mixture of forest and woodland with scattered bushes and open grasslands, but is rapidly being transformed into cultivated land. The main land uses in the area are pastoralism, tourism, and agriculture. The area was selected because of its vast array of land-use practices. The site was chosen based on a visual determination of the intensity of various land use practices like agriculture and forested land in order to cover a wider range of agronomically affected areas. The map (Figure 1) is a section of Loitokitok Sub-County.

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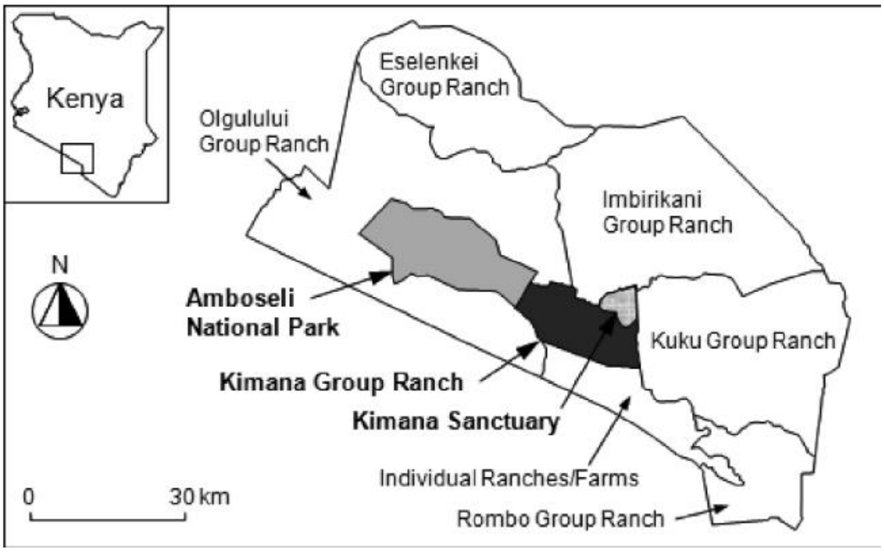

Figure 1: Map of Oloitokitok sub-county, Research gate.net, (2021)

2.2 Sample Size and sampling procedures

Among the seven ranches, namely Kuku, Eselenkei, Olgului, Imbirikani, Rombo, Kimana, individual farms, and Amboseli National Park, stratified random sampling was used to divide the study area into mutually exclusive groups based on the relevant characteristics. The study area was stratified into three habitats: 1) cultivated farms and human settlements. 2) Rangeland, and 3) natural forest edge.

Cultivated farms and areas under human settlement are more disturbed by agronomic activities; rangelands represent areas with a moderate level of agronomic disturbances, while the natural forest habitat is prone to minimal agronomic disturbances and therefore is chosen based on a visual determination of the intensity of various land use practices like agriculture and forested land in order to cover a wider range of agronomically affected areas.

Ten farms were selected using simple randomization along a transect of 3 km, running from the forest edge to the arable land. A sample area of 1 × 1 km square was picked at random from each of the three study areas. Those selected areas were further subdivided into 0.5 × 0.5 km smaller study areas, and a total of 3 belts were laid down randomly within the habitats. The areas consist of a mosaic of many different habitats and field types. In order to limit the habitats surveyed per transect, transects will be restricted to 500 m by 20 m in size.

For the area under agriculture and human settlements, they were selected by simple randomization along a transect of 3 km, running from the edge of the forest towards farmland. This also involved moving along a pre-determined route, and all bees seen were captured using a sweep net. The programme GPS Utility was used to place transects within each site. In each habitat, sampling was done twice for 16 days: once during the rainy season (January to April) and once during the dry season (May to October). This involved bee netting, using sweep nets to actively capture bees while foraging on flowers. Sampling was spread over three months, so that the habitats were visited at different times during each season. In the forest habitat, a 1.5-kilometre-long study transect was established along a path through the forest with a minimum

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distance to the forest border of 150 m to avoid edge effects. Each transect was visited for 13 continuous days between 7:00 a.m. and 6:00 p.m. This ensured that bees active at different times of the day were represented in the data. On the remaining three days, a 350-metre-long section of the forest border was visited because some bee species normally live in the tree crowns and only come down to lower vegetation levels along forest edges.

2.3 Data collection

In each habitat, nesting and visiting bees were observed using a pair of binoculars in each sampled habitat. Bees in the sampled habitats were noted and captured by the use of a sweep net over a 1km belt transect. After each collection, the bees were killed using ethanol, sun-dried for three days, and preserved in storage containers, which were preserved using naphthalene to guard them from pest attack and damage. This was followed by pinning, labelling, and archiving in the National Museum of Kenya laboratory.

For bees that may not be captured from the flowering plants, there were three pan traps of different conspicuous colours, blue, white, and yellow (Morandin et al., 2007; Campbell and Hanula, 2007), laid at random points per habitat in order to trap any bees that may not be collected by sweep nets. There was 200 ml of rainwater and 4 ml of unscented cleansing agent placed in each laid trap. The collected bees were put in vials, sun-dried for three days, and then pinned and transported to the laboratory at the Zoology Department in the National Museums of Kenya, Nairobi, for identification. The collected bees were morphologically distinguished by colour and body size and then classified according to genus level. All the bees identified were used for the determination of abundance and diversity. In the course of the observation period, bees were differentiated by colour and body size. This was simultaneously done in the three habitats at an interval of 15 minutes in each habitat to avoid variations (Gikungu, 2002).

2.4 Data Analysis

Descriptive statistics, such as frequencies and percentages, were used to describe the data. A one-way ANOVA was used to compute the statistical significance of bee species abundance across the three agroecological habitats. Data on bee species diversity in the three habitats was calculated using the Shannon diversity (H) index (Shannon and Weiner, 1949). Species richness is a biologically appropriate measure of alpha (α) diversity and is usually expressed as the number of species per sample unit (Whittaker, 1972). The Shannon diversity index (H) was computed using the following equation:

$$\text{Shannon Index } (H^{/}) = \sum p_i (\ln p_i)$$

Where, $H^{/}$= diversity, ∑= Summation, $p_i = n_i/N_{total,}$ ln = natural logarithim, Ni= number of individuals of species *i*, Ntotal = Total number of individuals on all species.

3.0 RESULTS

3.1 Abundance of bees

A total of 1,106 bee specimens from 2 families and 7 species were collected from the three study habitats. *Apidae* was the most abundant family, with four bee species. There were six

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unidentified bee species: three from the *Apidae* family and three from the *Halictidae* family. The distribution of total bee specimens collected comprised 600 *Apis mellifera,* 200 *Pseudapis spp.*, 90 *Lasioglossum spp.,* 70 *Xylocopa spp., Braunsapis spp.* had 60, *Ceratina spp.* had 50, and *Heriades spp.* had 36 individuals (Table 1).

Table 1: Bee family, genera and species names

Family	Genus	Species	No. of Individuals	Abundance (%)
Apidae	*Apis*	*Mellifera*	600	54.3
	Xylocopa	*Sp.*	70	6.3
	Ceratina	*Sp.*	50	4.5
	Braunsapis	*Sp.*	60	5.4
Halictidae	*Pseudapis*	*Sp.*	200	18.1
	Lasioglossum	*Sp.*	90	8.1
	Heriades	*Sp.*	36	3.3

In terms of percentage abundance, out of the aggregate number of honey bee specimens collected, 54.3% were *A. mellifera*, followed by 18.1% *Pseudapis spp.*, 8.1% *Lasioglossum spp.,* 6.3% *Xylocopa spp.,* 5.4% *Braunsapis spp., and* 4.5% *Ceratina sp.,* while *Heriades spp.* had the least, 3.3% of the total bee specimens collected, as shown in Figure 2.

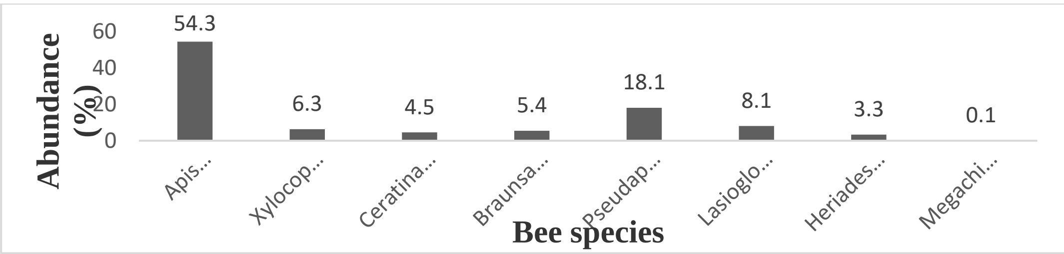

Figure 2: Bee species abundance

3.1.1 Abundance of bees in each habitat

The natural habitat recorded the highest bee species abundance of 594 individuals followed by rangeland and the cultivated land had the least bee species abundance of 218 as illustrated in Table 2.

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Table 2: Bees species abundance in each habitat

Bee species	Cultivated Farm		Rangeland		Natural forest edge	
	No. of individuals	Percentage	No. of individuals	Percentage	No. of individuals	Percentage
Apis Mellifera	110	50.5	150	51.0	340	57.2
Xylocopa sp.	13	6.0	20	6.8	37	6.2
Ceratina sp.	16	7.3	15	5.1	19	3.2
Braunsapis sp.	12	5.5	20	6.8	28	4.7
Pseudapis sp.	39	17.9	51	17.3	110	18.5
Lasioglossum sp.	20	9.2	28	9.5	42	7.1
Heriades sp.	8	3.7	10	3.4	18	3.0

A summary of the bee species distribution in each habitat was computed, and the natural habitat recorded the highest bee species abundance of 594 individuals, followed by rangeland, and the cultivated habitat had the least bee species abundance of 218 individuals, as illustrated in Table 3.

Table 3: Summary of bee species abundance in each habitat

Habitat	No. of individuals	Abundance (%)
Cultivated land	218	19.7
Rangeland	294	26.6
Natural forest edge	594	53.7

3.1.2. Similarity of bee species abundance between different habitats

A one-way ANOVA was used to compute the statistical significance of bee species abundance across the three habitats. There was a statistical significance ($p < 0.05$) between cultivated habitat and rangeland, cultivated habitat and natural forest edge, and also between rangeland and natural forest edge.

3.1.3 Commonest bee species based on number of encounters on each habitat

A. mellifera was the most common bee species in the three study habitats followed by *Pseudapis sp.* while *Heriades spp* was the least common bee species in the study habitats as shown in Figure 3.

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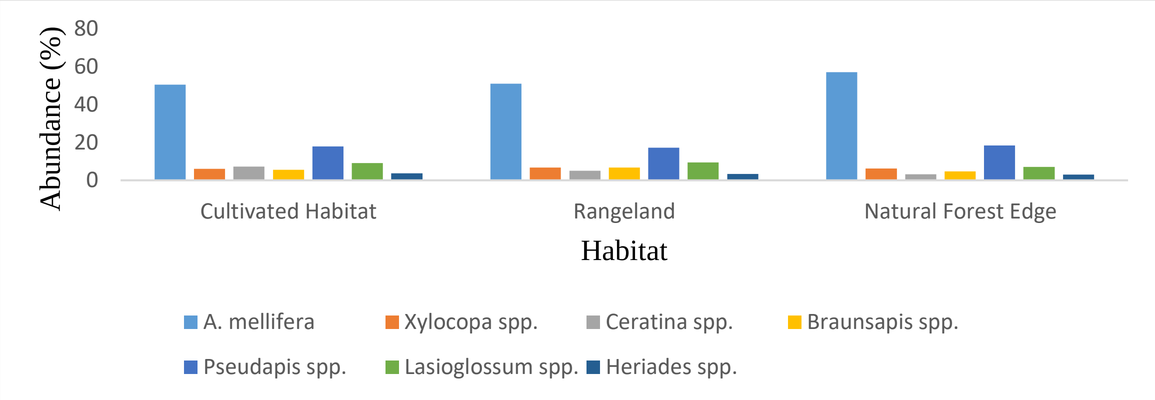

Figure 3: Commonest Bee species based on Number of Encounters on each Habitat

3.2 Diversity of the bee species

3.2.1 Diversity of the bees in the cultivated habitat

Bee species diversity in the cultivated habitat was computed based on individual bee species abundance. A diversity index, $H^{/}$= 1.511, was obtained as illustrated in Table 4.

Table 4: Diversity index of bee species in the cultivated habitat

Bee species	No. of individuals	pi= Sample/sum	ln(p*i*)	P*i** ln(p*i*)
Apis Mellifera	110	0. 505	-0.683	-0.345
Xylocopa sp.	13	0.059	-2.830	-0.167
Ceratina sp.	16	0.073	-2.617	-0.191
Braunsapis sp.	12	0.055	-2.900	-0.159
Pseudapis sp.	39	0.179	-2.720	-0.308
Lasioglossum sp.	20	0.092	-2.386	-0.219
Heriades sp.	8	0.037	-3.397	-0.122

Diversity index $H^{/}$; summation of p*i**ln (p*i*) of each bee species and therefore; $H^{/}$= 1.511.

3.2.2 Diversity of bees in rangeland habitat

Bee species diversity in the rangeland habitat was computed based on individual bee species abundance. A diversity index, $H^{/}$= 1.424, was obtained as illustrated in Table 5.

Table 5: Diversity index of bee species in the rangeland habitat

Bee species	No. of individuals	pi= Sample/sum	ln(p*i*)	P*i** ln(pi)
Apis Mellifera	150	0. 510	-0.673	-0.343
Xylocopa sp.	20	0.068	-2.688	-0.182
Ceratina sp.	15	0.051	-2.976	-0.152
Braunsapis sp.	20	0.068	-2.688	-0.183
Pseudapis sp.	51	0.173	-1.754	-0.303
Lasioglossum sp.	20	0.095	-2.354	-0.224
Heriades sp.	10	0.034	-1.079	-0.037

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Diversity index $H^{/}$; summation of p*i**ln (p*i*) of each bee species and therefore; $H^{/}$= 1.424.

3.2.3 Diversity index of Bees in the natural forest habitat

Bee species diversity in the natural habitat was computed based on individual bee species abundance. A diversity index, $H^{/}$= 1.351, was obtained as illustrated in Table 6.

Table 6: Diversity index of bee species in Natural habitat

Bee species	No. of individuals	p*i*= Sample/sum	ln(p*i*)	P*i** ln(p*i*)
Apis Mellifera	340	0. 572	-0.559	-0.320
Xylocopa sp.	37	0.062	-2.781	-0.172
Ceratina sp.	19	0.032	-3.442	-0.110
Braunsapis sp.	28	0.047	-3.058	-0.144
Pseudapis sp.	110	0.185	-1.687	-0.312
Lasioglossum sp.	42	0.071	-2.645	-0.188
Heriades sp.	18	0.030	-3.507	-0.105

Diversity index $H^{/}$; summation of p*i**ln (p*i*) of each bee species and therefore; $H^{/}$= 1.351

Comparison of the diversity indices of the three habitats was done. Cultivated habitat had the highest diversity index $H^{/}$= 1.511 followed by rangeland with $H^{/}$= 1.424 while the natural habitat had the least at $H^{/}$= 1.351 as shown in Figure 5.

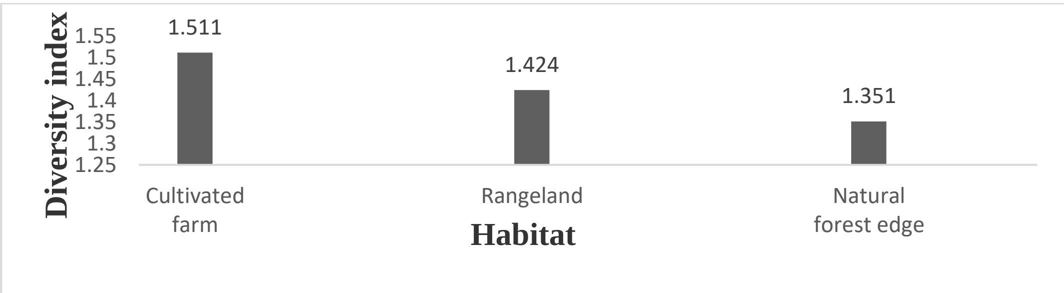

Figure 5: Comparison of the diversity indices of the three study habitats

3.2.4 Overall diversity index

The overall bee species diversity was computed based on individual bee species abundance. A diversity index, $H^{/}$= 1.430, was obtained as illustrated in Table 7.

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Table 7: Overall diversity index

Bee species	No. of individuals	pi= Sample/sum	ln(pi)	Pi* ln(pi)
Apis Mellifera	600	0. 542	-0.612	-0.332
Xylocopa sp.	70	0.063	-2.765	-0.174
Ceratina sp.	50	0.045	-3.101	-0.140
Braunsapis sp.	60	0.054	-2.919	-0.158
Pseudapis sp.	200	0.181	-1.709	-0.309
Lasioglossum sp.	90	0.081	-2.513	-0.204
Heriades sp.	36	0.033	-3.411	-0.113

4.0 DISCUSSION

4.1 Abundance and diversity of the bee community

4.1.1 Abundance of the Bees species

Seven bee species from seven genera belonging to two families were collected from the habitats studied. The bee species abundance increased across the cultivated habitat, rangeland, and natural forest habitat. Notably, honey bees are among the most poorly studied insect groups in East Africa, following a lack of adequate bee taxonomists (Masiga *et al.,* 2014). *Apis,* followed by *Pseudapis spp.,* recorded the highest bee abundance. The individuals of *A. mellifera* were great in number compared to other bee species. These results are in tandem with those obtained by Kasina *et al*. (2018), who established that *A. mellifera* was the most abundant bee species in common bean farms. The number of individuals of *A. mellifera* was higher than that of other bee species and kept dominating in each habitat compared to other bee species. This high abundance of *A. mellifera* can be attributed to its crucial role in offering pollination services to most flowering plants, as noted by Potts *et al.* (2016).

Mellifera is a social bee, and sociality is often central since social bees can communicate the availability of resources to their colony and recruit in large numbers to mass flowering crops such as coffee (Kioko *et al.,* 2017; Marzinzig et al., 2018). Additionally, *A. mellifera* is aggressive in nature and takes advantage of the intense nectar flow associated with coffee flowering (Vergara & Badano, 2009). It has the ability to inhabit and persevere in diverse habitat types, nest under a variety of conditions, and forage on a great variety of both native and alien flowers (Chacoff & Aizen, 2006). In support of these results, Vergara & Badano (2009) conducted a related study in Mexico and established that *A. mellifera* was the most abundant bee species, accounting for more than 80% of total bee assemblages.

4.1.2 Diversity of the Bee species

Typical diversity index values are generally between 1.5 and 3.5. In most ecological studies, the index is rarely greater than 4. However, higher values indicate lower diversity, while lower values indicate high diversity (Shannon and Weiner, 1949). The bee species diversity index was highest in the cultivated habitat with $H^{/}$= 1.55, followed by rangeland with $H^{/}$= 1.42, and the natural forest edge had $H^{/}$= 1.35. This study established that there was variation in bee species diversity in the studied habitats. These differences in diversity indices among the studied habitats can be linked to variations in agronomic activities, light intensity, and amounts of floral resources, as noted by Kioko *et al.* (2017). These findings are in tandem with those recorded by Shambhu *et*

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al. (2013), who recorded a diversity index of 1.01 on a cultivated farm. Individuals belonging to seven bee species were collected from Loitoktok Sub County. These findings are in agreement with those obtained by Masiga *et al.* (2014) on a farmland of French beans on the north-eastern slopes of Mt. Kenya, which recorded bees in five families, five genera, and eight species. Similarly, Gikungu (2006) recorded 17 bee species from a farmland of non-crop plants belonging to the Fabaceae family. Additionally, Gikungu (ibid.) found more than 200 species of bees in the forest and in the more open farmland. According to Greenleaf and Kremen (2006), the diversity of wild bee populations influences the efficiency of ecological bee services such as pollination, and therefore, agronomic activities pose dangers to bee species diversity, as noted by Lautenbach *et al*. (2017). Agronomic practices compounded with tropical deforestation have been documented to change bee communities due to foraging characteristics (Campbell *et al.,* 2018; Lautenbach *et al*., 2017; Gikungu *et al.,* 2018). Nevertheless, fallow farmland can provide resources for pollinators and greater bee diversity (Chiawo *et al.,* 2017). According to Martins *et al.* (2015), changes in land uses and climate are stressors to species declines such as *Meliponula* (stingless bees).

Thus, these study findings are of great significance since they can be used to devise policies for adoption in sensitising farmers, the public, and relevant stakeholders on the importance of the bee community, their contribution to livelihood, and their crucial role in augmenting food security and maintaining the forest cover.

5.0 Conclusion

Habitat heterogeneity is a significant factor that influences the diversity and abundance of bees in various agroecological zones. For instance, habitats with high heterogeneity exhibit great potential to meet the diverse ecological needs of the bee community.

In this study, the abundance of bee species decreased across the agroecological zones studied: natural forest edge, rangeland, and cultivated habitat. However, bee species diversity increased from natural habitat (rangeland to cultivated habitat. *A. mellifera* (Honey bees) was the most abundant bee species in the study area.

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6.3 Conflict of interest

None.

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