Beekeeping and forest conservation:

a case study of Arabuko Sokoke Forest, Kenya

By:

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Declaration

I, Susan Sande Okoth, declare that the thesis which I hereby submit for the degree of *Philosophiae Doctor* Entomology at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

Signature……………………………………………………

Date………………………………………………………..

This thesis is dedicated to the Almighty God. I live and move and have my being in Him.

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There is some overlap of information and references in this thesis because it is based on the following manuscripts:

Chapter 2: Sande, O. S., Crewe, R. M., Raina, S. K., Nicolson, S. W. and Gordon, I. (2009) Proximity to a forest leads to higher honey yield: Another reason to conserve. Biological Conservation 142, 2703 – 2709.
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Chapter 3: Sande, et al. (2010) Floral calendar around the Arabuko Sokoke Forest.
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Chapter 4: Sande, et al. (2010) Mangrove pollination and production of mangrove honey at Mida Creek, Kenya
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Beekeeping and forest conservation: a case study of Arabuko Sokoke Forest, Kenya

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Summary

Tropical forests are shrinking worldwide. This is mainly because human beings, in a bid to obtain a livelihood, have overexploited their timber and non-timber products. At Arabuko Sokoke Forest (ASF), Kenya, community-driven conservation projects have been initiated, to ensure that the people can draw a livelihood from this vital ecosystem without destroying it. Among the projects involved is apiculture in the vicinity of the forest. Although some studies have been carried out on various aspects of honey yields and pollination services of bees to agricultural and forested lands, none has targeted the following question: is honey quality and quantity enhanced by the presence of a forest? To address this question, a record was made of honey yield per harvest (kg) for hives placed at different distances from the forest. Honey samples from these hives were also obtained and tested for various biochemical characteristics. It was found that honey yield increased with proximity to the forest: 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 taken from these hives met internationally required quality standards. This part of the study

demonstrated that the conservation of tropical forest ecosystems can have real local economic benefits. The documentation of the services provided by nearby natural areas could help make conservation of these areas a priority, even for the local communities. For a full understanding of the potential of beekeeping as a sustainable livelihood for the local people, knowledge about flowering phenology of plants and trees potentially foraged by the bees is indispensable. Therefore, a floral calendar for the area around ASF was compiled, in which timing and duration of flowering of these plants was recorded. The calendar is especially essential because the ASF people are not traditionally beekeepers and so there is no indigenous knowledge of appropriate timing of activities with respect to beekeeping. Using a floral calendar, beekeepers can properly plan the establishment of new apiaries and handling of existing ones, with the aim of increasing the production of honey. Data were collected by direct observation and recording of flowering every fortnight for two consecutive years (2006 to 2007) and these were used to compile the floral calendar. Twelve common plants around ASF flowered for more than half of the year and 70 others flowered for at least two full months. Preservation of these plants could ensure year-round availability of ample forage for honeybees and promote increased honey production by strengthening the honeybee colonies and preventing the desertion of a hive by the colony (absconding). In addition, the calendar could form a basis for future studies on effects of climate change on forest phenology and the role of beekeeping for conservation of the local flora. Mangrove ecosystems are of particular importance from a conservation perspective: worldwide, they are arguably a more endangered habitat than dry forests. Furthermore, mangrove honey from ASF is prized above honey from the other portions because of its generally preferred taste. For these reasons, the role of bees in pollinating the mangrove portion of ASF and the properties of mangrove honey were also studied. Although the previous two studies were very intensive and data collection lasted two years,

the study on mangroves lasted a month during the flowering period and yielded important baseline and descriptive data. Data on flower opening, nectar volume and concentration and honeybee visits to their flowers were collected. Results showed that two of the most abundant species, *Ceriops tagal* and *Bruguiera gymnorrhiza*, have the potential to be pollinated both at night and during the day. There was no nectar produced by *Avicennia marina* during our period of study, yet it had a strong honey-like smell which seemed to attract bees and hence their pollination services. In B. *gymnorrhiza* nectar was available throughout the day. It also emerged that mangrove honey may differ in taste from honey produced by bees foraging other types of plants because of its higher sodium content, which we suggest could be a result of frequent salt spray from the ocean.

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CHAPTER 1

General introduction

The status of tropical forests

Tropical forests worldwide face the threat of destruction, mainly due to human activities which are usually geared towards short term economic gains for survival. This accelerating loss of biotic diversity can lead to extinction, which is irreversible. About 44% of the world's vascular plant species and 35% of terrestrial vertebrates are endemic to 25 hotspots of biodiversity, some of which are tropical forests (Margules and Pressey, 2000), yet none of the hotspots has even one-third of its original geographic extent still intact (Thomas et al., 2004). In fact the hotspots currently occupy only about 1.4% of the earth's land area. Therefore there is an urgent need to put conservation measures in place (Burgess et al., 1998; Brummitt and Lughadha, 2003). Large proportions of tropical dry forests were deforested or degraded in the recent past (Mooney et al., 1995; FAO, 2003), mainly for sale of timber or conversion to agricultural land. In 1995, it was estimated that 15 million hectares of the world's tropical forests were being destroyed every year since the 1960s (FAO, 2003).

In Africa, most of the communities living near the tropical forests are poor and they consider the forests as their natural heritage, a source of making a living. They are the forests' "rightful custodians". This has resulted in hostility between organisations fronting for conservation and the local people, except in cases where the communities have been involved in the process. Thus, there is an increasing need to formulating ways in which such communities can derive a living from these biodiversity-rich ecosystems without adversely affecting their integrity (Gordon and Ayiemba, 2003; Raina et al., 2010). This trend, coupled with extensive education and involvement of these custodians, has proven to be the best way of achieving the delicate balance between conservation and sustainable exploitation (Raina et al., 2009). The Convention on Biological Diversity, adopted at the 1992 Earth Summit in Rio de Janeiro, was among the earliest international meetings to acknowledge the need to protect and encourage customary use of biological resources in accordance with traditional cultural practices that are compatible with conservation or sustainable use. This has been re-emphasized in the past few years in various conservation forums. For this reason, there is also an increasing tendency towards conservation initiatives where both the local people and the government have a say (Glaser et al., 2003; Ngece, 2003; Tinga, 2004).

Beekeeping and forest conservation

Although there are reports of beekeeping being used to improve the status of poor communities, none specifically targets beekeeping in order to conserve a forest. In Kenya, charcoal burning in Mwingi District was successfully reduced by introducing beekeeping as an alternative economic activity; as a result, incomes per household have increased by up to 120% from their initial earnings from traditional beekeeping (Raina et al., 2009). It has become a good example for other areas, and a motivation for this present study. In endeavoring to promote beekeeping with the intention of encouraging forest conservation, research is necessary in order to ensure the community involved gets maximum benefit from their efforts. Earlier, a report by Latham (2002) gave a detailed description of locally available plants that could be maintained by beekeepers in Southern Tanzania in order to conserve natural flora in an area that is largely converted from woodlands to agriculture.

Social bees forage for pollen and nectar because they are vital for the maintenance and development of the colony (Winston, 1987). Pollen is the main source of protein for the colony, required for brood rearing and glandular development of young worker bees (Winston, 1987). High-protein pollen is known to contribute to colony growth and bee development (McCaughey et al., 1980; Schmidt et al., 1987). In addition, pollen grains contain lipids, carbohydrates, starch, sterols, vitamins, and minerals which bees require (Herbert, 1992). Overall, honeybees seem to prefer foraging for sufficient amounts of pollen with the greatest available nutritional value (Cook et al., 2003; Peng et al., 1985). During foraging, they use cues related to the reward for its successful collection (von Frisch, 1967, Rasheed and Harder, 1997). Meaningful ecological studies on the foraging behavior of honeybees require sampling protocols that take into consideration temporal fluctuations in floral abundance and composition (Raina pers. comm.).

Honey is a liquid resulting from the modification of nectar and sugar exudates of plants by honeybees. It contains various sugars, vitamins, enzymes, amino acids, and minerals, making it a very healthy food source, a cosmetics ingredient, and it is sometimes used for medicinal purposes (Molan, 1997; Cooper and Molan 1999). Honeybees store it in honeycombs within their hives. The composition and properties of honey vary mainly due to the flowers utilized by honeybees (Costa et al., 1999; Terrab, et al., 2002). Terrab, et al., (2002), for example, found that various Moroccan honey formed from different plant species had varied biochemical properties. In their study, they considered any type of honey containing more than 45% of pollen from one species unifloral and named them appropriately. Among the honey types they used were eucalyptus, citrus and multifloral categories. However, it is important to note that sometimes various kinds of wild and managed bees forage extra-floral plant fluids and incorporate them in the process of forming honey (Baker et al., 1978), hence the term extra-floral honey. Honeybees from hives Arabuko Sokoke Forest for example, have been observed foraging on overripe fruits that have fallen off the forest and crop plants (personal observation, see Fig. 3.2).

The honeybees found in ASF belong to the subspecies *Apis mellifera litorea* (Smith) and *Apis mellifera scutellata* (Lepeletier). There has been minimal traditional beekeeping in the forest vicinity, with the use of log hives. The amount of honey harvested by some of these beekeepers is restricted as some is left for the young brood and the adults. To avoid migration of honeybees from the hive, the propolis (plant based substance used by honeybees as a cement or sealant in the construction of their hives) is left totally intact. A beekeeping project was initiated within areas adjacent to the ASF in 1998. Arabuko-Sokoke Conservation and Management Project (ASCMP) supports beekeepers within two kilometres of the forest. To start beekeeping enterprises they are provided with Top Bar hives at a subsidised price, and technical support. There are around 171 households involved in beekeeping with a labour force of over 200 people (ASFMAT, 2002). Apiculture in the mangrove section is on a much smaller scale, as only a strip of around 6 km of mangrove tree species exists. The International Centre for Insect Physiology and Ecology (*icipe*) became involved as a partner with the above organizations in 2005 and has provided beekeepers with additional equipment and training for better honey yields, royal jelly production, harvesting of wax and propolis (Raina et al., 2009). It is also notable that the community is unaware of the role of bees in pollination of the wild and cultivated flora.

Why the Arabuko Sokoke Forest?

Arabuko Sokoke Forest is special for various reasons. It is one of the largest remaining protected fragments of a forest mosaic that once stretched from southern Somalia to northern Mozambique. It covers a total of 417 km^2 (See Figs 1.1, 1.2 and 1.3). It was ranked by Collar and Stuart (1988) as the second most important forest for threatened bird conservation on mainland Africa, being home to six globally threatened bird species, including Clarke’s weaver which is found nowhere else in the world. An additional five bird species that occur here are coastal endemics (Bennun and Njoroge, 1999). In fact, it is one of 19 Important Bird Areas (IBAs) in Kenya, and therefore a critical site for intensive and immediate conservation action (Bennun and Njoroge, 1999).

There are three rare near-endemic mammals (Ader’s duiker, golden-rumped elephant shrew, and the Sokoke bushy-tailed mongoose) and unique amphibians including the Bunty’s toad. This unique concentration of rare species is probably due to long isolation and a markedly variable habitat. The main forest is situated offshore and 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 *Afzelia quanzensis* L.). These three off-shore vegetation types are characterised by slightly different soil types and amounts of precipitation. There is also a very small strip of mangrove trees detached from the main dry land forest at Mida Creek to the north east. Seven mangrove species occur here; *Avicennia marina* (Forsk.), *Bruguiera gymnorrhiza* (L.) Lamk., *Ceriops tagal* (Perr.) C. B. Robinson, *Lumnitzera racemosa* (Willd)., *Pemphis acidula* (Forst), *Rhizophora mucronata* (Lamk.) and *Sonneratia alba* (Smith).

For almost 20 years, this forest has been under multi-institutional management and thus more effectively managed than the other 17 forest reserves in the Coastal Forests hotspot (Arabuko Sokoke Forest Management Team, 2002). The management team comprises mainly the Forestry Department and Kenya Wildlife Services, but also includes other stakeholders: Birdlife International, USAID and other NGOs, who have united their efforts for conservation. Village communities surround the forest, with a population of about 110,000 people. Although the area is agriculturally poor, with low crop yields, subsistence agriculture that includes the production of maize, cassava, and beans, with income supplemented by cash crops such as cashew, mango, and coconut, is their main occupation. 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. Most households own goats (average of five per household), but tsetse flies and a lack of grazing area are constraints to cattle keeping. Although many uses of the forest for subsistence or income generation are illegal, they still continue. Forest usage includes collection of water, fuel wood, poles, and herbs, hunting of wildlife for meat, and butterfly farming.

The Kipepeo Project, involving butterfly farming for sale to live butterfly exhibitions, was the first to assist the local community to use biodiversity in a rational way to earn money, or simply for conservation development. Pupae are exported for the live butterfly exhibit industry in Europe and the United States. Cumulative community earnings from 1994 to

2001 exceeded $130,000, with significant positive effects on both livelihoods and attitudes (Gordon and Ayiemba, 2003). The project has been financially self-sustaining since 1999. Butterfly monitoring indicated that there have been no adverse effects on wild butterfly populations. Stemming from the successes of this pioneer project and the realization that it is not sufficient by itself, there is a unique opportunity at ASF to build a portfolio of the ways in which forest insects benefit adjacent communities. Managed bees and silk moths are becoming important in this respect and beetles may soon be added for collectors and as curios (Ian Gordon *pers. comm.*) Studies have also been carried out on the forest's potential sizeable carbon storage (Glenday, 2008). The sampling sites for all the three field studies presented in this thesis were within 0 to 5 km of the forest edge, an area generally considered as a buffer zone. The consent of beekeepers was sought well before the onset of sampling and participants largely comprised those who belong to the existing Kipepeo Project. African honeybees are known to forage for up to 5 km from their hives (Schneider and McNally, 1992; Winston, 1992; Schneider & McNally 1993; Hepburn and Radloff, 1998) and will only go further if there is an acute shortage of pollen and/or nectar. Following a behavioural and genetic study, *Apis mellifera* have been shown to alter their foraging behavior as a consequence of colony-level selection for quantities of stored food (Page et al., 1998).

There has been no research to show that practicing apiculture in the vicinity of a forest offers advantages over any other non-forest area. The ASF community needs to find out whether the presence of the forest is actually a boost to apiculture by way of offering a preferred (and sometimes the only) foraging site to the managed bees. Furthermore, there exists only a list of the indigenous plant species found in the ASF and its environs (Ian Gordon, *pers. comm.*), yet apiculture holds a lot of potential for this area. Finally, apiculture near ASF is also significant with respect to the role of honeybees in pollination of mangroves, and there is a need to study the properties of mangrove honey which is considered special and thus priced higher than honey from the dry section of the ASF.

Thesis organisation

The aim of this study was to investigate the role of beekeeping in forest conservation, using ASF as a model. Floral resources available for managed bees near a forest, the effect of the presence of a forest on honey yield and quality and some aspects of both the foraging of honeybees on mangroves and the resulting mangrove honey were documented. In order to achieve this, various studies on ecological interactions, biochemical properties and behaviour were carried out. Each data chapter in this thesis is presented as a research article. **Chapter two** investigated whether distance from a forest affects honey production in terms of quality and quantity. It aimed at demonstrating to the ASF community the importance of this forest for beekeeping and thus the reason it should be conserved. The major finding was that indeed honey yield is higher nearer the forest than further away. Hives placed at a distance less than 1 km from the forest yielded almost double the honey crop of those more than 3 km away. The biochemical properties of these honeys harvested from different distances met internationally required standards and none of them showed any significant differences. **Chapter three** dealt with the question of whether there were sufficient floral resources for honeybees to forage on and the occurrence of such throughout the year. By noting flowering plants that the researchers directly observed being foraged by honeybees or reported as bee plants by beekeepers, a floral calendar was compiled for this area. Such a calendar is of paramount importance as a guide for setting up apiaries, as it can show when to set up new apiaries, periods of dearth when managed bees will require supplementary food, and the types of plants one might decide to plant near an apiary in order to avoid absconding, boost colonies or ensure a constant/sustainable supply of food for managed bees. Honeybees were observed foraging on seventy plant species that flowered for a total period of at least two months annually. **Chapter four** is about mangrove honey and bee visits to mangrove flowers in the Mida Creek, which is a section of ASF. We compared ten biochemical properties of mangrove honey to the same properties in honey from the dry portion of the ASF. It is noteworthy that water, total ash and electrical conductivity levels were significantly lower in the mangrove honey. We also suggest that the unique taste of mangrove honey (which is preferred by many clients and thus renders it highly prized) is probably a result of frequent salt spray from the ocean. This gives it slightly higher sodium content, compared to honey from the dry section of ASF.

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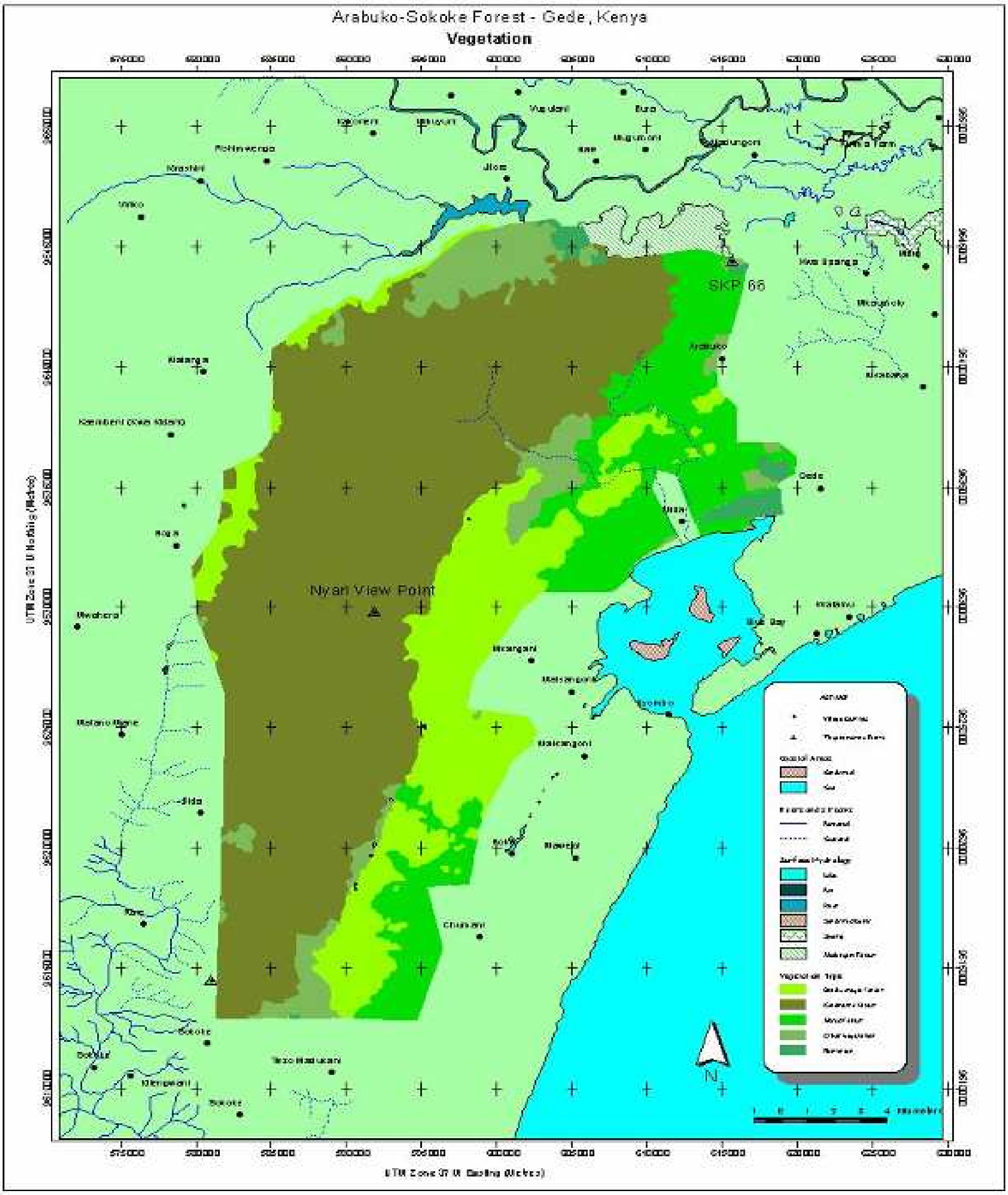

Source: Created by Dr. Bilal Butt for the Arabuko Sokoke Forest management team

Figure 1.1: Map showing the vegetation types and surrounding villages of Arabuko Sokoke Forest

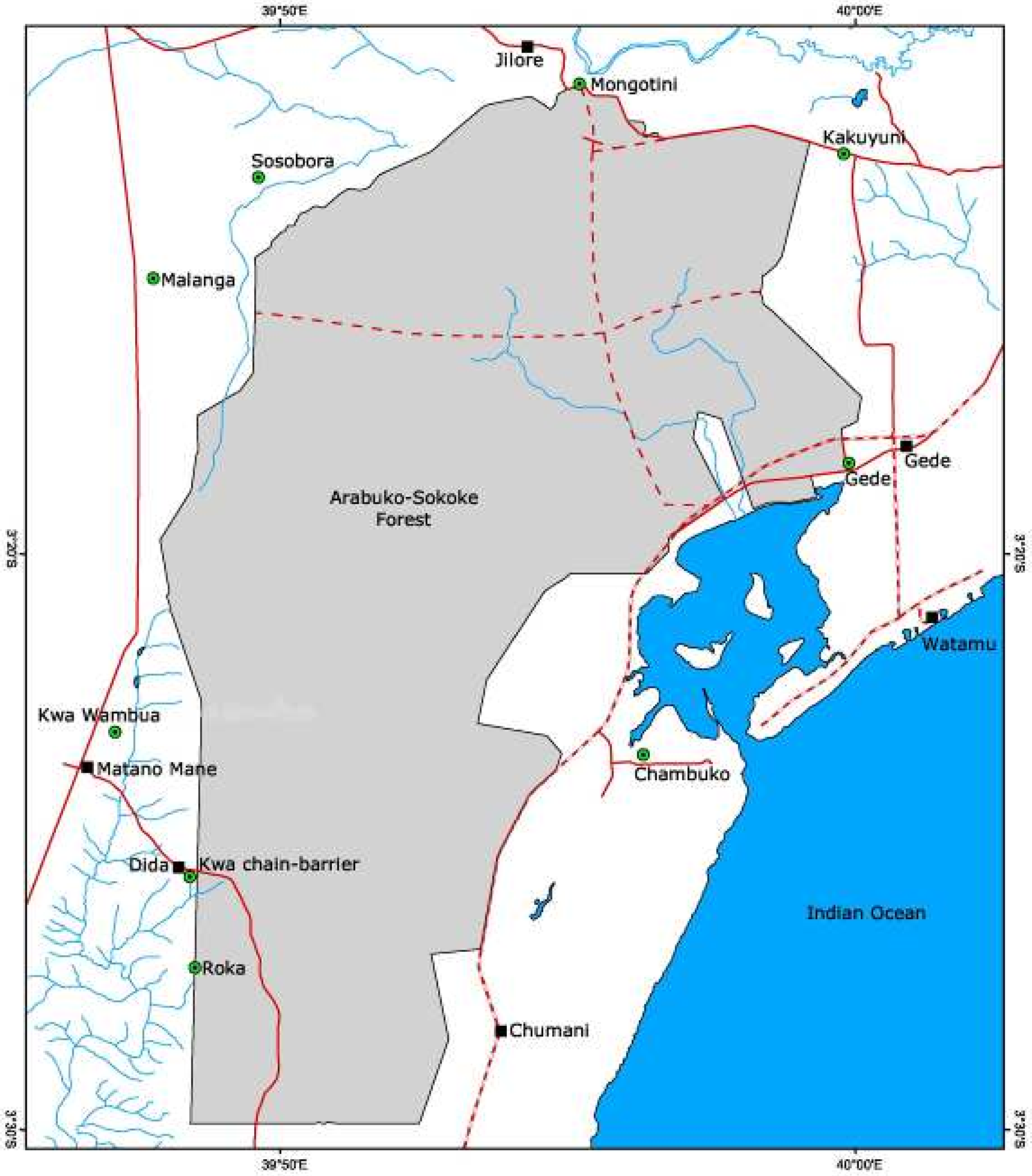

Figure 1.2: Map showing the distribution of group leaders of beekeeping associations within the Arabuko Sokoke Forest. Their homes are indicated by green circles. We established contact with all the beekeepers who participated in this research through these group leaders.

a)

Source of the above photo: Kipepeo Project's pictures

b)

The above picture was taken by Susan Sande c)

The above picture was taken by Susan Sande

Figure 1.3: Various portions of the Arabuko Sokoke Forest: (a) a section of the conserved dry forest; (b) a section of the forest environs under small scale agriculture in Malanga village; and (c) a stand of mangrove trees at the Mida Creek during a period of low tides.

CHAPTER 2

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

Abstract

Although tropical forest conservation should be a priority for human and environmental health, given the much discussed changes in climate, 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 biodiversity hotspot. 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 occurring 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.

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 species 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 *Afzelia 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 Ayiemba, 2003). This has resulted in patches of forest-associated vegetation and secondary colonizers in the area between zero and five kilometers away from the existing forest-edge. 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 Ayiemba, 2003). ASF is facing the same threat of exploitation as other tropical forests in the developing world, mainly for building poles (Gordon and Ayiemba, 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 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 honeybees 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 honeybees, 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 various types 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. Social 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 it’s pricing. Aspects of honey quality, such as sugar composition, acidity, taste and odour are influenced by the nectar source (Dodo 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 honeybees 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 whether hives placed near a forest yield more honey than those placed further away. We also investigated for the first time whether the biochemical quality of honey is influenced by distance from a forest as a foraging site.

MATERIALS AND METHODS

Study area

ASF is located on Kenya's Indian Ocean Coast (3^0 20'S, $39^0$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 annual rainfall is on its eastern side (1 000-1 100 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 Figure 1.1) 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 1 100 mm.

In the area around the forest (defined here as the buffer zone), there are patches of forest-associated vegetation and secondary colonizers. 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.

Data collection

A total of 366 hives were selected from apiaries situated in the buffer zone, 0-5 km away from the forest, which had established honeybee colonies (Fig 1.1). 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 each hive that was harvested: type of hive, distance from the forest and total honey yield per harvest (in kg). In addition, we took a 100g 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 to October 2006, March 2007, and August 2007 to 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. The data reported here are mean yields per harvest in kilograms. It is noteworthy that the average number of harvests was the same at every apiary, regardless of the distance from the forest, throughout our study period (Kipepeo honey records, unpublished data) and could not be a confounding factor. The beekeepers operate in groups and each group borrows safety gear in the form of bee suits from the Kipepeo office or from their group leaders. It was therefore easy to track the number of harvests that occurred. This could be because of the limitation of harvesting gear or because the beekeepers are yet to produce honey at its full potential as they are still in the learning process.

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 <1km zone.

For the effects of distance on honey quality, we report data from 46 apiaries, 18 from <1km, 19 between 1-3km and 9 at more than 3km 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 analyzed 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. Finally, proline was also determined spectrophotometrically according to AOAC (1998) using method 979.20.

Data analyses

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 *nmle*.

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.

RESULTS

The yield data were found to be normally distributed and thus subjected to ANOVA without transformation. In the atypical year 2006/2007 (Figure 2.1a), 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, 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; <1km = 7.26 ± 0.56, 1-3km = 6.26 ± 0.67 and >3km = 3.98 ± 0.34) (Figure 2.1b).

In our combined (overall) data, the coefficient of variation at distances less than 1km was 64.58%, at 1-3km it was 55.99% and at more than 3km it was 63.66%. Thus, there is less variability in the samples from distance category 1-3km. We obtained GLS estimates for the regression of honey yield on distance and hive type as shown in Table 2.1. 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 2.1, the relationship between distance (km) and honey yield (kg) for different hive types is as follows:

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.

As far as honey quality is concerned, 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 2.2).

DISCUSSION

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 honeybees being able to exploit the greater temporal and spatial diversity of floral resources both inside and outside the forest (Chacoff and Aizen, 2006), 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 social 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 catch boxes at the forest edge in order to promote colonization in new hives. There is additional evidence that forest proximity affects hive colonization: a survey at ASF in 2007 by Ngoka et al. (unpublished data) showed that the colonization rate of Langstroth hives introduced by *icipe* ranged between 60-100% in apiaries less than 1km from the forest, 27-

61% in apiaries 1- 3 km away from the forest and 0-15% in apiaries more than 3km 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 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 Freinsinger, 2003). Klein et al. (2003) also 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 forest-associated 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 they occur abundantly only up to one kilometre away from the forest edge due to clearing for various human-related activities (Sande et al., in prep). Ricketts (2004) found that visitation rates of managed bees to an area with flowers decreased with distance from it. In his study, coffee farms nearer a forest were visited more often than those further away. Another study by Williams and Kremen (2007) showed that even for solitary bees, proximity of nesting habitats relative to their foraging sites is an important factor. Furthermore, Ricketts et al. (2008) synthesised 23 studies done across five continents and found that the visitation rates of various types of bees dropped with increasing distance to their foraging sites. They also found that visitation rates are 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, 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 size (Ngoka et al., 2007, unpublished data). This could be because the honeybees were able to forage deep into the forest (particularly in the moist areas) for any remnant resources.

Some studies suggest that fragmentation may not always have negative effects on bee communities in terms of density and diversity (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).Thus, low agricultural activity around ASF may have 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 beekeepers 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.

Honey quality as a function of distance from the forest

The biochemical properties analyzed 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.

Honey yield as a function of hive type

Our results from the typical weather year confirmed that Langstroth hives yielded 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 >3km 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 honeybees. Therefore, while other apiaries at the same distance suffered absconding, their apiaries thrived and produced honey consistently. These effects were removed in 2007/2008 when the weather conditions became favourable and the yield per hive nearer the forests became higher than yield from these two beekeepers.

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.

Recommendations

The principal finding of this study is that honey yields are substantially higher close to the forest. We recommend that maintenance of high apifloral 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 vegetation near their apiaries. 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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Table 2.1: Generalized least squares parameter estimates and their standard errors for the regression of yield on distance for different hive types.

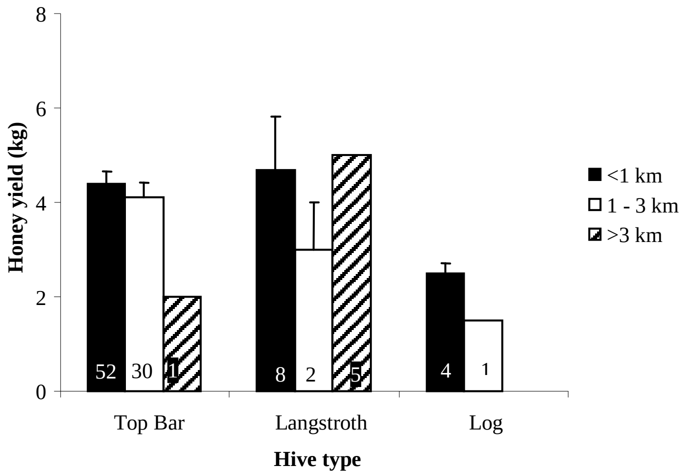
Parameter	Estimate	Std. error	t-value	p-value
Intercept	9.47	0.727	13.02	0.0000
Distance	-1.17	0.178	-6.60	0.0000
Top Bar hive	Reference			
Langstroth hive	2.79	0.735	3.80	0.0002
Log hive	-2.05	0.942	-2.18	0.0312

Table 2.2: Biochemical properties of honey harvested at varying distances from the forest edge.

	Biochemical Properties		Distance from forest (km)		
		0 to 1	1 to 3	3 to 5	Units
		N= 18	N= 18	N= 9	
1	Moisture	20.64±0.29^{a}	19.86±0.30^{a}	20.00±0.29^{a}	g per 100g
2	Sugar content				
	Total sugars	63.37±0.66^{a}	62.60±0.78^{b}	59.49±0.63^{c}	g per 100g
	Fructose	38.01±0.42^{a}	37.59±0.43^{b}	35.93±0.31^{c}	g per 100g
	Glucose	24.95±0.32^{a}	24.77±0.37^{b}	23.32±0.44^{c}	g per 100g
	Sucrose	0.33±0.08^{a}	0.21±0.07^{a}	0.22±0.10^{a}	g per 100g
	Maltose	0.04±0.01^{a}	0.03±0.01^{a}	0.02±0.01^{a}	g per 100g
3	Acid properties				
	pH	3.53±0.06^{a}	3.47±0.07^{a}	3.53±0.05^{a}	meq per kg
	Free acid	25.17±1.23^{a}	25.06±1.21^{a}	27.90±1.92^{a}	meq kg
4	HMF	7.01±1.41^{a}	9.78±1.31^{a}	10.78±2.15^{a}	mg kg
5	Proline	232.16±10.84^{a}	224.48±7.68^{a}	229.25±14.18^{a}	mg 100g
6	Diastase activity	20.18±2.38^{a}	16.27±1.01^{a}	19.54±2.79^{a}	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 = 45.The highlighted rows show properties that differed significantly in honey harvested from different distances.

a) 2006/2007



b) 2007/2008

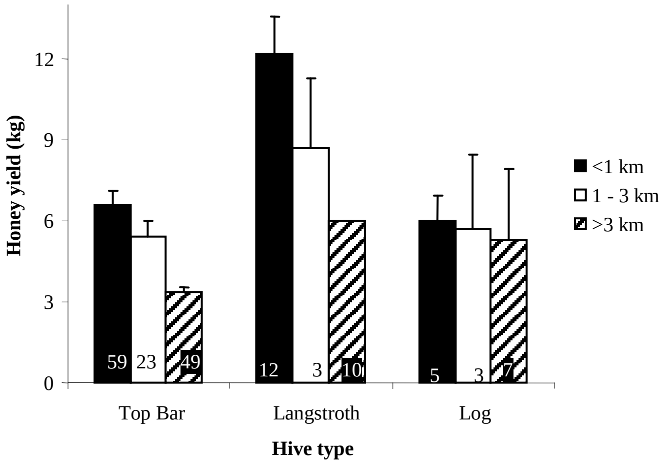


Figure 2.1: Honey yield per hive (kg) as a function of distance from the forest edge and hive type. The bars represent different hive types and bear the number of observational units (n) at each distance category. Results are expressed as mean values and bars bearing different letters represent statistically different yields. Some standard error bars were too small to appear on the figure.

a) 2006/2007

b) 2007/2008

CHAPTER 3

Temporal availability of floral resources for bee foraging around a protected coastal forest: Arabuko Sokoke Forest, Kenya

Abstract

Beekeeping in the buffer zone of a forest, instead of traditional destructive honey-harvesting from forest trees, is one option for using forest resources in a sustainable way. Although this option is possible at Arabuko Sokoke Forest (ASF) in Kenya, no floral calendar exists for the times and durations of flowering of plants that can be foraged by honeybees. This is especially needed because beekeeping is not traditional in the ASF community and so there is no indigenous knowledge of such a calendar. Such information is useful in timing the establishment of new apiaries and the management of existing ones, with the aim of increasing the production of honey to supply both local and national consumers. Data were collected by direct observation and recording of flowering every fortnight during two consecutive years (2006 to 2007) and a floral calendar was compiled. Twelve common plants around ASF flowered continuously for more than six months in a year and 70 others flower for at least two full months every year. Cultivation of these plants would ensure year-round availability of ample foraging grounds for honeybees and promote increased honey production by strengthening the honeybee colonies and preventing absconding. In addition, the calendar could form a basis for future studies on any possible effects of climate change and the intentional use of beekeeping as a basis for conservation of the local fauna.

INTRODUCTION

Arabuko Sokoke Forest (ASF) in Kenya, like all tropical forests, has faced the threat of annihilation, in spite of the fact that it belongs to the East African Coastal Forest Hotspot (Myers et al., 2000; Mittermeier et al., 2004). The major challenge to this forest has been the unsustainable harvesting of timber and non-timber products for economic purposes. The first major step towards stopping the threat was taken in the late 1980s, when human activity inside the forest was prohibited, following an order gazetted by the government of Kenya. Some illegal activities, however, still persisted, including logging for timber and charcoal, hunting of wildlife and destructive harvesting of honey from wild bee nests. Therefore, the ASF management team, which is made up of governmental and non-governmental conservation groups, has increasingly adopted the option of developing community-driven conservation projects to ensure that communities can draw a livelihood from this vital ecosystem without destroying it.

The Kipepeo Project was the first to assist the ASF local community to use biodiversity in a sustainable way to earn money. It involves rearing and exporting of the forest's beautiful selection of butterflies for live butterfly exhibition industries in Europe and the U.S. Cumulative community earnings from 1994 to 2001 exceeded $130,000 with significant positive effects on both livelihoods and attitudes (Gordon and Ayiemba, 2003). The project has been financially self-sustaining since 1999, and butterfly monitoring indicates that there have been no adverse effects on wild butterfly populations (Gordon and Ayiemba, 2003). Stemming from the success of this pioneer project, other ideas were embraced, including cultivation of mushrooms for the local tourist hotels, silk-moth rearing for commercial purposes, rearing of beetles for collectors and curios and also beekeeping for honey. There is a unique opportunity at ASF to build a portfolio of the ways in which forest insects (and other resources) benefit adjacent communities in a sustainable way (Ian Gordon *pers. comm.)*

Apiculture in the vicinity of the forest is important for production of honey and wax for sale and local consumption. Honey from this area has been found to meet international quality standards (Chapter 2; Sande et al., 2009). Its yield has been shown to increase with proximity to the forest; the yield was almost twice as high in hives placed less than 1 km from the forest compared to those placed more than 3 km from the forest (Chapter 2; Sande et al., 2009). Apiculture thus has the potential to improve livelihoods of the ASF community and to give them an incentive to participate in the conservation of this vital forest. Furthermore, managed bees are important pollinators and pollination is a crucial step in the re-establishment of deforested areas (Neal, 1998). Some 40 000 plant species have global importance as food resources to honeybees (Crane, 1990) and are thus potentially pollinated by honeybees.

Wild and managed bees mostly collect only two (food) resources from plants, nectar and pollen grains (Rasheed and Harder, 1997). They are also known to collect other plant substances including scent, antibiotic compounds and resin (Ambruster, 1984). The source of nectar ultimately affects the composition and properties of honey (Terrab et al., 2004, Sande et al., 2009). It is the sugar content of nectar that is usually of primary interest to bees as it is the energy supply for foragers, although it contains other important components including water. The amount of sugar in a given flower’s nectar fluctuates with foraging intensity and re-absorption by the plant (Corbet, 2002). Honeybees tend to prefer flowers providing a relatively small amount of nectar with high sugar concentrations, in contrast with sunbirds, for example, which frequently forage on flowers with copious amounts of relatively dilute nectar (Nicolson, 2002).

Pollen is essential for bees as a source of proteins for larval development and growth. Bumble bees collect pollen from a limited section of the available plant species and they exhibit different behaviour when collecting pollen than when collecting nectar (Rasheed and Harder, 1997). Such preferential collection is important as essential amino acids are available for larvae in particular pollen grains (Brodschneider and Crailsheim, 2010) and inadequate amounts of such pollen limit offspring production (Pirk et al., 2010). Flowers in return, are adapted in various ways to attract bees using the aroma of pollen (Dobson, 1987). Bees cause dispersal by sonication (Moore, 1996) and thus aid in both inter and intra-plant pollination. In an earlier study on Moroccan honey, Damblin and Lobreau-Callen (1991) concluded that honeybees showed higher selectivity for their pollen sources than for nectar sources.

When African honeybees have to forage on patches further than 5 km from their hive, they might not return, but establish other hives near the favorable patch (Schneider and McNally, 1992; Winston, 1992; Hepburn and Radloff 1998), a phenomenon known as absconding. Local as opposed to remote fragments of natural vegetation act as important refuges for them and for other pollinators (Neal, 1998). When the relative importance of a patch of vegetation falls, pollinators move on to others (Bronstein, 1995). In ASF, this usually results from deforestation or long periods of drought which cause a lack of flowering. Indeed, honeybees with their specific requirements for nutrition and nesting are good indicators of landscape structure and overall biodiversity of a forest, provided the ecological and seasonal patterns they show are taken into consideration (Raina pers. comm.).

This is the first study aimed exclusively at apifloral resources of a protected forest in the Eastern Arc and Coastal Forests biodiversity hotspot. Latham (2002) gave a detailed report of locally available plants that could be perpetuated for honeybee foraging by the beekeepers in southern Tanzania. Adopting of such plants by the locals could be a good boost towards conserving them, in this area where most of the natural vegetation has been cleared for agriculture. Other studies have documented relationships of honeybees and indigenous flora for other areas rich in biodiversity in Kenya (Martins, 2004; Martins, 2008). In addition, general honeybee flora have also been studied in northern Africa (Damblon and Lobreau-Callen, 1991), west central Africa (Villieres, 1987, Dongock et al., 2007), and extreme southern Africa (Hepburn and Jacot Guillarmod, 1991). Hepburn and Radloff (1995) review honeybee flora native to Africa as a whole.

Against this background, this study was intended to investigate the potential of beekeeping for forest conservation and to generate knowledge in order to advise ASF beekeepers on locally available flora that can be planted near their apiaries in order to avoid absconding. The ASF community has no tradition of beekeeping. Hence, there is a need to compile a floral calendar of plants available for bee foraging throughout the year. Such information is vital for apicultural management in making decisions about establishing new apiaries/colonies and in predicting the honey flow and dearth periods. Plants which flower twice a year for a period of at least two months are important resources for the maintenance of colonies in apiculture (Raina, 2004) and are therefore noteworthy when setting up and maintaining hives in any area.

MATERIALS AND METHODS

Study site

Arabuko Sokoke is a dry coastal forest lying at the northern part of the Kenyan coast, occupying an area of 420 km^2. It usually experiences an annual bimodal rainfall pattern, with a total annual precipitation of between 600 and 1000 mm, the long rains lasting from late March/April to June and the short rains from November to December (see Fig 3.1). Drought and famine years, however, are also common. In the couple of years before 2006, for example, there was a severe drought followed by torrential rain and flooding. During the drought year, some places recorded as little as 200 mm of rain. The driest months are January and February.

Villages surround the forest (see Fig. 1.1) with a population of about 110,000 people. Although the area is agriculturally poor, thus providing low crop yields, subsistence agriculture is the community’s main occupation. They grow maize, cassava, and beans, with income supplemented by cash crops such as cashew nuts, 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 (Anonymous, 2002). Most households own goats (average of five per household), but tsetse flies and a lack of grazing area are constraints to cattle keeping. Many uses of the forest for subsistence or income generation have been declared illegal. This includes collection of water, fuel wood, poles, herbs, and hunting of wildlife for meat. The forest vegetation is made of a mangrove portion touching the waters of the Indian Ocean at the Mida Creek, a stand of *Cynometra webberi* thicket, a *Brachystegia* *spiciformis* woodland and a portion with a mixture of *Cynometra, Brachystegia* and other tree species (Anonymous, 2002).

Data Collection

At intervals of 14 days between May 2006 and December 2008, a record of plants flowering and either reported or observed to be frequented by honeybees was made from the area 0-5 km around the ASF. In addition, plants with pollination syndromes associated with honeybees (open diurnally, possess honey guides and a sweet smell, have variable colors except bright red) were also recorded (Baker and Hurd, 1968; Thomson and Thomson, 1992). Plant samples were collected when they were dry (no dew or rain), and preferably before the heat of the day had wilted them. The former was a measure taken to avoid excessive moisture which can lead to rotting of pressed samples and the latter was to ensure that they maintained their natural size and proportions as much as possible. Flower and foliage samples were taken, along with photographs of various views of the plant, and a GPS record of the source plant was made. The flowers and foliage were flattened and then pressed using a wooden plant press. Folded paper towels, used to absorb moisture from the samples, were changed daily. After the third changing/transfer, the samples were left alone until they were completely dry. They were then removed from the paper towels and placed on A4 size printing paper. A note of the name of the plant, and the time and place of its collection was made and maintained throughout, as accompanying paper, within each sample. For the plants that could not be identified immediately in the field, expert identification was later done by Mr Matthias Ngonyo, a botanist at the Gede Ruins Office of the National Museums of Kenya. Daily rainfall data records shown in Fig. 3.1

were obtained from the Msabaha Weather Station, which is mandated by the government of Kenya to maintain weather records of the area within and around the forest.

RESULTS

A total of 82 plant species were recorded flowering for a period of at least two months and as potentially foraged by honeybees. Of these, 70 were directly observed by the researcher and/or beekeepers (54 and 16 respectively) to be visited by honeybees, and the remaining twelve were suspected, based on their floral characteristics (shape, colour, scent). Only 18 species in this calendar are crop species and the rest (69 species) are secondary colonizers of the formerly forested regions, made up of trees, shrubs, herbs, or grasses. It is notable that the farms were not planted regularly/at every possible opportunity so during some growing seasons, some farms were fallow. This removed the possibility of a crop(s) growing and flowering more times during the year. Some twelve common plants also showed resilience by flowering for over 6 months in a year, regardless of the dry seasons, and honeybees were observed foraging on all of them (See Table 3.2). Coconut trees (highlighted), the only crop among the twelve, flowered throughout the whole year.

At the beginning of 2006, following less than average rainfall which occurred after prolonged drought, flowering was reduced, in terms of number of plant species flowering. The floral abundance was also reduced. During this year, 53% of the plants that flowered were directly observed being foraged as opposed to 77% in 2007. Most of the plants that flowered during the atypical period were perennial trees. The honeybee floral calendar of ASF is presented in Table 3.1. Although many more plants flowered during the study period, the plants listed in this floral calendar are those that we were able to identify and had continuous flowering for at least a period of two months per year. Honeybees were also observed foraging on extra-floral plant resources (Fig. 3.3).

DISCUSSION

If provided with sufficient moisture, either from the rain or from irrigation, the number of plant species flowering around ASF for at least two months annually (see Raina, 2004) can easily support larger numbers of healthy honeybee colonies than are kept currently. This would result in a higher production of honey for beekeepers. During the dry period of 2006 which followed a long drought and famine, one farmer who irrigated his crops continued harvesting honey while the rest experienced massive absconding and thus no harvesting (Chapter 2; Sande et al., 2009).

Flowering time is determined by an interaction of genetic and environmental factors and the first flowering dates of annual plants are more variable than those of perennials (Fitter et al., 1995). In this study, at the beginning of the atypical year (2006) following less than average rainfall which occurred after prolonged drought, flowering was almost non-existent, in terms of number of plant species flowering and even the abundance of flowering. It was also noted that the few plants that flowered during this period were mostly perennial trees. Augspurger (1981), when studying a common shrub in Colorado Island of Panama, found that variation in water stress results in some local variation in flowering phenology. There is, however, not always a straightforward relationship between moisture and flowering as many other factors may come to play in nature. For example, Murali and Sukumar (1994), while studying the reproductive phenology of a tropical dry forest in India, found that the number of species flowering attained a peak at a dry site with limited soil moisture during the dry months, and that the insect-pollinated guild showed seasonality in flowering only in a wetter site.

The increase in number of flowering species during 2007, a year of normal rainfall, was probably due to the fact that biotic factors play a more important role in moulding phenological events in tropical environments than in temperate environments. Murali and Sukumar (1994) also found that more abundant and insect-pollinated species tended to flower during the wet season in an Indian dry tropical forest. This is in agreement with the findings of Opler et al. (1980), who found that small trees and shrubs in a dry Costa Rican forest flowered mainly during the wet season. In a seasonal neotropical forest, also in Costa Rica, however, Janzen (1967) concluded that the need to avoid competition and to synchronise flowering with the availability of pollinators was probably responsible for trees flowering during the dry season.

Damblon and Lobreau-Callen (1991), while studying north west African honeys, found that native flora continued to be attractive to honeybees even near cultivated crops, although the crops attracted a significant proportion of the honeybee foragers. Arabuko Sokoke Forest, on the other hand, is an area of marginal agricultural productivity and there is not much crop cover to supplement the natural flora. In fact, honeybees kept by the local residents may have resorted to absconding into the forest during the drought because there are no alternative foraging sites in terms of crops. Rasheed and Harder (1997) found that bumble bees display sensitivity to plant density and Carvalheiro et al. (2010) recorded a decline in the numbers and species richness of floral visitors (pollinators) of mango with increase of distance from the natural savanna vegetation to the mango farm. Research on watermelon farms in northern California (Kremen et al., 2004) also showed that conserving as little as one-tenth of the wild bee flora could meet 40 percent of their pollination needs. These studies imply that natural/wild flora not only perpetuates but boosts pollinator populations. Honeybees are amongst the most efficient foragers and pollinators. Worldwide, they have been used to pollinate many crops, including date palm, watermelon, tomato, and beans (Free 1996), and their presence has frequently been associated with increased yield (e.g. Gingras et al., 1999). In their review of pollination studies in Africa, Rodger et al. (2004) suggest that although research on honeybees elsewhere in the world has shown their great potential to be managed for pollination (of agricultural systems), there is not much research done in Africa, except in South Africa. These workers propose that such studies should be undertaken widely in Africa as their findings could contribute to food security and biodiversity conservation. In the ASF community for example, there seems to be no knowledge about the role of bees in pollination among the beekeepers and this information should be taught to them in order to fully exploit the potential of beekeeping. Some beekeepers even clear bushes around their apiaries to keep it ‘clean’ yet some of these plants are foraging sites for the bees.

Distance from a food source is among the major limiting factors for honeybees (Visscher and Seeley, 1982) thus colonies which have to travel more than 5 km to forage tend to move from their original hives and make new hives near or within the foraging sites. Since human activity is forbidden inside the ASF, beekeepers are unable to access colonies that may abscond due to lack of foraging sites occasioned by drought or clearing of nearby bushes for other uses, including agriculture. Beekeepers have therefore been advised, as a result of the present study, to plant or maintain the plants in the floral calendar near their apiaries, to avoid absconding. Such a move will also result in conservation of these plants in the forest's surroundings. They have also been advised that some of their crops are important forage sites for bees and can help in both maintaining and boosting hive populations.

From the pattern of flowering in this calendar, we propose that it would be prudent for a bee-keeper to set up a new apiary either in the month of April or May. The periods when either watering of nearby bushes or provision of supplementary food to honeybees may be necessary are January to March. Honey harvesting was done during the months of August to March 2007/2008 (Chapter 2: Sande et al., 2009). Therefore, coupled with information from this floral calendar, it is concluded that the dearth periods in ASF are April to July.

These kinds of data, if collected over a long period of time, are also useful for following or predicting the effects of global warming and climate change on flowering (Fitter et al., 1995). Coupled with further studies, this floral calendar could also be used for scientific work on foraging behaviour of honeybees, such as on decision-making while foraging, depending on available nectar and pollen sources, abundance of these sources, distance to the hive, profitability of each source etc. The observation of honeybees on agricultural crop areas could also be a basis for further investigation. Since the agricultural production of this area is marginal, honeybees could be used to boost pollination and ultimately yield of various crops during the rain-fair years. Plants which could benefit from honeybee pollination include fruits such as watermelons, guavas, mangos, cashew nuts, and Indian plum (*Ziziphus mauritiana*), that are currently grown at subsistence levels, and wild growing *Grewia* trees which could then be cultivated. These fruits have ready markets in coastal and other areas of Kenya. Finally, as was the objective of this study, the calendar is useful in the setting up of apiculture since the community around ASF is not traditionally apiculturist.

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Table 3.1: The floral calendar of bee-foraged plants around the Arabuko Sokoke Forest

Scientific Name	Local/ Common Name	Plant Type	Foraging Status	Months of the year 1	2	3	4	5	6	7	8	9	10	11	12
Family: Acanthaceae															
Asytasia enselloides	Thalakushe	Herb	Obs.	_*	**					**					
Asystasia gangetica	Thalakushe	Herb	Obs.	**	* *	**	**	*_	_*	**					
Asystacia sp.	Thalakushe	Herb	Obs.		_*	**	*_	_*	**						
Justicia flava	Mtumwa wa thalakushe	Herb	Obs.			**		*_	_*	**			**		
Sclerohiton vogelil		Herb	Susp.	_*	**	*_	__	**	**	*_					
Family: Amaranthaceae															
Amaranthus hybridus	Mchicha	Herb	Obs.	**	_*		*_		_*	*_			**		
	Kidemu	Herb	Obs.			*_	**	**		*_					
Family: Anarcadiaceae															
Anacardium occidentale	Mkorosho	Tree/crop	Rep.	**	* *	**	**	**		_*	**		**		
Ozoroa obovata	Mkayukayu	Tree	Obs.	* *	* *	**	**	**	**	*_			**		
Mangifera indica	Mwembe	Tree/Crop	Obs.		_*	**	**	**	_*	**			**		

Scientific Name	Local/Common Name	Plant Type	Foraging Status	Months of the year 1	2	3	4	5	6	7	8	9	10	11	12
Family: Apocynaceae															
Landophia kirkii	Mtongazi	Shrub	Susp.				**			**					
Thevetia peruviana	Mkode	Tree	Rep.	**	* *	**	**	**	**	**	**		**		
Family: Arecaceae															
Cocos nucifera	Mnazi	Tree/Crop	Obs.	**	* *	**	**	**	**	**	**	**	**	**	**
Family: Asclepiadaceae															
Sarcostema viminale	Mvilla		Rep.			-*	*-		-*	*-					
Family: Asphodelaceae															
Aloe rabaiensis	Herb		Rep.						-*	*-			**		
Family: Asteraceae															
Bidens pilosa	Kidungadunga	Herb	Obs.	**	-*				**	*-			**	**	*-
Helianthus anuus	Sunflower	Crop	Obs.	**	**	**		**							**
Launea cornuta	Mchunga	Herb	Susp.						-*	**	**				

Scientific Name	Local/ Common Name	Plant Type	Foraging Status	Month of the year											
				1	2	3	4	5	6	7	8	9	10	11	12
Family:Boraginaceae															
Bourreria petiolaris	Mbunduki	Tree	Susp.	-*			-*	-*	**	**					
Heliotropium steudneri	Muua	Herb	Obs.	**	**	**	**	**	**	**	**				
Family: Caesalpiniaceae															
Chamaecrista mimosaides		Herb	Obs.	**	* *	**	-*	-*	**	*-					
Family: Caricaceae															
Carica papaya	Mpapai	Crop	Obs.		*-	*-			**	**	**	*-			
Family: Colchicaceae															
Gloriosa superba		Climber	Susp.	-*	* *	*-		-*	**	**					
Family: Combretaceae															
Terminalia sp	Mkungu	Tree	Rep.		**	**	*-		**	**	*-				

	Local/ Common	Plant	Foraging	Month of the year											
Scientific Name	**Name**	**Type**	**Status**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Family: Commelinaceae															
Comellina sp	Dzadza	Herb	Obs.	**	* *	**	**	**	**	**	**	*	**	*-	
Family:Compositae															
Gutenbergia sp	Mtalalabamba	Herb	Obs.	-*	* *	**	**	**	**	*-					
Vernonia zanzibarensis		Herb	Susp.							**	*-			**	
Family: Convolvulaceae															
Jacquemontia tenuifolia	Hende ra nzovu	Herb	Obs.			**	*-		**	**	*-		**	*-	
Family:Cucurbitaceae															
Curbita sp	Malenge	Crop	Obs.						**	**			**	*-	
Family: Cyperaceae															
Cyperus sp	Ndagu	Grass	Obs.	-*	*-	**	**	**	**	-*	*-		**	*-	
Mariscus sp	Ndagu	Grass	Obs.	**	* *	**		**	**	*-					

Scientific Name	**Local/ Common Name**	**Plant Type**	**Foraging Status**	**Month of the year**											
				1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Family: Euphobiaceae															
Bridelia cathatica	Mkalakala	Herb	Rep.						**	*-					
Manihot esculentum	Mhogo	Crop	Obs.	- *	**	**								**	
Family: Fabaceae															
Cajanus cajan	Mbaazi	Crop	Obs.		* *	**	*-		-*	**	*-				
Senna occidentalis	Mtsalafu	Herb	Susp.	**	**	**	**	-*	**		-*	**	**	*-	
Vigna unguiculata	Maharage	Crop	Rep.			**			-*	**					
Family: Labiatae															
Becium filamentosum	kimbiri-like'	Grass	Susp.	**	*-	**				**					
Hoslundia opposite	Mtserere	Shrub	Obs.	**	*-	-*	**	**	**	**	**	*-			
Leucas tsavoensis var. kilifiensis	Mkakazi	Herb	Obs.	* *	* *					-*	**	*-		-*	**
Ocimum suave	Luvumbane	Herb	Obs.	* *	* *			-*	**	**	**		**		
Labiatae sp.	Kabanda jembe	Herb	Obs.	-*	**	**	**	**	**						

Scientific Name	Local/ Common Name	Plant Type	Foraging Status	Months of the year											
				1	2	3	4	5	6	7	8	9	10	11	12
Family: Malpighiaceae															
Acridocarpus zanzibaricum	Mboho	Tree	Rep.			**		_*	*_						
Family: Malvaceae															
Abutilon sp.	Mpamba tsaka	Climber	Obs.		_*	*_			**	*_				*_	
Hibiscus micranthus	Mrembeganga	Shrub	Obs.	**	* *	**	**	**	**	*_			**		
Hermania exappendiculata	Mhangusa mavi	Herb	Obs.	**	* *	**	**	**	**				**		
Sida ovata		Herb	Obs.	**	* *	**	**	**	**				**	*_	
Thespesia denais	Muhowe			**				**							
Family: Meliaceae															
Azadirachta indica	Mkilifi	Tree/Crop	Obs.			**	_*	*_	**					_*	**

				Month of the year											
Scientific Name	**Local/ Common Name**	**Plant Type**	**Foraging Status**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Family: Mimosaceae															
Acacia brevispica	Kikwatha	Tree	Obs.	_*	* *	**	**	**	**					_*	*_
Acacia sp.	yellow' acacia					**								_*	*_
Dichrostachys cinerea	Mkingiri	Shrub	Obs.	**	**	**	*_	_*	**	*_					
Family: Moringaceae															
Moringa oleifera	Mzumbwi	Tree/Crop	Susp.		*_	**	**	*_	**						
Family: Myrtaceae															
Eucalyptus sp.		Tree	Obs.	_*	*_	**	**	**	**	**	**	*_			
Psidium guajava	Mpera	Crop/Tree	Obs.			*_			**	*_					**
Family: Nyctaginaceae															
Boerhavia diffusa	Mgalagala	Shrub	Rep.	**	*_	*_	*_	_*	**	*_					

	Local/ Common	Plant	Foraging	Month of the year											
Scientific Name	**Name**	**Type**	**Status**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Family: Ochnaceae															
Ochna mossambicensis	Mdhahabu	Shrub	Susp.		**		_*	**	**	*_		**		**	
Family: Passifloraceae															
Passiflora edulis		Crop	Obs.	**	*_		*_	*_	**				**		_*
Family: Pedaliaceae															
Sesamum sp	Msimusimu	Herb	Obs.	**			**								
Family: Poaceae															
Panicum maximum	Mondo	Herb	Obs.	**	**	**	**	**	**	*_			**		_*
Zea mais	Mahindi	Grass/crop	Rep.	**	**	*_			**	**	**		**		
Family: Polygonaceae															
Oxygonum salicifolium	Kimbiri	Grass	Obs.	**	**	**	**	**	**	*_		**	**	**	*_

	Local/ Common	Plant	Foraging	Month of the year											
Scientific Name	**Name**	**Type**	**Status**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Family: Rhamnaceae															
Ziziphus mauritiana	Mkunazi	Tree/Crop	Obs.	_*	**	**	**	*_	**			**	*_		
Family: Rubiaceae															
Agathisenthemum boijeri	Kaidhima	Herb	Obs.	**	* *	**	**	**	**	**	**				
Oldenlandia sp		Herb	Obs.							*					
Polysphaeria parvifolia	Mmangi	Tree	Rep.	**	*_	*_			**						
Family: Solanaceae															
Solanum sp	Mnavu kipuli	Herb	Rep.	*					*_						
Solanum incanum	Mtondo	Herb	Rep.	**	**	**	*_	**	**	**	**	**	**	*_	
Lycopersicon esculentum	Nyanya	Crop	Obs.	**	**	_*				**	**		**	*_	
Family: Tiliaceae															
Grewia sp-1	Mbavubavu	Tree	Obs.	**	**	**	*__	_*	**	*_					

Scientific Name	Local/ Common Name	Plant Type	Foraging Status	Month of the year											
				1	2	3	4	5	6	7	8	9	10	11	12
Family: Tiliaceae cont.															
Grewia sp-2	Mkone	Tree	Obs.	_*	**	**	_*	*_	**	*_					
Grewia sp-3	Mkone kilaa	Tree	Obs.	_*	**	**	**	**	**	**	**		**		
Triumfetta rhomboids	Kiramata	Herb	Rep.	**	* *	**	*_		_*	*_					
Family: Verbenacea															
Premna chrysoclada	Mvuma	Tree	Obs.	**	**	**	**	**	**	**	**		**		
Lantana camara	Mshomoro	Shrub	Obs.	**	**	**	**	**	**	**	**	**	**	**	**
Family: Vitacea															
Cyphostema adenocaule	Mgangalungo	Shrub	Rep.					_*	**	*		_*	**	*_	
Cissus rotundifolia	Mtsula pengo	Shrub	Obs.				_*		**	**	**	*_			
Capsicum sp	Mpilipili	Crop	Obs.	_*	*_			**					**		

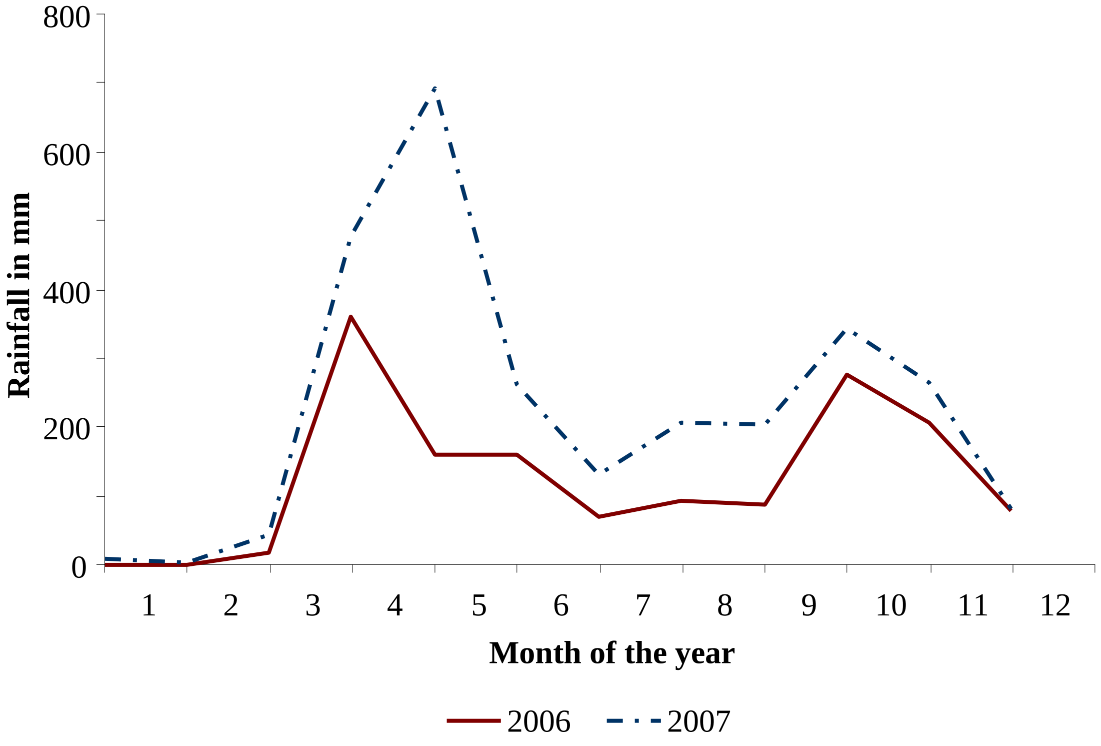
	Local/ Common	Plant	Foraging	Month of the year											
Scientific Name	**Name**	**Type**	**Status**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Family unknown															
Gnidia latifolia		Tree	Obs.						**	**	*-				
	Mawele	Crop	Obs.	**	**	*-					**	*-			-*
	Mrenda	Herb	Obs.	-*	* *	**	**	-*	**	*-					

KEY:

* flowering for a period of 2 weeks	Obs. – the researcher observed the plant being foraged by honeybees
- absence of flowering for a period of 2 weeks	Rep. – locals reported that they observed the plant being foraged by honeybees
	Susp. - floral characteristics show potential candidacy for honeybee foraging but we never observed them being foraged and got no reports of the same

Table 3.2: Bee foraged plants that were observed flowering for a continous period of six or more months annually around Arabuko Sokoke Forest. *Cocos nucifera* (coconut) flowered throughout the year.

Scientific name	***Giryama/Swahili name***
Agathisenthemum boijeri	Kaidhima
Cocos nucifera	Mnazi**
Comellina sp	Dzadza
Grewia sp-3	Mkone kilaa
Hibiscus micranthus	Mrembe ganga
Hoslundia opposite	Mtserere
Lantana camara	Lantana
Solanum incanum	Mtondo
Oxygonum salicifolium	Kimbiri
Panicum maximum	Mondo
Senna occidentalis	Mtsalafu
Thevetia peruviana	Mkode



Source of weather data: Dabaso Weather Station

Figure 3.1: Mean monthly rainfall (in mm) recorded at ASF between January 2006 and December 2007.

Figure 3.2: Honeybees (and a moth) foraging on overripe fallen mango fruits

CHAPTER 4

Mangroves of Mida Creek, Kenya: Bee visitation and qualities of mangrove honey

Abstract

Honey from the mangrove portion of Arabuko Sokoke Forest (Mida Creek) is priced more highly than honey from its dry section. This is because many honey consumers prefer its distinct taste. We studied some floral characteristics of the Mida Creek mangroves, the foraging behaviour of honeybees on them, and compared the chemical composition of honey harvested from hives placed at the creek with those of honey from hives placed in the non-mangrove portion of ASF. Three of the seven mangrove species that occur at Mida Creek were flowering during our study. Results showed that *Ceriops tagal* and *Bruguiera gymnorrhiza* have the potential to be pollinated both at night and during the day, since their flowers open at both times. There was no nectar produced by *A. marina* during our period of study yet its flowers had a strong honey-like smell that seemed to attract both honeybees and stingless bees. Nectar was available throughout the day in *B. gymnorrhiza* but *C. tagal* had nectar for only five separate hours during daylight. Although earlier studies on nectar volume and concentration have implied an inverse relationship between the two, we did not find the same in the nectar sampled from *B. gymnorrhiza* and *C. tagal*. Of the five abiotic conditions studied (orientation of the sun, temperature, relative humidity, time of the day, tree species) orientation of the sun could be the most significant determinant in the number of honeybee visits to the three mentioned mangrove tree flowers at Mida Creek. When we tested the biochemical properties of mangrove honey against those of honey from the dry forest, water content, ash content and electrical conductivity were found to be

significantly lower. From our results, we concluded that the unique taste of mangrove honey could be due to its unique mineral content (which determines its ash content and electrical conductivity) and salt spray from the sea, although the latter was not within the scope of this study.

INTRODUCTION

Mangroves are salt tolerant, evergreen trees and shrubs found in the inter-tidal areas between dry land and sea. Approximately 24 families and 83 species of mangroves have been identified (Ricklefs and Latham, 1993; Duke et al., 1998; Kathiresan and Bingham, 2001). Of these, 15 species occur in Africa. They occur in relatively sheltered locations, such as estuaries, coastal lagoons and creeks, in tropical areas (Teas, 1983; Tomlinson, 1986). These brackish conditions are too harsh for growth of other land plants but mangroves have developed strategies to cope with the high salinities. These include salt excretion through the leaves, prevention of excessive salt entry into the plant, and aerial roots (pneumatophores) to avoid ‘asphyxiation’ from the perpetually anaerobic, waterlogged soil (Tomlinson, 1986). Mangrove seeds cope by germinating very fast before they can be washed away by the tides; some even begin germinating on the mother plant before they fall. Varying tolerance to these conditions results in zonation of species, with each zone dominated by one species. *Avicennia marina* (Forsk.) Vierh. (Avicenniaceae) is the most tolerant of mangrove trees, capable of growing (albeit stunted) in water three times as salty as normal seawater.

Mangroves are useful in many ways. They absorb the impact of intense storms (Carlton, 1974; Tomlinson, 1986; UNEP-WCMC, 2006). They also reduce erosion and increase sedimentation of the coastline, and are important areas for coastal pioneer species of fishes, birds, amphibians, turtles, and many others. In trapping silt and stabilizing the shore they protect coral reefs, which are very susceptible to damage by siltation (Tomlinson, 1986; UNEP-WCMC, 2006). Indeed mangroves act as a basis for complex, biologically diverse and productive ecosystems (Tomlinson, 1986; Kathiresan and Bingham, 2001; UNEP-WCMC, 2006).

Although mangroves are able to cope with the natural fluctuations in their environment, the chief factor modifying mangrove distribution is human activity (UNEP-WCMC, 2006). Ranging from direct destruction of mangroves to pollution of the environment, human activity has left the mangrove ecosystem threatened worldwide. Strict regulations alone have a history of chronic failure (Glaser et al., 2003) but community involvement and formulation of sustainable ways of using this resource offer a more promising option for conservation. Most efforts to replant mangroves have also been quite frustrating worldwide, with as few as 9 percent of seedlings surviving (Lewis, 2009). As a result, attention is being directed towards efforts to conserve entire mangrove habitats (Bosire et al., 2008; Lewis, 2009) as opposed to reclaiming portions of these habitats.

Eight species of mangroves occur at the Kenyan coast (Kokwaro, 1985) of which only *Xylocarpus granatum* Koen. (Meliaceae) is absent at Mida Creek in ASF (Table 4.1). Most of the Mida Creek mangrove species have a continuous distribution in the tropics but there are a few exceptions. *Pemphis acidula* Forst. (Lythraceae), for example, is found in East Africa but is absent from the intervening area in South India to Sumatra, only reappearing at about 137^{o}E in eastern Malaysia (Tomlinson, 1986). Mida Creek mangrove species are used for various purposes (Table 4.1) and, like mangroves everywhere, they face the threat of depletion. Various community based programs have been set up to conserve the Mida Creek mangrove ecosystem. First, the Mida Creek community was educated through an extensive awareness campaign in the early 1990s, on the ecological importance of mangroves. This campaign became relevant to the community in view of impending dangers such as having no buffer zone in case of a tsunami, reduced fish catches because destruction of mangroves results in the destruction of spawning sites, and other threats to the community's livelihoods drawn from the creek (Watamu Turtle Watch, Malindi Marine Park Authorities, Kenya Forest Research Institute (KEFRI), Arabuko Sokoke Forest Management Team (ASFMT), unpublished data). With the willingness of the community, various solutions have been sought:

1. Discouraging unsustainable economic practices such as shrimp and salt farming in order to curtail destruction and pollution of the mangrove ecosystem;
2. Restoration of mangroves by replanting their seeds (mostly carried out by groups of fishermen);
3. Planting alternative trees for construction, fuel and medicines (especially *Casuarina* spp. and neem trees);
4. Improved co-operation between the community and authorities in monitoring mangrove destruction;
5. Providing or encouraging the community living nearby to practice alternative, more sustainable sources of income in and near the mangrove ecosystem, such as beekeeping.

The perpetuation of any angiosperm community largely depends on its floral and seed biology. In the past two centuries, much research on mangrove reproduction was centered on seed biology (Primack et al., 1981), largely because mangroves are viviparous. Less is known of their floral biology, pollination and breeding mechanisms (Clarke and Myerscough, 1991; Ge et al., 2005). However, previous workers have reported insect flower visitors that are presumed to be pollinators (Tomlinson, 1986; Kondo et al., 1987, Clarke and Myerscough, 1991; Noske 1993) and a detailed study on the floral scent chemistry of eight mangrove species was carried out in Taiwan (Azuma et al., 2002). Mangrove species at a single location have been reported to overlap with one another in flowering phenology (Duke, 1992) and appear to be pollinated by a diverse array of animals, except for *Rhizophora* spp. and *Ceriops tagal* (Perr.) Rhizophoraceae which are also wind-pollinated. The broad spectrum of pollinators means that no plant is dependent on one specific pollinator (Kathiresan and Bingham, 2001).

There is limited information available on potential pollinators of some of the Mida Creek mangroves. Tomlinson (1986) divided the genus *Bruguiera* Lamk. (Rhizophoraceae), into two groups, based on flower size and pollination vector. He placed *Bruguiera gymnorrhiza* (L.) Lamk. (Rhizophoraceae) among the species with large, curved flowers considered to be bird pollinated, a fact that was later confirmed by Noske (1993) who observed sunbirds pollinating this species in Malaysia. *Ceriops tagal* is reportedly pollinated by bees and flies in the late afternoon and night (Tomlinson, 1986; Raju and Karyamsetty, 2008) while bats and hawk moths reportedly pollinate *Sonneratia alba* J. Smith (Sonneratiaceae) nocturnally (Tomlinson, 1986; Hockey and de Baar, 1991). Clarke and Myerscough (1991) observed numerous potential insect visitors on *Avicennia marina* (Forsk.) Vierh. (Avicenniaceae) but the most common were honeybees.

Bees have been reported as the most common visitors of mangrove flowers and have been observed pollinating *Avicennia*, *Acanthus*, *Excoecaria*, *Rhizophora*, *Scyphipora*, and *Xylocarpus* species (Tomlinson, 1986; Clarke and Myerscough, 1991; Noske 1993; Raju and Karyamsetty, 2008). It is a common practice for beekeepers at ASF to place catch boxes in the mangrove forest when setting up apiaries as the bee population there is high and hive colonisation by either honeybees or stingless bees is faster than in other locally available flora. In addition to honeybees, there are stingless bees at Mida Creek, which have recently become a focus of study by the International Centre for Insect Physiology and Ecology for domestication purposes (Macharia et al., 2007). There has been documentation of mangrove honey production in China (Yao et al., 2006), Brazil (Glaser et al., 2003), India (Jana and Bera, 2004), and generally in all parts of the world that have mangrove ecosystems. Indeed, Yao et al. (2006) concluded that mangrove ecosystems have a considerable potential for medium- to large-scale beekeeping ventures for the production of good quality honey. Although the existence and use of mangrove honey has been mentioned in various studies and its palynology studied (Yao et al., 2006), there has been no detailed analysis of its biochemical properties or a comparison made with ‘typical’ terrestrial honey. Mangrove honey is priced above the normal dry forest honey at ASF, because of its higher demand among the tourists and many beach hotels. It reportedly has a salty and not too sweet taste (M. Fungomeli, pers. comm.) and the local people claim that it has better medicinal properties than the usual forest honey.

The objectives of this study were to investigate honeybee foraging on mangrove flowers at Mida Creek, ASF and to study the biochemical characteristics of the resultant mangrove honey, in comparison with honey from the nearby non-mangrove section of ASF.

MATERIALS AND METHODS

Study site and mangrove species

Mida Creek bears a stand of mangrove trees that is adjacent to Arabuko Sokoke Forest, the largest remnant portion of a coastal forest mosaic that used to run from Somalia all the way to Tanzania in eastern Africa. It lies across Kilifi and Malindi district at around 110 km from Mombasa. Although it was originally a continuous block with the dry portion of ASF, the mangrove stand is now separated from it by human settlements and is less than 1km wide and around 6km long. In order to observe bee visits, we chose Dabaso Point, which lies at S 3^{o} 20’21 4”, E 39^{o} 59’14 9” on Mida Creek (Fig. 2.1). This was because all the seven Mida Creek mangrove species are present here, it was possible to make observations for most of the day given their position on the coast, and there were already colonized bee hives present. During the study period, four out of the seven mangrove species were flowering at Dabaso: *Avicennia marina*, *Bruguiera gymnorrhiza*, *Ceriops tagal* and *Rhizophora mucronata*. We studied the first three because, although the majority of *R. mucronata* trees flowered well, they were on the ocean side and only accessible for half the day due to the prevailing tidal patterns. All these three species were observed for bee visits. Patterns of flower opening and characteristics of nectar were observed for *B. gymnorrhiza* and *C. tagal*. Mangrove honey used for analyses was from hives situated all over the Creek, not just at Dabaso Point. Data were collected during daytime between 18 February and 14 March 2008.

Avicennia marina (Fig. 4.2 a) is a tree that can grow up to 30 m with actinomorphic, yellow to orange, 4-8 mm wide flowers, a corolla with mostly five lobes and a strong honey-like scent (Tomlinson, 1986). Although they had a nectar-like glossy surface, the flowers did not contain any nectar throughout this study period. *Bruguiera gymnorrhiza* trees (Fig. 4.2b) can grow up to 40 m high with solitary flowers 2–4 cm wide, fleshy calyx lobes (more than 6), delicate petals and an explosive mechanism of pollen release triggered by visiting insects. After explosion, the pollen is retained by the hairy brown and cream interior of the flower. It is commonly known as the red mangrove because of its reddish calyx and saplings upon germination (Tomlinson, 1986). *Ceriops tagal* is a shrub or rarely a tree, growing to 7-15 m; with tiny whitish flowers approximately 0.5 cm wide which turn brownish with age, probably as a result of being pollinated (personal observation). On average they have five corolla lobes and the anthers are brownish in colour.

Data collection

Flower opening, nectar properties and bee visitation

As mentioned earlier, three mangrove species were in bloom and accessible for all-day studying. Two of these (*B. gymnorrhiza* and *C. tagal*) were studied for their flower opening, nectar attributes and bee visits while one (*A. marina*) was observed only for bee visits because the trees were not accessible for flower opening studies. Three *B. gymnorrhiza* trees and three *C. tagal* trees were randomly chosen. On each tree three sections with no open flowers were marked. The number of new flowers opening was then recorded at 06.00 h and 18.00 h on each subsequent day. At hourly intervals, between 07.00 h and 18.00 h, three one day old flowers were collected from these trees, selected randomly with respect to height above the ground and aspect, to be used for nectar volume and concentration measurements. Disposable hematocrit tubes of 50 mm and a capacity of

50 µl were used for measuring large volumes, and 1 µl capillary tubes for small volumes. The nectar volume was determined from the length of the nectar column in the tubes. The concentration of each nectar sample was then determined by dropping a portion of it onto a hand-held refractometer (Bellingham and Stanley, UK) that had been specially adjusted for low volumes. Temperature and relative humidity at each tree were recorded using a hand-held thermo-hygrometer (TES Electrical Electronic Corp, Taiwan). During the pilot study, some of the flowers selected for the nectar studies had large populations of mites. At the *icipe* Biosystematics Unit these mites were found to belong to Astigmata and could possibly be *Hattena panopla* Domrow 1966 (Acarina: Ameroseidae), as also found in flowers of *B. hainesii* (C.G. Rogers) Rhizophoraceae flowers in Malaysia (Noske, 1993). Their presence at our study site was usually associated with very little, if any, nectar. Since they are presumed to have been consuming nectar, their unpredictable presence could have confounded any results obtained from exclusion experiments. The nectar volume results presented here thus represent only standing crop and not the total possible nectar production by the plants.

During the first two days, observations were made from dawn to dusk to determine the times of the day when foraging by honeybees and other flying insects occur. In addition, a sweep net was used every hour to collect flying insects observed on or within a meter of the vicinity of the open flowers. Although it was noted that sunbirds also visited these trees, no record was made as it was beyond the scope of this study. Three trees, one of each species (*A. marina*, *B. gymnorrhiza* and *C. tagal*) were observed continuously over 10 days to determine temporal patterns in honeybee and stingless bee visitation. From 07.00 h to 17.00 h, 30 min observations were made every two hours from the western and eastern side of each tree concurrently, in order to record the effects of the sun’s orientation. Using a hand-held counter, the numbers of visits by honeybees and stingless bees to the flowers were recorded by two people. Each sat on one side of a tree, recorded for 15 min, then switched sides so that each side got a total of 30 min of observation. The bees were classified as either honeybees or stingless bees by direct observation because of their marked difference in size, body structure and flight behavior.

Characteristics of mangrove honey

In order to find out why Mida Creek mangrove honeybee honey has a unique preferable taste to honey from the dry portion of the ASF, we tested its biochemical properties. Three samples of mangrove honey, from Langstroth honeybee hives in three apiaries situated at three different sections within the Mida Creek, were taken for analysis in the *icipe* Commercial Insects Studies Laboratory. Here, they were strained using a stainless steel sieve with a mesh diameter of 0.5 mm, and the filtrate stirred thoroughly to homogenize. The honey was then ready for subsequent analyses for the following characteristics: diastase, moisture, pH, free acids, conductivity, HMF and sugars (HPLC) using standard methods (Bogdanov, 1999). In addition, a subsample of each honey was sent to the Kenya National Plant Heath Institute (KEPHIS) for the analysis of sodium and potassium content.

The same characteristics were measured in three honey samples from langstroth hives placed near the non-mangrove sections of the ASF. The latter samples were representative of the three major sections of the ASF (dominated by *Cynometra weberi*, *Brachystegia spiciformis* or a mixed stand of these two species). These samples were from apiaries at the forest edge because at Mida Creek, the sampled hives had also been set up at the edge of the mangrove forest.

Data analysis

The number of flowers opening during the night (18:00 h – 06:00 h) and day (06:00 h – 18:00 h) were compared using a Chi square test. A normality test (Kolgomorov -Smirnov) on the nectar volume data showed that they were not normally distributed, so they were $\log_{10}$ transformed. Both nectar volume and nectar concentration data from *B. gymnorrhiza* were then subjected to ANCOVA with time as the independent factor and temperature and RH as covariates. Data from *C. tagal* were insufficient for statistical analysis. Pollinator visits were also analyzed using ANCOVA with time as the independent factor and temperature and RH as covariates. Honey quality data were subjected to ANOVA using the General Linear Model (GLM), assigning honey type as the fixed factor and biochemical property as the response variable. Where ANOVA showed significant differences, Tukey's test was performed to separate the means. All the mentioned analyses were done with the program SAS (SAS 2005). For all tests, the level of significance was $\alpha \leq 0.05$ and all values are reported as means ± SE.

RESULTS

During the first two days of this study, honeybees were observed foraging between 06:00 h and 18:00 h. They began foraging at (06.00 h to 06.30 h) and ended just before dusk (18.00 h to 18.30 h). The peak of foraging activity, without considering the mangrove species being visited, was between 6:00 h and 10:50 h and again from around 16:15 h to 18:00 h. The hours between 11:00 h and 16:00 h experienced minimal or no foraging. Honeybees found here belong to two subspecies: *Apis mellifera scutellata* (Lepeletier, 1836) and *Apis mellifera litorea* (Smith, 1961). Other insects collected by the sweep net were mainly

Lepidoptera and three species of stingless bees; *Dactylurina schimdti* (Stadelmann), *Hypotrigona gribodoi* (Magretti) and *Meliponula ferruginea* (Cockerel). Also caught in the sweep nets were members of the sub family Cryptocephalinae, the orders Reduviidae, Braconidae and Megachilidae, and some *Cotesia* species.

The number of flowers opening at night was not statistically different from the number opening during the day (χ^2 = 1.05; P = 0.3061) in both *B. gymnorrhiza* and *C. tagal* trees. Nectar concentration of *B. gymnorrhiza* showed no statistically significant variation with temperature ($F_{1, 3}$ = 3.39, P = 0.076), but varied with time of day ($F_{1, 3}$ = 4.21, P = 0.049) and RH ($F_{1, 3}$ = 6.38, P = 0.017). Nectar volume of the same species showed no significant variation with RH ($F_{1, 5}$ = 0.07; P = 0.786), temperature ($F_{1, 5}$ = 0.00; P = 0.989) or time ($F_{1, 5}$ = 0.94, P = 0.339) (Fig. 4.3). On the other hand, nectar from *C. tagal* was available within three hours in the morning (07.00 h-08.00 h; 10.00 h- 11.00 h) and within two separate hours in the evenings (15.00 h and 18.00 h).

The number of honeybee visits varied significantly with the tree species ($F_{1, 7}$ = 38.46, P = 0.000), time of the day ($F_{1, 7}$ = 9.53, P = 0.000), and orientation of the sun ($F_{1, 7}$ = 3.82, P = 0.052). Honeybee visits, however, were not significantly affected by temperature ($F_{1, 7}$ = 0.19, P = 0.665) or relative humidity ($F_{1, 7}$ = 0.25, P = 0.623). The model showed that 23% of the variation in the data could be explained by the effect of all the (five) studied factors which means that other factors not studied here also come to play. A significantly lower number of honeybee visits was observed on *A. marina* than on *C. tagal* and *B. gymnorrhiza* (Fig. 4.4a). On the other hand, the number of stingless bee visits varied significantly with tree ($F_{1, 7}$ = 24.63, P = 0.000), time ($F_{1, 7}$ = 7.37, P = 0.000) and temperature ($F_{1, 7}$ = 17.07, P = 0.000) but was not significantly affected by relative humidity ($F_{1, 7}$ = 0.321, P = 0.568) and orientation of the sun ($F_{1,\ 7}$ = 0.03, P = 0.874). The model showed that 24% of the variation in the data could be explained by the effect of five factors. As shown in Fig. 4.4b, significantly higher numbers of stingless bees visited *C. tagal* as compared to the other two mangrove species.

All the biochemical properties of the mangrove honey from Mida Creek were within the required international standards. As shown in Table 4.2, water, total ash and electrical conductivity levels in mangrove honey were significantly lower than those in honey from the dry forest ($F_{1,\ 5}$ =11.77, P = 0.026; $F_{1,\ 5}$ = 17.26, P = 0.014; $F_{1,\ 5}$ = 21.90, P = 0.0094, respectively). The other seven biochemical properties, including Potassium and Sodium showed no statistically significant differences between the two honey types ($P > 0.05$).

DISCUSSION

Floral characteristics of mangroves at Mida Creek

Our results showed that *Ceriops tagal* and *Bruguiera gymnorrhiza* may be pollinated at night and in the daytime, since the number of flowers opening at night versus the number opening during the day was not significantly different. We suggest that nocturnal pollination could be by bats or moths which are common in this area. Given that its flowers appear in clusters, are whitish in color and have deeply hidden nectar, *C. tagal* is a typical candidate for pollination by moths. Indeed, this species has been reported as pollinated by insects flying late in the afternoon and by moths (Juncosa and Tomlinson, 1987; Raju and Karyamsetty, 2008). Raju and Karyamsetty (2008) specifically reported small flies and bees pollinating this species in an Indian mangrove ecosystem. On the other hand, *B.*

gymnorrhiza has larger flowers with explosive pollen dispersal and nectar that is comparatively easier to access. The genus *Bruguiera* has been reported as pollinated by sunbirds (Noske, 1993) and butterflies (Kondo et al., 1987). Kondo et al. (1987) also suggested that bees are potential pollinators of *B. gymnorrhiza* as they depend on its pollen during the dry season. In the present study, both honeybees and stingless bees were observed foraging on these flowers daily and could indeed be pollinators. Some bee-pollinated mangroves, like other angiosperms, are known to possess pleasant smells as a result of emitting diverse volatiles; in *A. marina* these are mainly trans-β-ocimene, α-farnesene, 2,3-butanediol, and 3-hydroxy-2-butanol (Azuma *et al.*, 2002). Although the flowers had a sweet honey-like scent and were frequented by stingless bees, no nectar was found in them during this study. However, Clarke and Myerscough (1991), while studying mangroves of south eastern Australia came across ‘a nectar-like substance’ and also observed bees (*Apis mellifera*) visiting the trees frequently. The present results suggest that honeybees are attracted by the scent of these flowers, which could be emanating from the substance observed by these workers or from pollen (Cook et al., 2005). This is probably a case of ‘false enticement to pollinate’ without any incentive, or in other words mimicry. Further studies are needed in order to validate this suggestion and examine the diversity of other potential pollinators attracted by this plant. If validated, it could also be interesting to find out the hypothetical evolutionary consequences of such a trait.

Nectar concentration in *B. gymnorrhiza* was found to vary significantly with time of day and this could be as a result of direct effects of increased temperature and reduced relative humidity. This is in agreement with many earlier studies on the relationship between nectar standing crop, temperature and RH. As in the case of nectar volume, temperature itself was found to have no significant effect but for concentration, relative humidity played a highly significant role. The nectar concentration decreased with increasing humidity. Humidity is influenced by evaporation rates which are in turn determined not only by temperature but by the prevailing wind speed and the presence or absence of water in the environment i.e. high or low tides. However, although it has been widely thought that there is an inverse relationship between nectar concentration and volume, our results do not show that. It is noteworthy though, that our sampling period was only two weeks. Probably more samples taken over the whole flowering period or several flowering periods would give a clearer picture. The amount of sugar in a given flower's nectar fluctuates with foraging intensity and reabsorption by the plant (Corbet, 2002). We also realised that although exclusion nets can help in determining the nectar standing crop more accurately, the presence of nectarivorous mites in the flowers of *B. gymnorrhiza* was always associated with lack of nectar and these mites cannot be excluded in this manner.

Ceriops tagal on the other hand, had a discontinuous presence of nectar in the early morning and again after 15.00 h. We propose that this data was too little for statistical analyses. We suggest that probably the timing of this study did not coincide with its prime flowering time, or that it probably produces the bulk of its nectar in the night to cater for nocturnal pollinators. A 24-hour study is recommended, in order to verify these assumptions. Since our main interest was honeybees and we only used stingless bees for comparison, our study was restricted to observations during the light hours of the day.

Bee visitations to Mida Creek mangroves

The tendency for more honeybees than stingless bees to forage on *B. gymnorrhiza* than on *C. tagal* and *vice versa* could be a case of resource partitioning. Some plant communities have evolved mechanisms to aid resource partitioning. For example, Stone et al. (1998), while studying pollinator activity on an African *Acacia* community found that when faced with competition, the tree stands show synchronized peaks of pollen availability at any time of the day and that this pattern was absent when there was no competition. The pollinators involved were mainly calliphorid flies, megachilid bees and honeybees.

In this study, we found that the orientation of the sun also affected number of bee visits in that more honeybees visited the side of the plant that faced the sun, than the shadowed side, at any given time. However, this could also be just because they like to forage in the sun, for thermoregulation purposes. On the other hand, the visits by stingless bees suggest that the orientation of the sun does not seem to play a significant role in determining their foraging activities. Although various workers have shown that honeybees use the intensity of ultra violet rays emitted by the sun as cues in their flights and waggle dances (including von Frisch, 1968; Dyer and Dickinson 1994), we have not come across any study documenting that honeybees show a marked preference to forage in direct sunlight. The present results could also form the basis of a more structured experiment to validate these suggestions. In addition to being influenced by the sun's orientation, reduced honeybee foraging in the middle of the day could also be due to high temperatures and reduced nectar standing crop, in our study site

Mangrove honey vs. dry forest honey

Significantly lower water content in the mangrove honey means that it is less prone to fermentation. This characteristic makes it more desirable for the market. Although the honey from the Kenyan coast generally has a higher water level compared to honey from inland, even our samples from the dry portion of ASF were within the required limit of not more than 21%. Mangrove honey had moisture close to that recorded by Muli et al. (2007) while studying honey from the same area. They recorded 19.62% and we recorded 18.83%.

Electrical conductivity is a measure of mineral content and higher values usually indicate a more varied floral source of the honey (Bogdanov et al., 2004). Electrical conductivity (EC) is also used for the authentication of unifloral honeys (Bogdanov et al., 2004) and to distinguish between floral and honeydew honeys. The EC value depends on the ash and acid content in honey: the higher their content, the higher the resulting conductivity (Bogdanov, 1999). It is increasingly replacing the use of ash content as an index (Codex Alimentarius, 2001). Most blossom honeys have a lower EC than honeydew honeys, except for a few types e.g., strawberry tree (*Arbutus unedo*), bell heather (*Erica*), *Eucalyptus*, lime (*Tilia* sp.), ling heather (*Calluna vulgaris*), manuka or jelly bush (*Leptospermum*), tea tree (*Melaleuca* sp.) (Codex Alimentarius, 2001). In this study, honey from the dry forest had a significantly higher electrical conductivity, in keeping with the greater floral diversity from which honeybees could forage, as opposed to the few mangrove species from which honeybees foraged to form the mangrove honey. Electrical conductivity of honey is generally accepted to be highly variable and determined by among other factors: mineral content, proteins in the honey and types of the constituent organic acids (Codex Alimentarius, 2001; Bogdanov, 2004). Therefore, it is as variable as the flower species foraged by honeybees. The Codex Alimentarius sets acceptable limits for blossom honey at lower than 0.8 mS/cm (with a few exceptions), whereas it has been reported to be higher in other parts of the world. For example, avocado honey from Israel has EC greater than 1.5 mS/cm (Afik et. al., 2009). Some African blossom honey is known to have even higher EC for example, Chefrour et al. (2009) reported conductivities of above 5 mS/cm in Algerian honey, Gangwar et al. (2010) reported that honey from *Trifolium* species in Ethiopia had EC of 1.37 mS/cm and Terrab et al. (2003) reported that four types of Moroccan honey had an EC above one, although most of their other samples had an EC lower than 0.8. In our case, all the honey samples from ASF honey, mangrove or otherwise, had acceptably low electrical conductivity.

Ash content is also a criterion for testing whether blossom honey has been adulterated, mixed with honeydew honey or is pure/clear (White, 1978). A level of up to 0.6% is accepted as pure/clear; thus the Mida Creek mangrove honey samples were pure/clear blossom honey. Ash content is also closely related to EC and thus the same relationship is expected. In fact, Gomes et al. (2010) found a positive correlation between the EC and acidity of commercial honeys from Portugal. Al et al. (2009) and Gomes et al. (2010) correlated dark honey colour with high ash content but this was not the case in our study. All our mangrove honey samples were darker than the dry forest honey samples, yet the latter had higher ash content than the former. However, this theory could hold within each specific honey type and could be a focus for a future study. Furthermore, honey colour is determined by several other factors not studied here.

The level of sodium in the mangrove honey was higher, though not significantly, than the level in dry forest honey. In this study, potassium levels did not differ although it has been noted elsewhere (Pisani et al., 2008; Chudzinska and Baralkiewicz, 2010) that a honey's profile of potassium and sodium, among a few other key minerals, can be used as a principal characteristic in distinguishing its botanical origin. Chudzinska and Baralkiewicz (2010) also found that honey with darker color has more potassium than honey with lighter color. Although the Mida Creek mangrove honey is typically darker than the dry forest honey throughout the year, no significant differences were found in potassium content. It is possible that the difference in taste of mangrove honey, leading to the preference by customers, is probably due to its unique mineral make up and the salt spray effect, details of which were not subjects of our studies. Salt residues on nectar, left by the salt spray, are likely taken up by honeybees during foraging and incorporated into mangrove honey during its production. While studying honey from different regions in Portugal, Silva et al. (2009) found that the sodium levels ranged between 90.22 mg per kg and 727.79 mg per kg. The values for ASF honey are at the top end of this range. Silva et al. (2009) concluded that the mineral content of their samples of blossom honey was highly dependent on the type of flowers foraged by honeybees. In our study, this could also be a factor to consider.

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Table 4.1: Mida Creek mangroves and their uses

Scientific Name	Local name (Giryama/ Swahili)	Economic uses in Kenya
Avicennia marina (Forsk.) Vierh. (Avicenniaceae)	Mchu	Dhow construction, timber for furniture, fuel, tannin and dyes, aphrodisiac, contraceptive, medicinal (boil leaves and roots against diarrhoea)
Bruguiera gymnorrhiza (L.) Lamk. (Rhizophoraceae)	Mshinzi	Construction and telephone poles, tannin and dyes, twigs used as firewood, fish smoking and making fishing stakes
Ceriops tagal (Perr.) C.B. Robinson (Rhizophoraceae)	Mkandaa	Construction and fence posts, tannin, high quality firewood and charcoal, twigs used for making fishing stakes
Lumnitzera racemosa Willd. (Combretaceae)	Mkanda dume	Building poles, good firewood and charcoal
Pemphis acidula Forst. (Lythraceae)	Mkaa pwani (or Kilalamba kike)	Firewood
Rhizophora mucronata Lamk. (Rhizophoraceae)	Mkoko	Building, tannin, good charcoal, medicinal (boil leaves and roots for stomach and heart problems)
Sonneratia alba J. Smith (Sonneratiaceae)	Mpira	Construction of boats, condiments, tannin, edible fruits believed to be medicinal for the stomach, handicrafts
Xylocarpus granatum Koen. (Meliaceae)	Mkomafi	Poor quality building poles, tannin, dhow masts, handicrafts, firewood, medicinal (boil bark and fruits for stomach aches), aphrodisiac

Source: Unpublished data compiled by Watamu Turtle Watch, Malindi Marine Park Authorities, Kenya Forest Research Institute (KEFRI) and Arabuko Sokoke Forest Management Team (ASMAT)

Table 4.2: Biochemical properties of honey from Arabuko Sokoke Forest

	Parameter	***Unit***	***Dry forest (N= 3)***	***Mangrove (N= 3)***
1	Water	g per 100g	20.53±0.33 [a]	18.83±0.37 [b]
2	Sugar content			
	Total sugar	g per 100g	60.51±0.44	60.70±2.23
	Fructose	g per 100g	36.47±0.38	36.60±1.10
	Glucose	g per 100g	23.70±0.26	23.51±1.07
	Sucrose	g per 100g	0.31±0.17	0.49±0.21
	Maltose	g per 100g	0.04±0.03	0.04±0.02
3	Acid properties			
	pH	meq per kg	3.67±0.13	3.37±0.15
	Free acidity	meq per kg	30.67±2.90	24.67±2.40
4	HMF	mg per kg	13.27±1.98	11.70±4.45
5	Proline	mg per 100g	210.77±8.13	242.53±33.43
6	Diastase activity	SScale	17.33±1.69	18.50±4.71
7	Ash content	% per gram	1.83±0.28 [a]	0.46±0.17 [b]
8	Electrical conductivity	mS per cm	0.46 ±0.05 [a]	0.19±0.04[b]
9	Potassium	mg per kg	100±30	110±40
10	Sodium	mg per kg	500±30	570±37

The values are means±standard error.

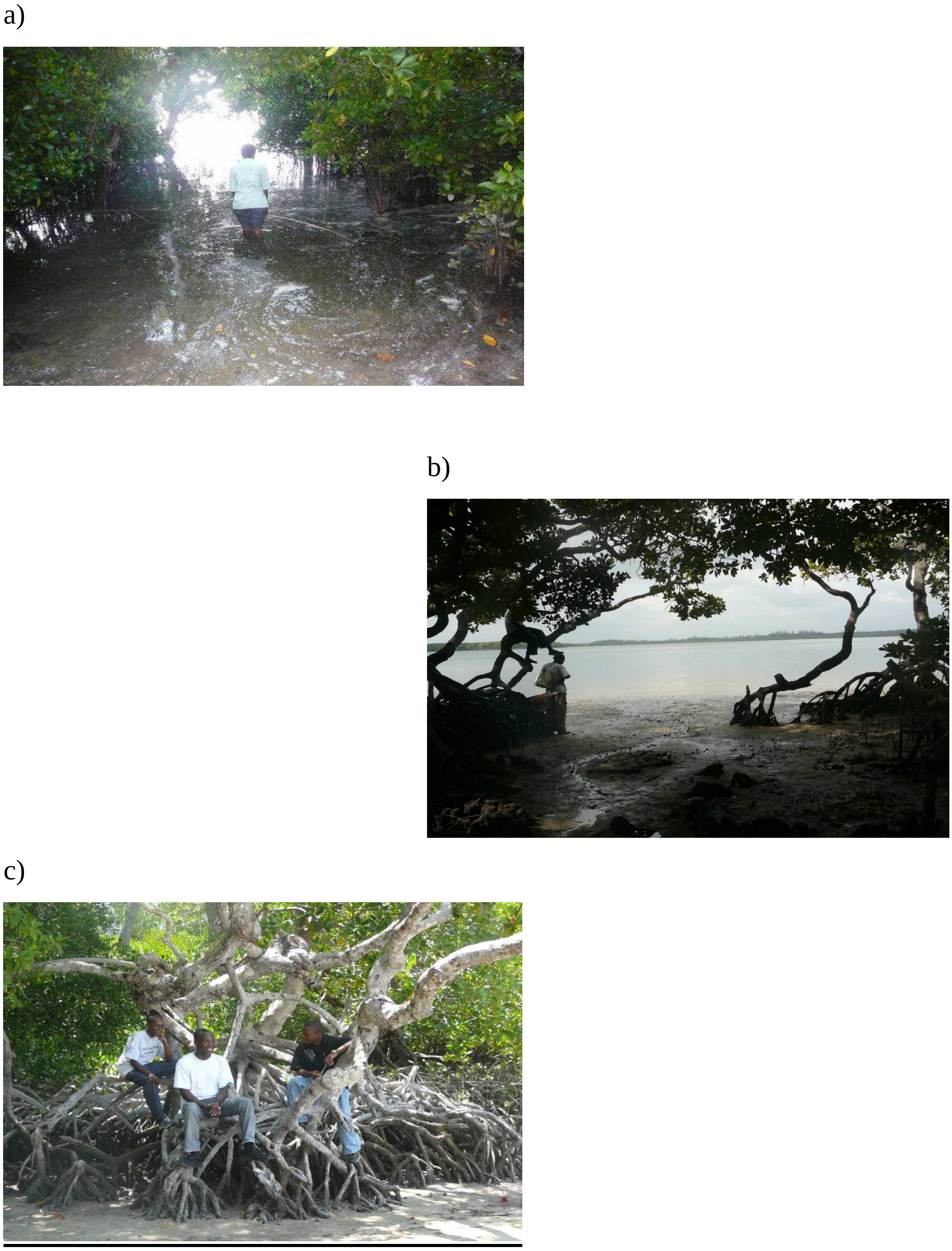


Figure 4.1: Mida Creek, Dabaso point (a) during a high tide (b) during a low tide (c) after a few hours of low tide. When dry, the aerial roots of *Rhizophora mucronata* are used for resting by fishermen or, in this case, by members of the research team

a) *Avicennia marina*

b) *Bruguiera gymnorrhiza*

c) *Ceriops tagal*

The above picture was (c) was adopted from wildshores.blogspot.com

Figure 4.2: Pictures showing the three flowering mangrove species studied between February and March 2008 at Dabaso, Mida Creek.

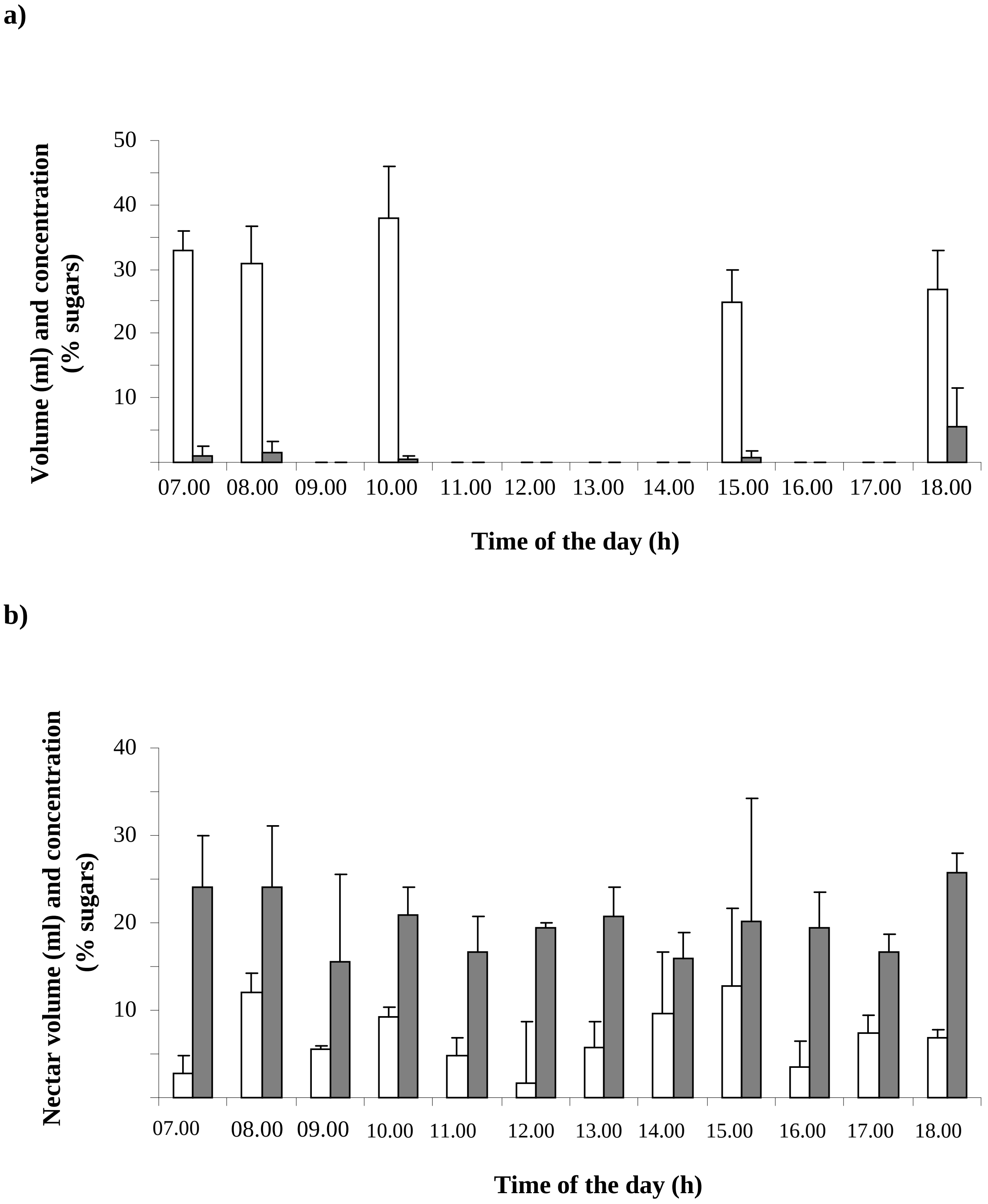
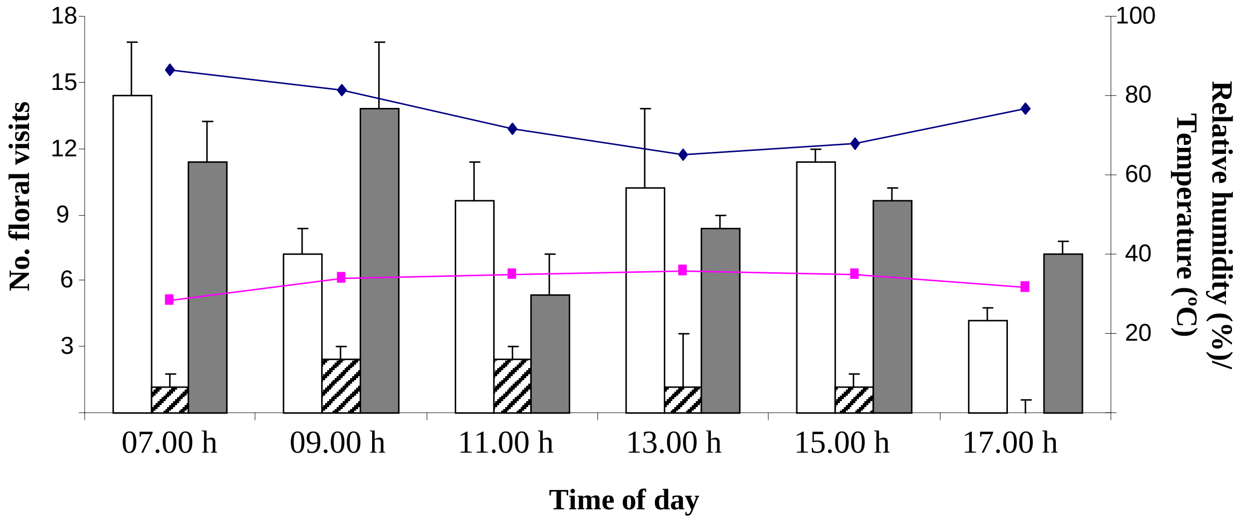


Figure 4.3: Nectar standing crop: changes in volume (☐) and concentration (■) in *Ceriops tagal* and *B. gymnorrhiza* respectively, at Mida Creek, throughout the day. Sampling was carried out during the period between 18 February and 14 March 2008. The values presented are means ± standard errors.

a) Honeybees



b) Stingless bees

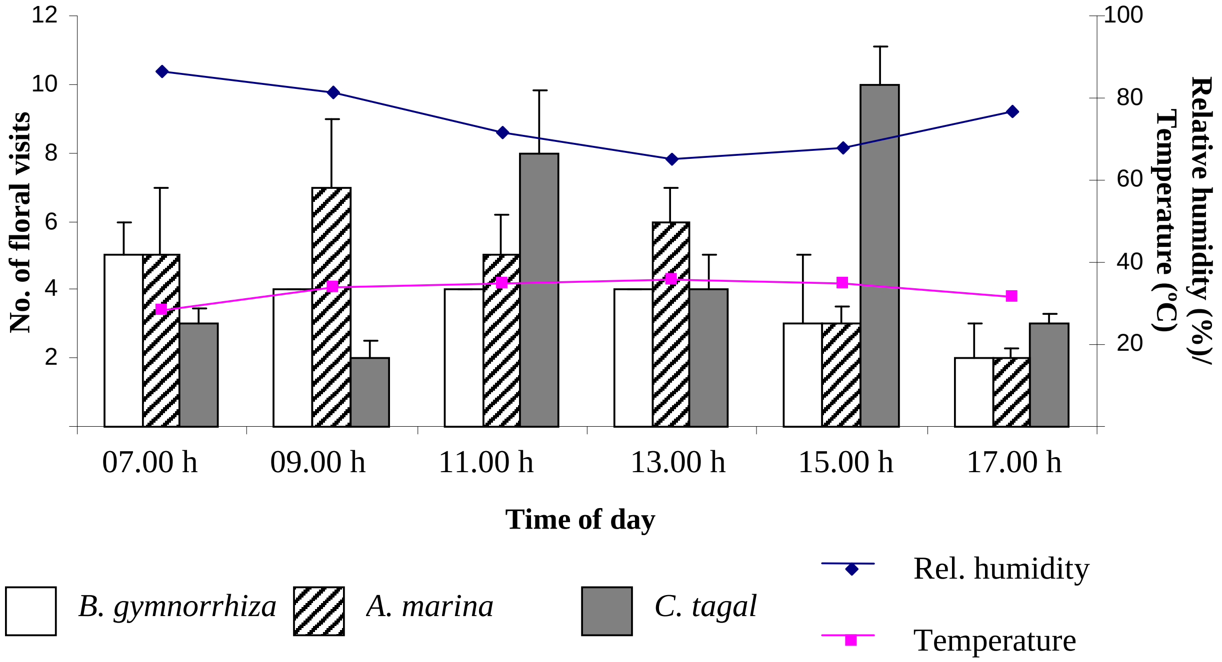


Figure 4.4: Graphs showing the number of honeybee- and stingless bee-visits on various mangrove tree species at Mida Creek during different times of the day. The bee visits were recorded for 30min periods. The values are presented as means ± standard errors. The temperature and relative humidity readings at each sampling time are also included as line graphs.

CHAPTER 5

Beekeeping and forest conservation at Arabuko Sokoke Forest: Lessons learnt

Using Arabuko Sokoke Forest (ASF) as an example, this thesis has documented the potential of beekeeping as a sustainable economic activity that can contribute towards the conservation of protected and threatened forests. Field data for this thesis were collected bi-weekly for two consecutive years and laboratory analyses were done concurrently. First we tested whether honey yield is enhanced by the proximity to a forest, by studying hives placed at various distances from ASF. Second, to find out if enough floral resources existed to support a flourishing beekeeping program, we drew a floral calendar for the area within 5 km of the forest edge. Our focus was on the phenology of plants that flower for a period of at least two months per year, as these are considered important for sustaining honeybee populations. Finally, we focused specifically on the mangrove strip that once belonged to the ASF but is now separated from the dry portion by human settlements. Our focus was mainly because honey from this strip is preferred by consumers and is thus highly priced. In addition, mangroves face a special threat worldwide and even at ASF only a discontinuous strip of less than 1 km in width and about 6 km long remains in the Mida Creek area. The following gives the key findings from each of the preceding chapters and documents the research areas that could form a basis for future studies.

Honey yield as determined by distance from the forest

Results showed that honey quantity increased with proximity to the forest: 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. We suggest that this is probably because, as Ricketts (2004) found, visitation rates of managed bees to an area with flowers decrease with distance from it. In his study, coffee farms nearer to a forest were visited more often than those further away. Furthermore, Ricketts et al. (2008) in their synthesis of 23 previous studies on effects of fragmentation, found that the visitation rates of various types of bees to their foraging sites drop to half depending on the individual characteristics of the study area, with visitation rates expected to drop more steeply in tropical areas. Thus, fragmentation of natural habitat through such practices as deforestation increases distances from managed apiaries to the bees' foraging sites, reducing their foraging potential. However, some studies suggest that fragmentation may not always have negative effects on bee communities and may favor an increase in their density and diversity (Winfree et al., 2007; Cane, 2001; Becker et al., 1991). Karanja et al. (2010), while studying coffee farms in Kenya, found that maintaining other plants around the coffee monocultures acted as a boost to populations of pollinators, bees included. In ASF, a marginally productive area, agriculture does not offer a supportive option for pollinators as it is practiced in an inconsistent, small scale manner. Although human activity is now prohibited within the forest, it will still remain a 'store' for honeybee populations, either to set up new apiaries or boost the population of existing apiaries. The forest will also act as a seed bank/source for bee foraged plants which beekeepers can obtain and plant near their apiaries. That is why we recommend that apifloral species, which have been laid out in a calendar in chapter three, be perpetuated around apiaries in order to ensure high honey yields. Most of these bee-foraged plants occur naturally in the forest’s buffer zone and are easily available to the beekeepers. By having them near apiaries, beekeepers may avoid bees absconding into the forest, as has frequently happened in the past. We also recommend an increase in the use of Langstroth hives since they yielded more honey, compared to the top-bar and traditional log hives. Although they are more expensive to purchase, the overall gain supersedes returns from the other two hive types. This study has provided yet another argument for the conservation of forests and thus biodiversity.

For the future, we recommend that a long-term study be done to link floral peaks with honey yields over the years.

Arabuko Sokoke’s Floral Calendar

For a full understanding of the potential of beekeeping, knowledge about flowering phenology of flora potentially foraged by the bees is indispensable. Therefore, a floral calendar for the area around ASF was also compiled, in which timing and duration of flowering of these plants was recorded. We learnt from this calendar that twelve common plants around ASF flowered continuously for more than six months per year and 70 others flowered for at least two full months. Perpetuation of these plants around the apiaries would ensure year-round availability of ample forage for honeybees, promoting increased honey production by strengthening the colonies and preventing absconding. Most of these plants are also available in the forest and are secondary colonizers of formerly forested areas, thus occurring in patches within 5 km of the ASF perimeter.

From the pattern of flowering in this calendar, we propose that it would be prudent for a beekeeper to set up a new apiary in the months of April or May. In a typical rain-fair year, the period when either watering of nearby bushes or provision of supplementary food to honeybees may be necessary is January to March. Honey harvesting was done during the months of August to March 2007/2008 (Chapter 2: Sande et al., 2009). Therefore, coupled with information from this floral calendar, it is concluded that the dearth period in ASF is April to July.

For future studies, we recommend that these kinds of data, if collected over a long period of time, are also useful for following or predicting the effects of global warming and climate change on flowering (Fitter et al., 1995). Secondly, using this floral calendar as a basis, scientific studies on foraging behaviour of honeybees, such as on decision-making while foraging, depending on available nectar and pollen sources, abundance of these sources, distance to the hive, profitability of each source (i.e. optimal foraging studies), can be carried out in a field situation. Finally, the observation of honeybees on agricultural crop areas could also be a basis for further investigation. Since the agricultural production of this area is marginal, honeybees could be used to boost pollination and ultimately yield of various crops during the rain-fair years. Plants which could benefit from honeybee pollination include fruits such as watermelons, guavas, mangos, cashew nuts, and Indian plum (*Ziziphus mauritiana*), that are currently grown at subsistence levels, and wild growing *Grewia* trees which could then be cultivated. These fruits have ready markets in coastal and other areas of Kenya. There seems to be no knowledge about the role of bees in pollination among ASF beekeepers and this information should be taught to them in order to fully exploit the potential of beekeeping. Some beekeepers even clear bushes around their apiaries without knowing that the plants are foraging sites for the bees. The information in this calendar is certainly useful in establishing a vibrant apiculture program at ASF since the community is not traditionally apiculturist.

Arabuko Sokoke's mangrove honey

Finally, the mangrove section at ASF (Mida Creek) was studied with special interest because its honey is prized above honey from the other portions owing to its generally preferred taste. Additionally, like the other mangrove ecosystems of the world, it is threatened, and therefore warrants special attention with respect to conservation efforts. Studies on this section involved a smaller sample size (in terms of physical and time efforts) and although they yielded note-worthy results, we also recommended future studies with larger sample sizes in order to validate our findings. We studied the foraging behavior of honeybees on three mangrove species for four weeks during their flowering period. Stingless bees are also abundant in this area and are increasingly being studied by other workers in order to include them in the honey project, alongside honeybees. Using these abundant stingless bee populations as a comparison, we observed the number of honeybee visits to these three mangrove species and correlated it with time of the day, direction of the sun, and nectar standing crop.

Mangrove honeys may differ in taste from honey produced by bees foraging other types of plants because of two reasons. First, they have a unique mineral content which is evident from their significantly lower electrical conductivity and ash content. Second, they have a slightly higher sodium content, which we suggest could be a result of frequent salt spray from the ocean.

More honeybees than stingless bees foraged on *Bruguiera gymnorrhiza* and more stingless bees than honeybees visited *Ceriops tagal*, a phenomenon we proposed to be a possible case of resource partitioning. The two bee types forage for nectar and pollen resources and avoid competition by foraging at different times of the day. Alternatively, it could also be an evolutionary effort on the part of the mangrove plants. Some plant communities have evolved mechanisms to aid resource partitioning. For example, Stone et al. (1998), while studying pollinator activity on an African *Acacia* community, found that when faced with competition, the tree stands showed synchronized peaks of pollen availability at any time of the day and that this pattern was absent when there was no competition. Wilms et al. (1996), on the other hand, found that although there was evidence of potential competition between stingless bees and Africanised bees in the Brazillian Atlantic rain forest, there was a high chance that they were able to co-exist by avoiding each other at the plant or flower-patch level. However, since these suggestions are based on very little data, a more detailed study is definitely needed.

We also found that more honeybees visited the side of the plant that faced the sun, than the shadowed side, at any given time. On the other hand, the orientation of the sun does not seem to play a significant role in determining the foraging activities of the stingless bees. Although various workers have shown that honeybees use the intensity of ultra violet rays emitted by the sun as cues in their flights and waggle dances (including von Frisch, 1968; Dyer and Dickinson 1994), the present results could form the basis of a more specifically designed experiment to validate this suggestion.

Finally, although not part of the main objective of this study, we found that two of the most abundant species (*Bruguiera gymnorrhiza* and *Ceriops tagal*) showed the potential to be pollinated both at night and daytime. Data on the nectar volume and concentration of *C. tagal* were so limited and could not be statistically analysed. Therefore, we propose that data be collected over a period of 24 hours, instead of only during daytime; and that an entire flowering period or even several flowering periods be considered. *Avicennia marina* was also flowering during our study period and had a strong sweet honey-like smell but we never found nectar in its flowers. This is probably a case of ‘false enticement to pollinate’ without any incentive, or in other words, mimicry.

However, further studies are needed in order to validate the suggested mimicry and examine the diversity of other potential pollinators attracted by *A. marina*. If validated, it could also be interesting to find out the hypothetical evolutionary consequences of such a trait. In future, a study aimed at investigating why mangrove ecosystems seem to be highly attractive to honeybees and are thus used as trapping sites (Personal Observation) when establishing new hives, would be prudent. Finally we also recommend a study on its medicinal values versus the medicinal values of other types of honey.

The combined findings in this thesis provide indispensable information for the beekeepers, illustrate the profitability and potential of conserving this forest in general, and the mangrove section in particular, and have generated testable hypotheses for further scientific work.

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