International Journal of Environmental Studies

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/genv20

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INTERNATIONAL JOURNAL OF ENVIRONMENTAL STUDIES
https://doi.org/10.1080/00207233.2022.2085447

Bee species diversity and nesting sites in cultivated savannah, northern Zimbabwe

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ABSTRACT

Bees play key roles in savannah ecosystems but face myriad threats. A combination of flower sweep netting and visual observations was used to determine bee-species diversity and preferred nesting sites in five villages in Nyamakate communal area, northern Zimbabwe. Almost 2000 bees were collected comprising two bee families and five species with diversity of Shannon-Weiner index (H') = 0.45 (0.19). *Apis mellifera scutellata* was widely distributed and the dominant bee species; it has a wide choice of nesting sites and high adaptation ability. Effective conservation of nesting habitats such as forest, woody vegetation, and riverine water sources is required to maintain bee-species diversity in an agro-based savannah ecosystem.

KEYWORDS

Bees; *Apis mellifera*; diversity; savannah; agro-ecosystem

Introduction

The worldwide increase in the human population and consequent demand for land for industry, agriculture and settlement at the expense of natural ecosystems threatens the health and survival of many bee species, [1,2] most directly by disrupting food chains and, not least, in savannah ecosystems.[3,4]

To date, approximately 25,000 bee species have been named from an estimated 40,000 species.[5,6] Worldwide, honeybees (*Apis mellifera* L.) are widely distributed on almost every continent[7,8]. They are the only managed pollinators in Africa and their distribution has been increased through domestication and the introduction of alien plants: on the other hand, slash-and-burn agriculture has reduced both arboreal and ground-nesting populations. A few studies in east Africa have indicated that the agro-based savannah ecosystem supports greater species diversity and abundance than the natural wild ecosystem. There have been few comprehensive studies, however, on bee species diversity and distribution in most African savannah ecosystems. They are needed to help guide conservationists, farmers, and policymakers on sustainable use and management,[8–10] in particular to identify ecosystems with high bee species diversity and endemicity where conservation should be a priority. Recent research indicates that land use affects bees' habitat availability, nutrition and forage availability and a holistic approach including making agricultural practices more

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Published online 09 Jun 2022

bee-friendly is the key to effective bee conservation. Species distribution modelling (SDM) has been used to predict future bee species distribution. The main predictors for fauna species distribution include food availability and competition.[11]

The few studies in Zimbabwe have been concerned mostly with apiculture and bee conservation. The East African lowland honey bee (*Apis mellifera scutellata*) is the common bee species in Zimbabwe's wild and agro-based savannah ecosystems,[12] nesting in trees (trunks, branches, cracks and openings) and ground surfaces but agriculture presents dire threats: in particular, tobacco farming destroys woodland not only for land clearance but for firewood and poles; one tobacco farming season may require about 60 trees per farmer for tobacco curing and other requirements.[13,14] Afforestation programmmes have met with little success and farming practices continue to threaten bees' habitat; indiscriminate use of agrochemicals contaminates the nectar and pollen that the bees depend on; and herbicides destroy many plants that are sources of pollen, nectar, and nesting sites.[13,15,16]

The objectives of this study were to: (i) determine bee species diversity and (ii) establish bee species nest site selection in Nyamakate communal area, northern Zimbabwe.

Material and methods

Study area

Nyamakate communal area lies within Hurungwe district, northern Zimbabwe (Figure 1), lat. 16° 30' S, long. 29° 30' E. Land use includes small- and large-scale farming and Community-Based Natural Resource Management programs. Annual rainfall ranges between 500 and 750 mm; maximum temperatures from 26°C to 32°C, and minimum temperatures from 19° to 23°C.[17] The soils have a moderate amount of clay and bases,

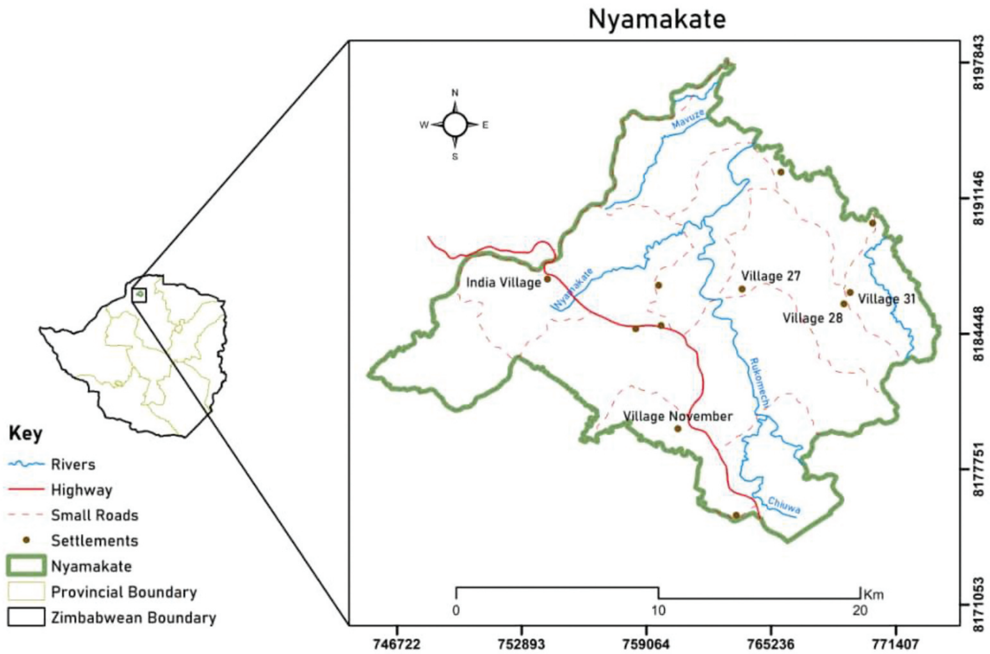

Figure 1. Study area in Hurungwe district, northern Zimbabwe.

with less active clays, high kaolinite and oxides. Soils vary from one place to the other depending mainly on the parent rock and drainage condition. Soils from ubiquitous granite are yellow to yellowish-brown in well-drained areas. Some are red to reddish-brown where the parent material is mafic. The presence of a moderate amount of oxides results in most soils being fairly porous, well-drained and fairly resistant to erosion.[18] A wide range of crops includes maize, tobacco, cotton, beans, sorghum and groundnuts. The district has an estimated human population of 329,197 and covers about 19,200 sq. km.[19] Diverse, native *Miombo* woodland is being replaced by *Acacia* woodland or farmland and the Nyamakate and Rukomechi rivers, once perennial, are now seasonal and suffer serious siltation because of bad farming practices.[17] The land adjacent to the Hurungwe Safari area is home to elephants, kudu, eland, lions, hyenas and leopards. The main domestic animals are cattle, goats and chickens.

Data collection

Stratified random sampling was applied. Five villages were selected randomly from the 48 villages in Nyamakate communal area (villages 27, 28, 29, November and India, hereafter referred to as 1, 2, 3, 4, and 5 respectively). Twelve belt transects (50x200m) were established per village (six transects from cropped fields and six non-cropped).

Bee species diversity

The belt-transect survey was conducted between October 2018 and February 2019, each transect being surveyed once for the whole study period. Sampling was conducted between 08.30 and 14.30 hours, during which period, most bees are foraging given suitable weather.[20,21] In each belt transect, net sweeping was used to capture and collect the bees encountered. Field visual observation, photographs, and recordings were also used to account for some species which were not captured by sweep net. The trapped bees were rinsed and stored in 70% ethanol in separate vials. Species identifications were made following Levchenko & Tomkovich[22] and Prys-Jones & Corbet[23] and, where specimens were not identified to species level in the field, they were taken to Zimbabwe National Museum, Entomology Section in Bulawayo for expert identification. Other insects (*Arachnida, Diptera, Coleoptera, Hemiptera*, and *Thysanoptera)* were not examined further after classification to order level.

Bee species nest site selection

The visually observed nest sites were profiled and recorded using GPS with a clinometer to measure nests' height above. We recorded whether it was a natural site or artificial (beehive of any type).

Data analysis

Occurrence data on bee species for the five villages were collated and used to compute their diversity, evenness, and dominance. Bee species diversity was analysed using the Shannon-Weiner Diversity Index.[23]

$$H' = -\sum_{i=1}^{s}(P_i \times \ln P_i)$$

where *H'* = the Shannon-Weiner diversity index, Pi = fraction of the entire population made up of species I, S = numbers of species encountered, ∑ = sum from species 1 to species S.

All data variables were tested for normality and homogeneity of variance using the Shapiro-Wilk test and Levene's test, respectively. Variables did not conform to the normality assumptions. Therefore, Kruskal-Wallis tests were used to determine whether there were differences in the diversity indices across the five villages. To determine the association of study sites across the villages based on the abundance of bee species, multivariate analysis by a linear ordination technique and principal component analysis using the factoextra package. All statistical analysis was computed in R 4.0.0.

Results

Bee species diversity

A total of 1,929 bees were collected comprising two bee families (*Apidae* and *Megachilidae*) and five species (*Apis mellifera scutellata, Plebeina hildebrandti, Hypotrigona Araujo, Xylocopa caffra, and Megachile rotundata*). *A.m. scutellata* was the dominant bee species in all sampled villages (Table 1) Village 5 recorded the highest number of bees, viz., 658 bees, during the survey. Village 1 had a high number but mostly dominated by *A.m scutellata* and its evenness was low. Village 4 recorded low bee species diversity of 0.94 (0.29) with low species dominance of 0.48 ± 0.22. There is a marginal difference in species evenness from all five villages sampled.

A correlation matrix for the transformed bees dataset from a high-dimensional to a low-dimensional data cube from PC1 up to PC4 is shown in a PCA biplot (Figure 2). In terms of the factor loadings, PC1 with eigenvalues of 1.19 contains more of *A. m. scutellata*, and *X. caffra* is represented on the positive. The other two are shown in very low quantities on the negative. PC2 vector represented three of the species as negatives with very low values even for *X. caffra* represented on the positive. The variance was high for PC1 and has been decreasing with increasing numbers of PC output from PC1 up to PC4.

Cumulative variance continued to increase. *H. araujo* cannot be represented as a positive vector for all the four PC components unless it is transformed using multiplication by its inverse. The PC analysis shows that there are more *A. m. scutellata* and *X. caffra* recording 0.69 and 0.69, respectively, and are all represented on PC1. In summary, much of the data has been represented on the negative side of the vectors as shown on the 2D PCA where such data appear as outliers deviating from the mean centre. Such deviations are prominent in villages 3, 4 and 5.

Table 1. Diversity indices of bee species recorded in the five study villages.

	Study Area						
Diversity Indices	Village 1	Village 2	Village 3	Village 4	Village 5	KW-χ^2, (4 d.f.)	p-value
Shannon	0.45 (0.19)	0.66 (0.49)	0.81 (0.46)	0.94 (0.29)	0.76 (0.52)	3.1	0.541
Evenness	0.39 ± 0.15	0.65 ± 0.27	0.56 ± 0.36	0.58 ± 0.31	0.49 ± 0.32	3.35	0.502
Dominance	0.80 ± 0.13	0.58 ± 0.23	0.59 ± 0.35	0.48 ± 0.22	0.59 ± 0.35	2.68	0.612

The values presented are the median and interquartile range (IQR) in parenthesis.

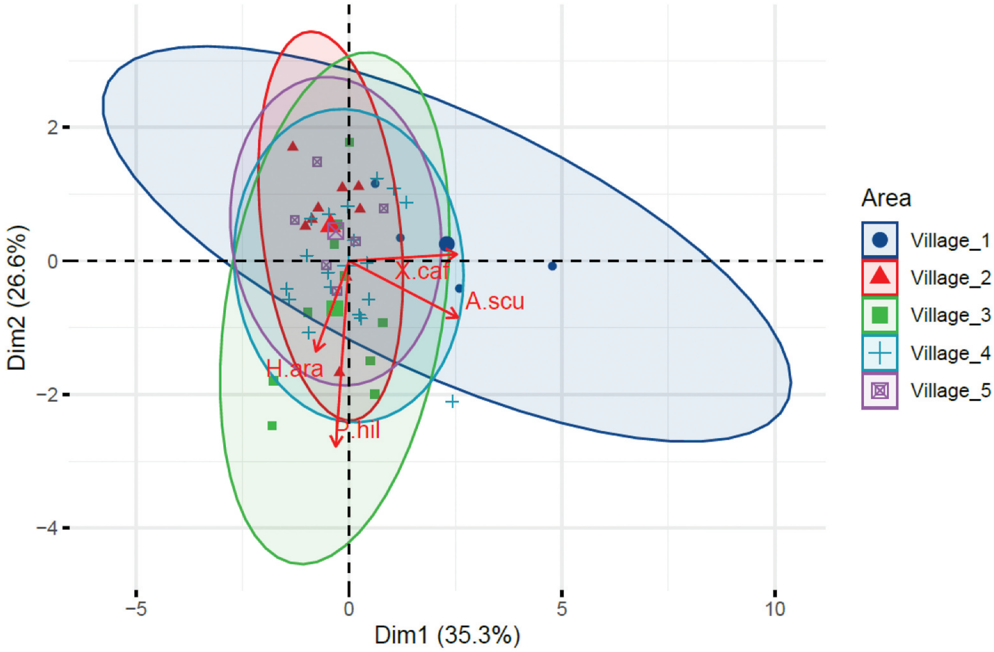

Figure 2. Principal component analysis biplot for bee species in five villages.
Notes: *A.scu – Apis mellifera scutellata; H.ara -Hypotrigona araujo; X. caf – Xylocopa caffra; P.hil – Plebeina hibrbrandti.*

Nest sites

Artificial structures/beehives were the preferred nesting sites, but ground/anthills were the least preferred nesting sites for the *A.m. scutellata* (Table 2). *P. hildebrandti, H. Araujo*, and *X. caffra* only used natural wood openings and ground/anthills for nesting. The *M. rotundata* was not found nesting on the ground/anthills. *A.m. scutellata* (19 sites) were observed on the ground/anthills. *M. rotundata* (5 sites) were found nested in natural wood openings.

The mean height of tree-based nesting sites varied significantly with open natural tree branches (any part of a tree branch) having a height of 2.82 ± 0.10 m. A natural wood opening (any hole or opening in a tree) had a height of 2.37 ± 0.10 m (Table 3). The survey established 658 and 105 bee nest sites for *A.m. scutellata* for village 4 and village 5, respectively (Table 2). The average nearest distance of nest sites from a major water source ranged from 300 m to 1,500 m.

Discussion

The study presents the first attempt to look at the bee species diversity and nesting site preferences in an agro-based savannah ecosystem in northern Zimbabwe. *A.m. scutellata* was the dominant bee species in all sampled villages; Village 4 recorded the highest numbers. *A.m. scutellata* has a wide adaptation and resistance to anthropogenic activities such as deforestation, use of environment-unfriendly agro-chemicals, and regular harvest of honey in communal areas;[20] unlike *P. hildebrandti, X. caffra, Megachile rotundata* and

Table 2. Established bee nest types in the five villages.

	Study area and number of bee species																								
	Village 1					Village 2					Village 3					Village 4					Village 5				
Type of nest	As	Ph	Ha	Xc	Mr	As	Ph	Ha	Xc	Mr	As	Ph	Ha	Xc	Mr	As	Ph	Ha	Xc	Mr	As	Ph	Ha	Xc	Mr
Natural wood openings	59	30	16	11	5	52	47	11	28	6	56	54	29	13	3	53	93	24	0	5	18	35	16	6	4
Open natural tree branches	2	0	0	0	0	1	0	0	0	0	2	0	0	0	0	23	0	0	0	0	8	0	0	0	0
On the ground/anthills	3	0	0	0	0	4	0	0	0	0	1	0	0	0	0	9	0	0	0	0	2	0	0	0	0
Artificial structures/bee hives	103	0	0	0	0	149	0	0	0	0	298	0	0	0	0	573	0	0	0	0	77	0	0	0	0

Notes: As- *A.m. scutellata*; Ph- *P hildebrandti*; Ha- *H Araujo*; Xc- *X caffra*; Mr- *M rotundata.*

Table 3. Established nests for *A.m. scutellata* re distance from water source and height above ground.

Type of nest	Study area and number of bee species					Mean height of a nest above ground (m)
	Village 1	Village 2	Village 3	Village 4	Village 5	
Natural wood openings	59	52	56	53	18	2.37 ± 0.10 m
Open natural tree branches	2	1	2	23	8	2.8 2 ± 0.10 m
Artificial structures/bee hives	103	149	298	573	77	2.13 ± 0.10 m
Mean distance from perennial water source (m)	300–1,500	300–1,200	300–900	300–900	300–1,200	

H. Araujo, A.m. scutellata can easily be domesticated and bred by apiculturists, as was observed in the village 4 which had 573 occupied beehives. This observation is consistent with other studies which found *A.m. scutellata* to be widespread across Africa and other continents because of its ability to adapt.[24–28]

We observed 1200 artificial beehives occupied by *A.m. scutellata* within 5 villages. In addition, 298 natural bee nests for 4 bee species were observed. Villages 3 and 4 recorded high numbers of artificial beehives and they share a boundary with the Hurungwe safari area which has undisturbed natural forest. The reason for high occupancy and use of artificial beehives by *A.m. scutellata* could be their spaciousness, well-sited to reduce predation, strategically positioned close to water and feed, and their ability to protect bees from adverse weather, natural fires, pests, and diseases. Human influence through apiculture and good habitat plays a significant role in influencing bee species diversity and population distribution, whereas areas with intense human settlement and agricultural activities fail to support diverse bee species owing to the impact of pesticides, nutritional deficits, habitat destruction, veld fires, and soil disturbance.[9,14,21]

A.m. scutellata makes use of a variety of nest sites across all sampled villages. All sites that were not on the ground were more than 2 m above ground (Figure 3), and only 19 nest sites for *A.m. scutellata* and 5 nest sites for *M. rotundata* were on the ground/anthills. Nest site selection is critical: poor choice can increase predation and nest destruction and result in reproductive failure.[6] *Apis dorsata* and *A. florea* can nest in open combs, whereas *Apis cerana* mainly nests in cavities at an average height of 1.5 m.[6]

Figure 3. Observed honeybee nesting sites Nyamakate communal area (Agness Gapa).

In the present study, about 274 of the honey bee natural nest sites were above 2 m from the ground surface and many *Apis* species nests on sites such as cliff faces or underneath branches of tall trees are inaccessible to most predators except skilled climbers and fliers.

The average distance of nest sites from a major water source ranged from 300 to 1,500 m. Water and forage availability determine possible areas where honey bees could nest. *Apis* bees in the tropics have home ranges from 100 m to 5 km.[29,30] Climate change has an impact on water and forage availability and this may increase honey bee home ranges and their distribution.[14,26,27]

Our findings have significant implications for the conservation and management of honey bees at a landscape scale. Since *A.m. scutellata* use woodland, agricultural land, and tall trees for nesting as well as rivers and streams for water, increasing scarcity of such sites is limiting their distribution and abundance. Over the geographical range of *A.m. scutellata* in Africa, the rate of deforestation is very high and selective logging of tall trees can affect the nesting of bees. We infer that poor farming practices such as deforestation, use of toxic chemicals, and stream bank cultivation are major threats to honey bees in an agro-based savannah ecosystem – and the protection of nesting sites such as large trees, riverine areas, and forests is crucial for maintaining the viable populations of this keystone pollinator. Hence, the protection of *A.m. scutellata* nesting sites such as large trees, riverine areas, and forests is crucial for maintaining the viable populations of this keystone pollinator.[9,31]

Separate long-term studies on solitary bee species diversity are needed. Solitary bees have a limited period of activity (approximately one to two months) which normally corresponds with the flowering of their host plants.

Conclusions

We recorded two bee families and five species, with *A.m. scutellata* being the dominant and widely distributed species.

Despite threats from human activities, *A.m. scutellata* was widely distributed with some variations in diversity among the study villages.

Artificial beehives and natural wood openings were the preferred nesting sites for *A.m. scutellata* and *P. hildebrandti*. Habitat, forage availability, and water play an important role in bee diversity and nesting sites selection. Protection of such sites is essential for bee conservation.

We recommend natural habitat protection and further analysis of *A.m. scutellata* and other bee species' relationship with land-use practices to ensure their long-term survival in the study area and beyond.

Acknowledgments

We thank L. Katurura, M. Gomwe, F. Hlongwane, A. Malunga and T.T.C Nyatanga for assistance in fieldwork and R. Gondo and N. R. Moyo for insightful comments. We are grateful to Nyamakate communal area village heads who permitted us to conduct the study within their communities.

Disclosure statement

Authors declare no conflict of interest.

Funding

The authors received no direct funding for this research.

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