



# Proximity to a forest leads to higher honey yield: Another reason to conserve

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## ABSTRACT

Although tropical forest conservation is a top priority for human and environmental health, deforestation persists, mainly because of food and economic needs. No community will totally give up economic activities for the sake of ecological integrity, unless it is given alternative economic activities from which to draw its livelihood. Beekeeping in the forest buffer zone instead of traditional destructive honey-harvesting from forest trees is one such option at Arabuko Sokoke Forest (ASF) in Kenya. ASF is a dry coastal forest which is home to endangered and threatened fauna and is a hotspot considered a priority for conservation. In order to find out whether honey quantity and quality differed with distance from the forest, we studied honey yield per harvest (kg) and obtained samples from hives placed at varying distances from ASF in two successive years. Honey yield increased with proximity to the forest. Indeed the yield almost doubled in hives placed less than 1 km from the forest compared to those placed more than 3 km from the forest. All the honey samples met internationally required quality standards, although sugar levels were at the lower limit. This study demonstrates that the conservation of tropical forest ecosystems can have real local economic benefits. The documentation of the services provided by nearby natural areas should help make conservation of these areas a priority, even for the local communities.

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## 1. Introduction

Tropical forests are facing annihilation worldwide. This is due to unsustainable harvesting of their timber and non-timber products for economic gains and also due to burning for various reasons, including clearing for agricultural use. Over the past decade, more than 13 million ha of tropical forest was cleared every year, and the largest proportion of this is the tropical dry forest type (Mooney et al., 1995; Bawa et al., 2009). Covering 42,000 ha, Arabuko Sokoke Forest (ASF) is one of the largest remaining protected fragments of a coastal dry forest mosaic in East Africa that once stretched from southern Somalia to northern Mozambique. It is a Key Biodiversity Area (Eken et al., 2004), within the Coastal Forests of Eastern Africa Biodiversity Hotspot, one of 34 such hotspots that are considered as priority areas for conservation among the world's natural resources (Myers et al., 2000; Mittermeier et al., 2004). Arabuko is home to 19 IUCN Red Listed species (6 birds, 5 mammals, and 8 plants) (CEPF, 2005). This unique concentration of threatened spe-

cies is probably due to long isolation and a markedly variable habitat (Burgess et al., 1998).

The main forest can be divided into three vegetation types, depending on the dominant tree species: *Brachystegia spiciformis* L. woodland, *Cynometra webberi* L. thicket, and mixed forest (formerly dominated by *Azelia quanzensis* L.). There is also a very small strip of mangrove trees detached from the main dry land forest at Mida Creek to the north east. All these vegetation types have been threatened by logging in the past because each has unique types of timber for various construction, carving, furniture, fuel and medicinal purposes (Gordon and Ayiamba, 2003). Agriculture in the forest's surroundings is unproductive because of poor soils and frequent elephant invasions, thus increasing local reliance on the forest. A few families carry out small scale subsistence farming of maize, cassava, and beans, with their income being supplemented by cash crops such as cashew, mango, and coconut. The mean size of farm holdings is 6.9 ha (0.5 ha per capita), with farms growing an average of 1.6 ha of maize (Gordon and Ayiamba, 2003). ASF is facing the same threat of exploitation as other tropical forests in the developing world, mainly for building poles (Gordon and Ayiamba, 2003), although it is also used for fuel and carving wood, herbs, hunting of wildlife and water collection. Even after some of these activities were forbidden, they still occurred illegally. For this reason, community-driven conservation projects have been undertaken to ensure that the communities can draw a livelihood from this vital ecosystem without destroying it. These include a pioneer

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butterfly rearing project, Kipepeo (Gordon and Ayiemba, 2003) which has had various spin-off effects including mushroom farming and wild silk moth rearing. There has also been a survey on the potential of ASF for carbon storage (Glenday, 2008).

Among the projects to augment other initiatives is apiculture. This is intended to replace the traditional practice of destroying portions of trees in order to harvest naturally occurring honey in the forest: such human activity is no longer allowed in this protected forest. Although some apiaries belong to individuals, most belong to groups that are partially sponsored by two non-governmental organisations, Nature Kenya and the International Centre for Insect Physiology and Ecology (*icipe*). All apiaries consist of the traditional Log, (Kenya) Top Bar and Langstroth hive types in varying proportions. The ASF bees are hybrids between two subspecies, *Apis mellifera scutellata* Lepeletier and *Apis mellifera litorea* Smith (Raina and Kimbu, 2005). They forage on about 70 plant species either observed or reported to be visited by honey bees, which flower at different times of the year around ASF (S. Sande et al., unpublished data).

Although many studies worldwide have been carried out on the effects of forest isolation on pollination services of bees and other insects (e.g. Bawa, 1990; Klein et al., 2003; Ricketts, 2004; Kremen et al., 2004; Mayfield, 2005; Priess et al., 2007; Ricketts et al., 2008), none has addressed the question: is honey quality and quantity enhanced by the presence of a forest? African honeybees will rarely fly more than 3 km to gather floral resources without an increased risk of absconding from their original hive and moving nearer to the food source (Roubik, 1989; Hepburn and Radloff, 1998). On the other hand, Visscher and Seeley (1982) observed European bees in a deciduous forest foraging within a 6 km radius of their nest. The colony will typically survey the available food patches in a large area by consolidating information collected by its workers, then focus its foraging effort on just a few high quality patches. Bees adjust their foraging efforts according to nectar concentration and distance to the nectar source (Visscher and Seeley, 1982; Beekman and Ratnieks, 2000).

In our study, we tested the following biochemical properties of honey samples; moisture levels, sugar content, acid properties, hydroxymethylfurfural (HMF), proline and diastase. These biochemical properties are routinely checked internationally to reveal the quality of honey before appropriate packaging for sale because they determine its desirability for various groups of consumers and thus its pricing. Aspects of honey quality, such as sugar composition, acidity, taste and odour are influenced by the nectar source (Oddo and Bogdanov, 2004). Apart from nectar, the quality of honey is also determined by pollen types and other plant materials (and the volatiles in them) that bees collect and incorporate into the honey (Crane and Walker, 1984). Therefore, the availability of flowering plant species and species with extra-floral nectaries as forage resources contributes to honey quality.

This two-year study is the first to investigate the intuitive assumption that hives placed near a forest yield more honey than those placed further away, which indirectly suggests that bee activity is affected by proximity to a forest. We also investigated for the first time whether the biochemical quality of honey is influenced by distance from a forest as a foraging site.

## 2. Methods

ASF is located on Kenya's Indian Ocean Coast (3°20'S, 39°55'E). Lying within Kilifi and Malindi Districts, 110 km north of Mombasa, the forest fragment currently covers just over 42,000 ha. The region has two rainy seasons; the long rains from April to June and the short rains from November to December, but some showers and short storms may occur throughout the year. The highest an-

nual rainfall is on its eastern side (1000–1100 mm) and the lowest in the north west (600–900 mm). However, as was the case in 2005/2006, the area may experience drought, due to failure of a season of rain (Msabaha Meteorology Office recorded less than 200 mm in some places). Flooding can also occur due to high rainfall either around the forest or in the mainland highlands. In the latter case, the flooding is restricted to the northern areas around Jilore (see Fig. 1) because of the Sabaki River, which passes by on its way to the Indian Ocean. During 2005/2006, ASF experienced droughts, followed by these two types of flooding. In 2007, weather patterns across the seasons were back to the usual and rainfall ranged between 600 mm and 1100 mm.

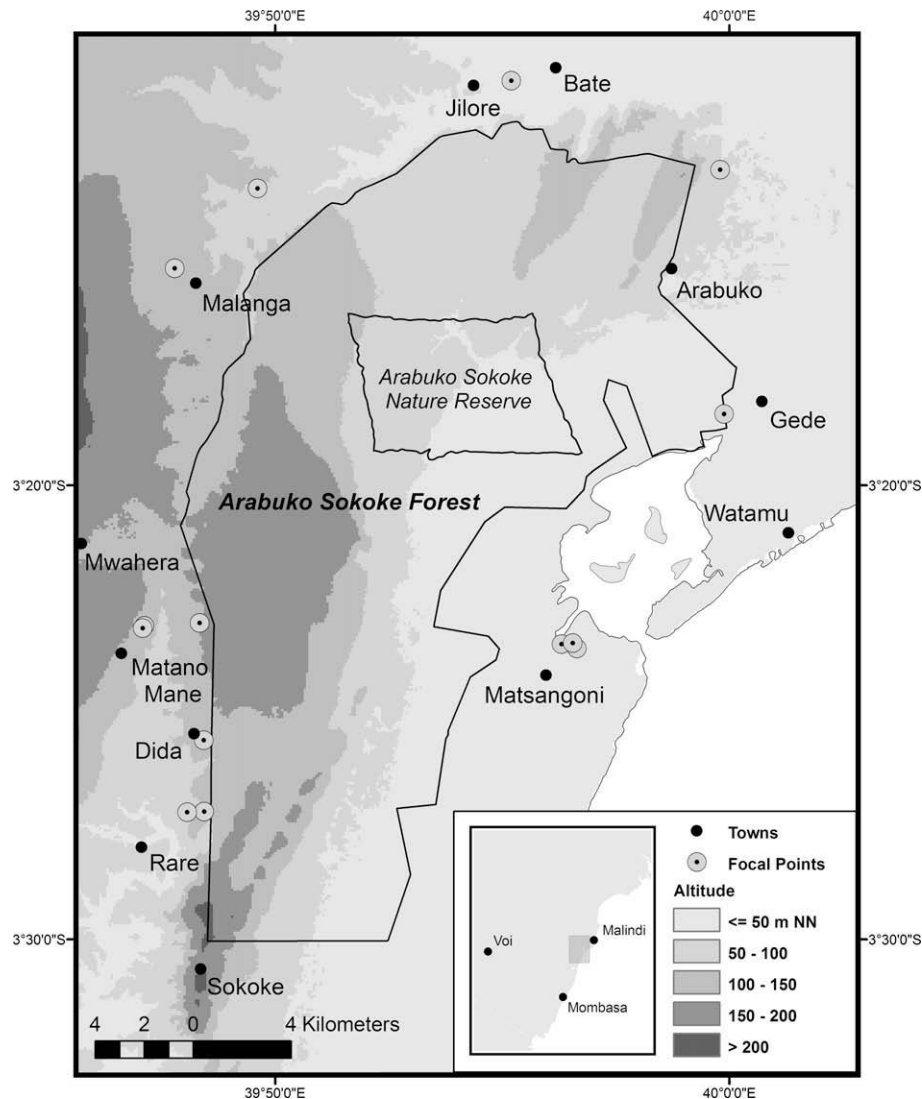
In the area around the forest (defined here as the buffer zone), beekeeping is on a small scale (1–5 hives per person and 10–40 per group) and typical apiaries have two or all of the following hive types: traditional Log hive, Top Bar hive or Langstroth hive. Apiaries are owned mostly by farmer groups and few by an individual farmer. Honey is usually harvested during the two dry seasons of the year.

We selected a total of 366 hives within apiaries situated in the buffer zone, 0–5 km away from the forest, which had established honeybee colonies (Fig. 1). Using a Garmin Geko 101 Global Positioning System (GPS) Personal Navigator, we marked and recorded each of these for future sampling. Between March 2006 and March 2008 the following information was recorded from any hive that was harvested: **type of hive**, **distance from the forest** and **total honey yield per harvest** (in kg). In addition, we took a 100 g sample of honey representing each hive type at each distance category for later analysis in the laboratory. There were three harvesting periods in total: August 2006–October 2006, March 2007, and August 2007–March 2008. Actual harvesting dates varied within these periods depending on the history of each hive, such as whether it had experienced absconding or not and, if so, whether successful re-colonisation and colony build-up had occurred or not. The length of each harvesting period also differed depending on the previous weather conditions with the longest being after a typical dry season (not drought) followed by an adequately watered rainy period (not flooding) and thus vigorous flowering. Furthermore, depending on the colony strength as influenced by weather conditions any hive type can be harvested 1–3 times per harvesting period. The data reported here are mean yields per harvest in kilograms.

Although we initially marked 366 hives for studying honey yield, honey was only harvested from 103 of them in 2006/2007 and from 171 (the former 103 and 68 more) in 2007/2008. The remaining hives had no yield mostly due to absconding effects following the drought and flooding of 2006, as mentioned earlier. The data reported here included 214 Top Bar, 40 Langstroth and 20 Log type hives. Almost half of these hives were in the <1 km zone.

For the effects of distance on honey quality, we report data from 46 apiaries, 18 from <1 km, 19 between 1 km and 3 km and 9 at more than 3 km from the forest. At each apiary, a sample was made up of honey collected from hives of one type, i.e. three samples corresponding to the three types of hives. These samples were transported within two weeks for laboratory analyses.

At the *icipe* laboratory in Nairobi, Kenya, biochemical properties of the honey samples were analysed as follows. Moisture content was determined by refractive methods (AOAC, 1998, method 969.38B), using a specially adjusted refractometer (Bellingham and Stanley Ltd., UK). Sugar composition was revealed by high performance liquid chromatography (HPLC). Free acidity was determined photometrically using method 967.21 in AOAC (1998). Hydroxymethylfurfural (HMF) was determined photometrically using harmonization methods of the International Honey Commission (IHC) outlined in Bogdanov (1999). Diastase activity was determined using spectrophotometry, as outlined by the IHC. Fi-



**Fig. 1.** Map showing the focal points from which sampling points were marked within 0–5 km from the forest. Most of these indicated centres are homes of development group leaders.

nally, proline was also determined spectrophotometrically according to AOAC (1998) using method 979.20.

## 2.1. Data analyses

### 2.1.1. Honey yield

Honey yield data for the years 2006/2007 and 2007/2008 were checked for normality using the Kolmogorov–Smirnov test, respectively. The yield data were then subjected to analysis of variance (ANOVA) using the General Linear Model (GLM) in SPSS 15.0.1, assigning distance and hive type as the fixed factors and yield as the response variable. Where ANOVA showed significant differences, Tukey's test was performed to separate the means. The honey yield data for the two years were then combined for regression analysis of honey yield on distance and hive type. Ordinary Least Squares (OLS) regression analysis results suggested the errors were not random, thus violating the assumption of independence of errors and leading to biased parameter estimates. Therefore we used Generalised Least Squares (GLS) which takes into account correlation of the errors. However, Diniz et al. (2003) argue that although spatial correlation should always be investigated, it does not necessarily generate bias. We estimated the regression coefficients

by GLS, implemented in R version 2.8.1 using the *gls* function in library *nlme*.

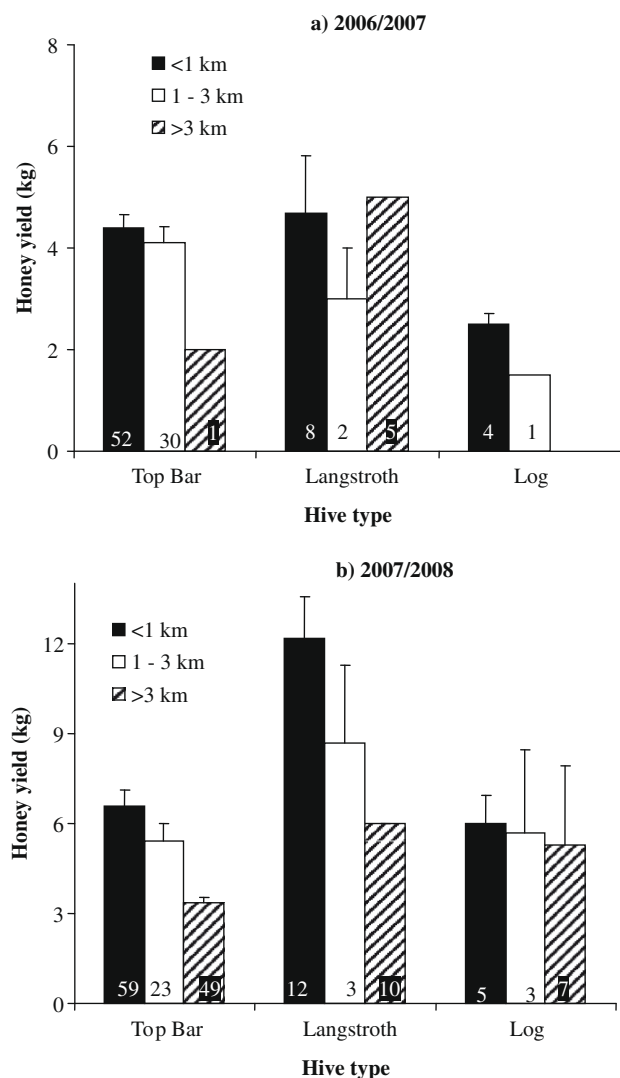
### 2.1.2. Honey quality

Honey quality data were subjected to ANOVA using the General Linear Model (GLM) in SPSS 15.0.1, assigning distance and hive type as the fixed factors and biochemical property as the response variable. Where ANOVA showed significant differences, Tukey's test was performed to separate the means.

## 3. Results

### 3.1. Honey yields

The yield data were found to be normally distributed and thus subjected to ANOVA without transformation. In the atypical year 2006/2007 (Fig. 2a), honey yield per harvest was not significantly different among the three hive types ( $F_{2,102} = 1.743$ ,  $P = 0.181$ ). Yield was also not significantly different between the distances from the forest ( $F_{2,102} = 0.822$ ,  $P = 0.443$ ). On the other hand in 2007/2008, a year with typical weather, honey yield was significantly different between the three hive types ( $F_{2,170} = 10.121$ ,



**Fig. 2.** Honey yield per hive (kg) as a function of distance from the forest edge and hive type. The bars represent different hive types and bear the number of observational units (N) at each distance category. Results are expressed as mean values and bars bearing different letters represent statistically different yields. Some standard error bars were too small to appear on the figure. (a) 2006/2007 and (b) 2007/2008.

$P = 0.000$ ) with Langstroth hives giving significantly higher yields than the Log and Top Bar hives. In 2007/2008, distance from the forest had a highly significant effect on hive yield per harvest ( $F_{2,170} = 8.292$ ,  $P = 0.000$ ;  $<1$  km =  $7.26 \pm 0.56$ ,  $1-3$  km =  $6.26 \pm 0.67$  and  $>3$  km =  $3.98 \pm 0.34$ ) (Fig. 2b).

In our combined (overall) data, the coefficient of variation at distances less than 1 km was 64.58%, at 1–3 km it was 55.99% and at more than 3 km it was 63.66. Thus, there is less variability in the samples from distance category 1–3 km. We obtained GLS estimates for the regression of honey yield on distance and hive type as shown in Table 1. The coefficient for distance is negative and highly significant, demonstrating that honey yield is reduced with increasing distance from forest. Honey yield from Langstroth hives was significantly higher than from Top Bar hives, whereas Log hive yields were significantly lower than those from Top Bar hives. These results are similar to the preliminary results obtained from OLS regression (not presented here) which gave an  $R$ -square of 51%. Using the estimates in Table 1, the relationship between distance (km) and honey yield (kg) for different hive types is as follows:

**Table 1**

Generalized least squares parameter estimates and their standard errors for the regression of yield on distance for different hive types.

Parameter	Estimate	Std. error	t-Value	P-value
Intercept	9.47	0.727	13.02	0.0000
Distance	−1.17	0.178	−6.60	0.0000
Top Bar hive	Reference			
Langstroth hive	2.79	0.735	3.80	0.0002
Log hive	−2.05	0.942	−2.18	0.0312

Yield =  $12.26 - 1.17$  (distance) (Langstroth hive)

Yield =  $7.42 - 1.17$  (distance) (Log hive)

Yield =  $9.47 - 1.17$  (distance) (Top bar hive)

Honey yield was found to show no significant difference across the forest regions ( $F = 0.93$ ,  $P = 0.396$ ) indicating that rainfall zones alone was not a factor in determining honey yields.

### 3.2. Honey quality

All the tested biochemical properties were within the required international standards and five of them did not differ significantly with hive type ( $P > 0.05$ ). However, fructose, glucose and total sugar content of honey showed a significant decline with increasing distance from the forest ( $F_{2,45} = 5.80$ ,  $P = 0.0059$ ;  $F_{2,45} = 4.444$ ,  $P = 0.0177$ ;  $F_{2,45} = 6.16$ ,  $P = 0.0044$  for fructose, glucose and total sugar, respectively) (Table 2).

## 4. Discussion

### 4.1. Honey yield as a function of distance from the forest

Various studies have shown that flower–insect interactions are negatively affected by landscape fragmentation and forest isolation (e.g. Brosi, 2009; Kremen et al., 2004; Klein et al., 2002; Aizen and Feinsinger, 1994; Rathcke and Jules, 1993; Powell and Powell, 1987). In the present study, honey yield (and thus income from beekeeping) decreased dramatically with distance from the forest during the typical-weather year. This could be due to decreased overall floral density and a decrease in bee-flora species further from the forest, since ASF is not an area surrounded by intense agriculture. There could also be an edge effect, with bees being able to exploit the greater temporal and spatial diversity of floral resources both inside and outside the forest (Chacoff and Aizen, 2005), although we did not test this possibility by including hives within the forest. High plant diversity and floral density are known to provide a better food base for bees, resulting in shorter foraging flights (Steffan-Dewenter and Kuhn, 2003), sustaining a higher population per honeybee colony. Moreover, the buffer zone 0–5 km away from the forest lacks a consistent crop cover due to agriculturally poor soils and the threat of elephant invasions. We expect that most of the bee foraging occurs at the forest edge and deeper into the forest, particularly in the wetter, swampier areas. In fact, beekeepers here habitually set up catcher boxes at the forest edge in order to promote colonisation in new hives. There is additional evidence that forest proximity affects hive colonisation: a survey at ASF in 2007 by Ngoka et al. (unpublished data) showed that the colonisation rate of Langstroth hives introduced by *icipe* ranged between 60% and 100% in apiaries less than 1 km from the forest, 27–61% in apiaries 1–3 km away from the forest and 0–15% in apiaries more than 3 km away from the forest.

Since bee foraging distances are dependent on energy efficiency (Visscher and Seeley, 1982), it is unlikely that bees will forage over a long distance if there is no foraging patch between the hive and their preferred patch. We suggest that the patches between their



**Table 2**

Biochemical properties of honey harvested at varying distances from the forest edge.

	Biochemical properties	Distance from forest (km)			Units
		0–1 N = 18	1–3 N = 18	3–5 N = 9	
1	Moisture	20.64 ± 0.29 <sup>a</sup>	19.86 ± 0.30 <sup>a</sup>	20.00 ± 0.29 <sup>a</sup>	g per 100 g
2	<i>Sugar content</i>				
	<i>Total sugars</i>	63.37 ± 0.66 <sup>a</sup>	62.60 ± 0.78 <sup>b</sup>	59.49 ± 0.63 <sup>c</sup>	g per 100 g
	<i>Fructose</i>	38.01 ± 0.42 <sup>a</sup>	37.59 ± 0.43 <sup>b</sup>	35.93 ± 0.31 <sup>c</sup>	g per 100 g
	<i>Glucose</i>	24.95 ± 0.32 <sup>a</sup>	24.77 ± 0.37 <sup>b</sup>	23.32 ± 0.44 <sup>c</sup>	g per 100 g
	<i>Sucrose</i>	0.33 ± 0.08 <sup>a</sup>	0.21 ± 0.07 <sup>a</sup>	0.22 ± 0.10 <sup>a</sup>	g per 100 g
	<i>Maltose</i>	0.04 ± 0.01 <sup>a</sup>	0.03 ± 0.01 <sup>a</sup>	0.02 ± 0.01 <sup>a</sup>	g per 100 g
3	<i>Acid properties</i>				
	<i>pH</i>	3.53 ± 0.06 <sup>a</sup>	3.47 ± 0.07 <sup>a</sup>	3.53 ± 0.05 <sup>a</sup>	meq per kg
	<i>Free acid</i>	25.17 ± 1.23 <sup>a</sup>	25.06 ± 1.21 <sup>a</sup>	27.90 ± 1.92 <sup>a</sup>	meq kg
4	HMF	7.01 ± 1.41 <sup>a</sup>	9.78 ± 1.31 <sup>a</sup>	10.78 ± 2.15 <sup>a</sup>	mg kg
5	Proline	232.16 ± 10.84 <sup>a</sup>	224.48 ± 7.68 <sup>a</sup>	229.25 ± 14.18 <sup>a</sup>	mg 100 g
6	Diastase activity	20.18 ± 2.38 <sup>a</sup>	16.27 ± 1.01 <sup>a</sup>	19.54 ± 2.79 <sup>a</sup>	SScale

Results are expressed as mean values ± standard error. Means within a row followed by the same letter(s) are not significantly different ( $P < 0.05$ , Tukey's test).  $N = 46$ . The italicized rows show properties that differed significantly in honey harvested from different distances.

nest and highest quality patch provide energy to keep them going. Indeed, optimal foraging theory predicts that organisms will forage in such a way as to maximize their colony's energy intake per unit time (MacArthur and Pianka, 1966). Research has also shown that honeybee colonies likely have a minimum foraging range required for an adequate resource base, making their existence in a competitive landscape possible (Visscher and Seeley, 1982).

Several studies show that there is a consistent decrease in pollinator richness and abundance in fragmented ecosystems as compared to continuous areas of natural (forest) vegetation (see review by Aizen and Feinsinger, 2003). Klein et al. (2003) found that the number of social bee species decreased with increasing distance from a forest in Indonesia. In developing a conceptual model to study the effect of land-use change (which may result in fragmentation) on pollination, Kremen et al. (2007) noted that varying sensitivity of mobile pollinators to ecological factors may affect their services and the quality of the resulting goods. Over 70 plant species around ASF have the potential to substantially support honeybee foraging, as they each flower for a total period of not less than two months per year, but their abundance decreases with distance from the forest (Sande et al., in prep.). Ricketts (2004) found that visitation rates of bees to an area with flowers decreased with distance from it. In his study, coffee farms nearer a forest were visited by bees more often than those further away. Another study by Williams and Kremen (2007) showed that solitary bees 'consider' proximity of nesting habitats relative to their foraging sites an important factor because, like other bees, they return to a central place after foraging. Furthermore, Ricketts et al. (2008) simulated the visitation rate of *A. mellifera*, showing that it drops to half of its maximum between 4 km and 2 km depending on the individual characteristics of the study area, with visitation rates expected to drop more steeply in tropical areas like ASF than in temperate areas. In our case, during the typical-weather year visitation rates may have dropped, leading to lowest honey yields at more than 3 km from the forest whereas during the atypical year, insufficient floral resources resulted in absconding. Indeed, in the period running up to May 2006, massive absconding occurred because of a long drought, thus leaving many apiaries in ASF empty. However, more than half of the apiaries near the forest edge (less than 1 km) did not experience total absconding, just a decline in colony sizes. This could be because the bees were able to forage deep into the forest (particularly in the swampy areas) for any remnant resources.

Some studies suggest that fragmentation may not always have negative effects on bee communities in terms of density and diver-

sity (Winfree et al., 2007; Cane, 2001; Becker et al., 1991). If fragmentation is associated with intensive agriculture, bee diversity and density may increase, because different bee species occupy different stages of succession after a landscape disturbance and intense agriculture may offer a large number of flowers over a longer period of time compared to the nature of flowering in forests (Winfree et al., 2007). Low agricultural activity around ASF may have thus contributed to the strong effect of forest proximity on yields that was observed in this study. Such a strong effect may not necessarily be seen in a forest surrounded by consistently farmed areas, as the floral resources provided by crops may act as a confounding factor.

Some other factors not studied here, such as the effects of drought, flooding, land-use by farmers and varying crop cover as a result of destruction by wildlife may probably account for the 42% influence not explained by our regression model. We suggest that further studies taking these additional influences into account could shed more light on this matter and on the generality of our results.

#### 4.2. Honey quality as a function of distance from the forest

The biochemical properties analysed here are routinely used to test whether honey meets the required international standards. Moisture content is the only composition criterion of the honey standard that has to be fulfilled globally (Bogdanov, 1999). As explained in Bogdanov (1999), honey with high moisture content is more prone to fermentation and thus less desirable, acidity is a measure of the degree of honey fermentation and HMF is an indicator of both handling procedures (heat and storage changes) and overall honey freshness. Like HMF, diastase activity is an indicator of honey freshness but also provides evidence of overheating. Proline level is a criterion for ripeness and can also be used as an indicator of sugar adulteration while sugar content, particularly the proportion of glucose and fructose, depends on the presence of the invertase enzyme found in honey and it is also sensitive to heat (Bogdanov, 1999).

All the honey samples, regardless of the source hive type and distance of origin, were of acceptable standards in terms of the tested biochemical properties, according to the International Honey Commission (Codex Honey Standards, 1986). The levels of glucose and fructose in all samples were, however, on the lower limit. Similarly lower glucose and fructose levels have been found in other Kenyan honeys (Muli et al., 2007), and may be attributed to the tendency of honey to crystallise (Crane, 1990). Although the

source of nectar ultimately affects the composition and properties of honey (Terrab et al., 2004). Lachman et al. (2007) showed that honey mineral content is also determined by a combination of a wide array of factors including environmental contaminants. It is noteworthy that in our study the honey samples taken nearer the forest had a comparatively higher concentration of fructose and glucose than honey from further away, and although we suggest that it could be a reflection of amount of available nectar, rather than the source of nectar, further research may be needed to verify this.

The above properties have also been traditionally used to confirm whether honey is of floral origin or adulterated and whether it has been handled and stored properly (Guler et al., 2006; Bogdanov et al., 2004; Crane and Walker, 1984). All the samples had acceptable sucrose levels, confirming that, as elsewhere in Kenya, the ASF beekeepers do not feed their colonies with sugar (Muli et al., 2007). Following the findings of this study, further confirmatory studies may show that it is possible to use the sugar content of honey as an indication of the floral intensity and thus standing crop of nectar. Although the moisture content, pH, free acidity, HMF, diastase activity, sucrose, maltose and proline content did not differ significantly among honey samples collected at various distances from the forest we suggest that it would be interesting to analyse their aroma, colour, consistency and other physical, biological and chemical properties to see if any trends are shown.

#### 4.3. Honey yield as a function of hive type

Our results from the typical-weather year confirm the general assumption that Langstroth hives, being the most modern of the types being used in ASF, yield more honey (and thus income) than the traditional Log and Top Bar hives. It is however, unexpected that the traditional Log and the Top Bar hives do not differ significantly in their yields since the latter is considered an improvement on the former. A possible explanation is that the community in question has mastered the handling of traditional Log hives with more proficiency than the Top Bar hives. Finally, the anomalous results (unexpected high yield) from the Langstroth hives in 2006/2007, could be attributed to the fact that two beekeepers situated at region >3 km from the forest edge, each having >30 such hives, kept irrigating their farms using piped water during the drought and also offered drinking water to their bees. Therefore, while other apiaries at the same distance suffered absconding, their apiaries thrived and produced honey consistently. These effects were 'ironed' out in 2007/2008 when the weather conditions became favourable and the yield per hive nearer the forests became higher than yield from these two farmers.

During the period 2006–2008, one kilogram of honey was sold for between 2.5 and 3.5 US dollars to the ASF honey market for processing and packaging before retailing. Therefore, our results suggest that in a typical-weather year, beekeepers near the forest edge that use the Langstroth and/or Top Bar hives are likely to earn twice as much income from honey sales as their colleagues at greater distances from forest-like vegetation, all other factors being constant.

#### 4.4. Recommendations

The principal finding of this study is that honey yields are substantially higher close to the forest. We recommend that maintenance of high apiflora species diversity and abundance, which happens naturally inside the forest, could be emulated by the beekeepers in order to ensure high honey yields. This they can do by maintaining and augmenting the naturally available apiflora in the vicinity of their hives rather than indiscriminately clearing veg-

etation near their apiaries. Ricketts et al. (2008) also recommended this in their review and synthesis of studies of landscape effects on pollination services. Forests will still remain a 'store' for honeybee populations, either to set up new apiaries or boost the population of existing apiaries. They will also act as a seed bank/source for bee foraged plants which beekeepers can obtain and plant near their apiaries. We also recommend an increase in the use of Langstroth hives since they yield more honey. Although they may be more expensive to purchase, the overall gain will ensure that Langstroth hives supersede the other two hive types. This study has provided yet another argument for the conservation of forests and thus biodiversity.

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