

**STUDIES OF THE ASIAN GIANT HONEY BEE,
APIS DORSATA FABRICIUS (APIDAE)
IN THE SUBMERGED *MELALEUCA* FOREST OF VIETNAM:
BIOLOGY, BEHAVIOUR, ECOLOGY AND APICULTURE**

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ABSTRACT

This thesis examines the bee, the plant and the human communities in the submerged *Melaleuca* forests of southern Vietnam. Chapter 1 gives a general introduction to the taxonomy and evolution of the genus *Apis* (honey bees), the research area and the general objectives of the thesis. Chapter 2 deals with biology of the Asian giant honey bee, *Apis dorsata* Fabricius and presents new data on the sizes and ratios of the drone and worker cells; the weight of the queen, drone and worker; and the egg production of *A. dorsata* queens. Chapter 3 demonstrates that properties of nest sites; such as the diameter, slope, length of the nest site, remnants of beeswax from the previous colony, and the size of the open space in front of the nest site, are criteria in the selection of nest sites by *A. dorsata* colonies. Chapter 4 discusses the floral relations of *A. dorsata* and other insect visitors in the forest. Three types of partitioning within and among plants and insects in the *Melaleuca* forest are found. These are the partitioning of visitors by *Melaleuca cajuputi* and *Nypa fruticans* flowers, the partitioning of visitation time by the two sympatric honey bee species, *A. dorsata* and *A. florea*, and the partitioning of visitation time on *Melaleuca* and *Nypa* flowers by either honey bee species. Results of Chapter 5 show that there is temporal partitioning of flower sources among the sympatric Asian honey bee species (*A. dorsata*, *A. cerana* and *A. florea*); however, there is a competition of flowers between the European bee (*A. mellifera*) and the Asian bee species. Chapter 6 discusses the important role of *A. dorsata* rafter beekeeping in forest protection, the conflicts between the beekeepers and new forest holders, and the economic efficiency of *A. dorsata* rafter beekeeping in comparison with those of *A. mellifera* and *A. cerana* beekeeping systems. Finally, Chapter 7 gives general conclusions of the thesis and recommendations for further study.

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CHAPTER 1

GENERAL INTRODUCTION

The genus *Apis* (honey bees)

Michener (2000) divides the family Apidae into three subfamilies: Xylocopinae, Nomadinae and Apinae. The subfamily Apinae has nineteen tribes including Bombini, Meliponini and Apini.

The tribe Apini is discriminated from its two closely related tribes, Bombini and Meliponini by only a few minor morphological criteria, but mainly by the following important behavioural ones (Ruttner 1988):

- Vertical combs with hexagonal cells constructed bilaterally and exclusively from self-produced wax. No special nest cover;
- Tendency for multifunctional, repeatedly used cells;
- Clustering behaviour;
- Progressive feeding of larvae;
- Communication and recruiting by “dance language”;
- Nest cooling by evaporating water collected in the field.

The tribe Apini comprises only one genus, *Apis* (honey bees). Traditionally, four honey bee species were recognised in the genus: *Apis mellifera*, *Apis cerana*, *Apis florea* and *Apis dorsata* (Ruttner 1988). However, recent studies have led to the discovery of more species, all from Asia. Otis (1997) states “...with evidence supporting at least an additional five species in Asia: *A. andreniformis*, *A. laboriosa*, *A. koschevnikovi*, *A. nigrocincta*, and a species from the highlands of Borneo...”

In his book, Michener (2000) suggested eleven species in the genus. They are:

- The small size group: *Apis florea* Fabricius 1787, *Apis andreniformis* Smith 1858;
- The medium size group: *Apis mellifera* Linnaeus 1758, *Apis cerana* Fabricius 1793, *Apis koschevnikovi* Buttel-Reepen 1906, *Apis nigrocincta* Smith 1861 and *Apis nuluensis* Tingek, Koeniger & Koeniger 1996;
- The large size group: *Apis dorsata* Fabricius 1793, *Apis laboriosa* Smith 1871, *Apis binghami* Cockerell and *Apis breviligula* Maa. The last two are probably allopatric segregates of *A. dorsata* and may not represent distinct species.

The clearest differences among the four traditionally recognised honey bee species (*A. dorsata*, *A. mellifera*, *A. cerana* and *A. florea*) are the size of worker bees, the nesting behaviour and the natural distribution. The sizes of the workers decrease gradually from *A. laboriosa*, *A. dorsata* to *A. mellifera*, *A. cerana*, *A. florea* and *A. andreniformis* (Figure 1). Eleven species could be divided into two groups of nesting behaviour: group 1 comprises *A. mellifera*, *A. cerana*, *A. koschevnikovi*, *A. nigrocincta* and *A. nuluensis*, which build their nest in a cavity and group 2 comprising *A. dorsata*, *A. laboriosa*, *Apis binghami*, *Apis breviligula*, *A. florea*, and *A. andreniformis*, which build nests in the open air. *Apis cerana* was once regarded as a sub-species of *A. mellifera*, but both species have separate natural distributions: *Apis mellifera* throughout Europe, Africa and West Asia, while *A. cerana* occurs in Asia. A desert belt at the border of Iran - Afghanistan and Iran - Pakistan acts as a natural barrier between the two species (Figure 2). Moreover, lethal hybrids (via instrumental



A. laboriosa



A. dorsata



A. mellifera



A. cerana



A. florea



A. andreniformis

Figure 1: Relative sizes of *Apis* workers (photo: Li Shao-wen from Crane 1990).

The body length of an *A. dorsata* worker is about the depth of its cell which is 17.4 mm as shown in Table 1 of Chapter 2.

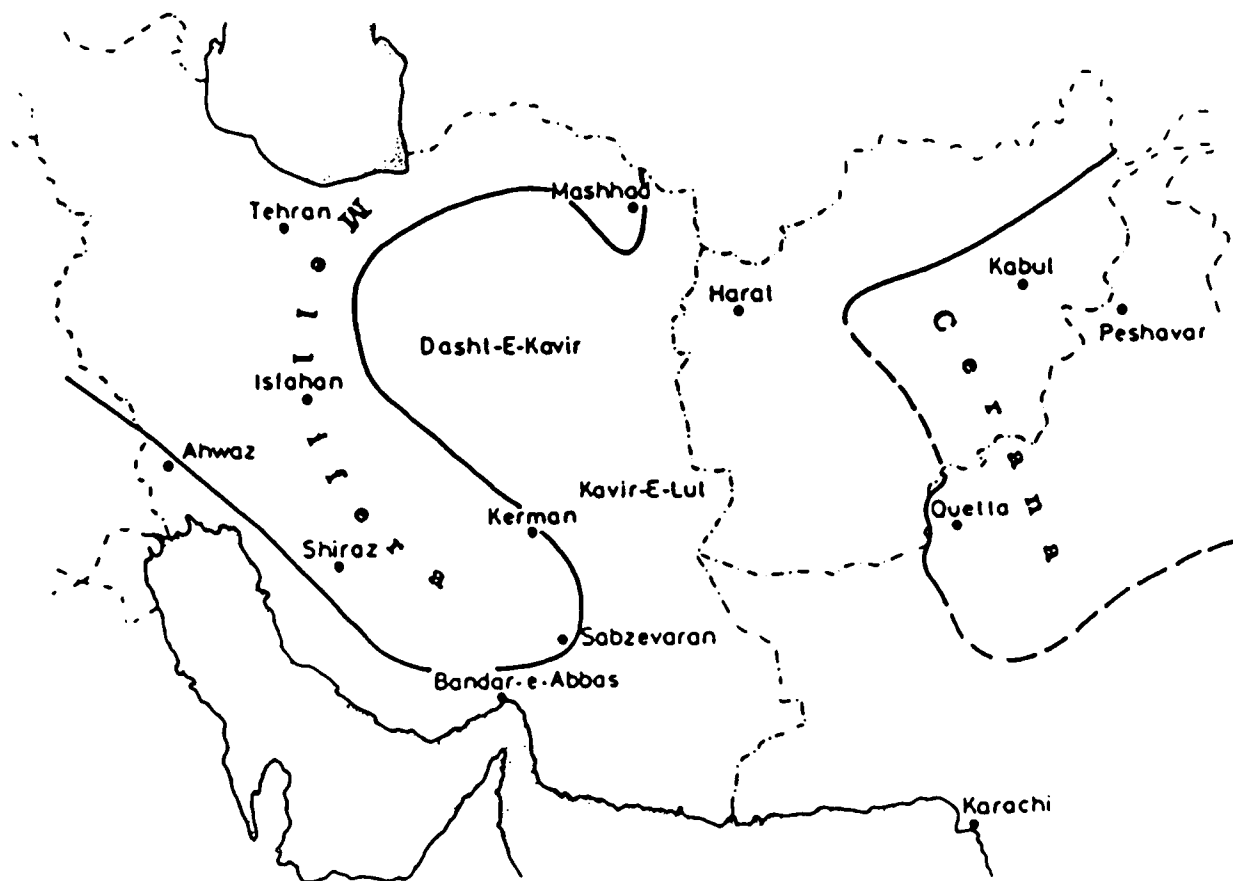


Figure 2: Eastern boundary of *A. mellifera* in Iran and western boundary of *A. cerana* in Afghanistan and Pakistan (from Ruttner 1988).

insemination) are evidence of the genetic incomparability between the two species (Ruttner 1988).

Two other important criteria discriminate between honey bee species: the isolation of mating periods and the anatomical differences in the male genitalia. Many bee researchers use these criteria to justify the specific status of new species. Table 1 summarises the mating periods of different species. In the area where many sympatric species coexist, the mating periods of different species are completely separate; e.g. the different drone flight times of four species in East Malaysia. Koeniger & Koeniger (2000) describe and compare the endophalli of nine honey bee species (Figure 3). Moreover, Koeniger & Koeniger (2000) also suggest that the mating sign, which is formed on the queen of some species after mating (Figure 4) and can be removed easily by the next drone, may be a reproductive barrier for heterospecific drones. Finally, the different sperm number in a drone and the different mechanism of sperm transfer (Figure 5) from a drone to the queen may act as a partial reproductive barrier.

Evolution in the genus *Apis*

Very early attempts to deduce the phylogenetic relationships of the four traditional species of *Apis* remain controversial and are reviewed in Ruttner (1988) as the follows:

Because *Apis dorsata* and *A. florea* make exposed nests while *A. mellifera* and *A. cerana* are cavity nesters, Buttel-Reepen (1906) considered the former as “primitive”. However, open-air nesting can just as well be interpreted as a derived adaptation to tropical conditions, of primarily cavity nesting bees (Koeniger 1976). The

Table 1: Drone flight time of *Apis* species.

Species	Flight time	Country/Area	Author
<i>A. mellifera</i>	12 - 17 h	Europe	Ruttner (1966)
<i>A. cerana</i>	16.15 - 17.15 h	Sri Lanka	Koeniger & Wijayagunasekera (1976)
	13.15 - 16.30 h	Japan	Yoshida <i>et al.</i> (1994)
	14.00 - 16.15 h	East Malaysia	Koeniger <i>et al.</i> (1994a) & Koeniger <i>et al.</i> (1996)
<i>A. koschevnikovi</i>	16.45 - 18.30 h	East Malaysia	Koeniger <i>et al.</i> (1994a)
<i>A. nuluensis</i>	10.44 - 13.12 h	East Malaysia	Koeniger <i>et al.</i> (1996)
<i>A. florea</i>	12.00 - 14.30 h	Sri Lanka	Koeniger & Wijayagunasekera (1976)
	14.00 - 16.45 h	Thailand	Rinderer <i>et al.</i> (1993)
<i>A. andreniformis</i>	12.15 - 13.45 h	Thailand	Rinderer <i>et al.</i> (1993)
<i>A. dorsata</i>	18.00 - 18.45 h	Sri Lanka	Koeniger & Wijayagunasekera (1976)
	18.15 - 18.45 h	Thailand	Rinderer <i>et al.</i> (1993)
	18.27 - 18.52 h	East Malaysia	Koeniger <i>et al.</i> (1994b)

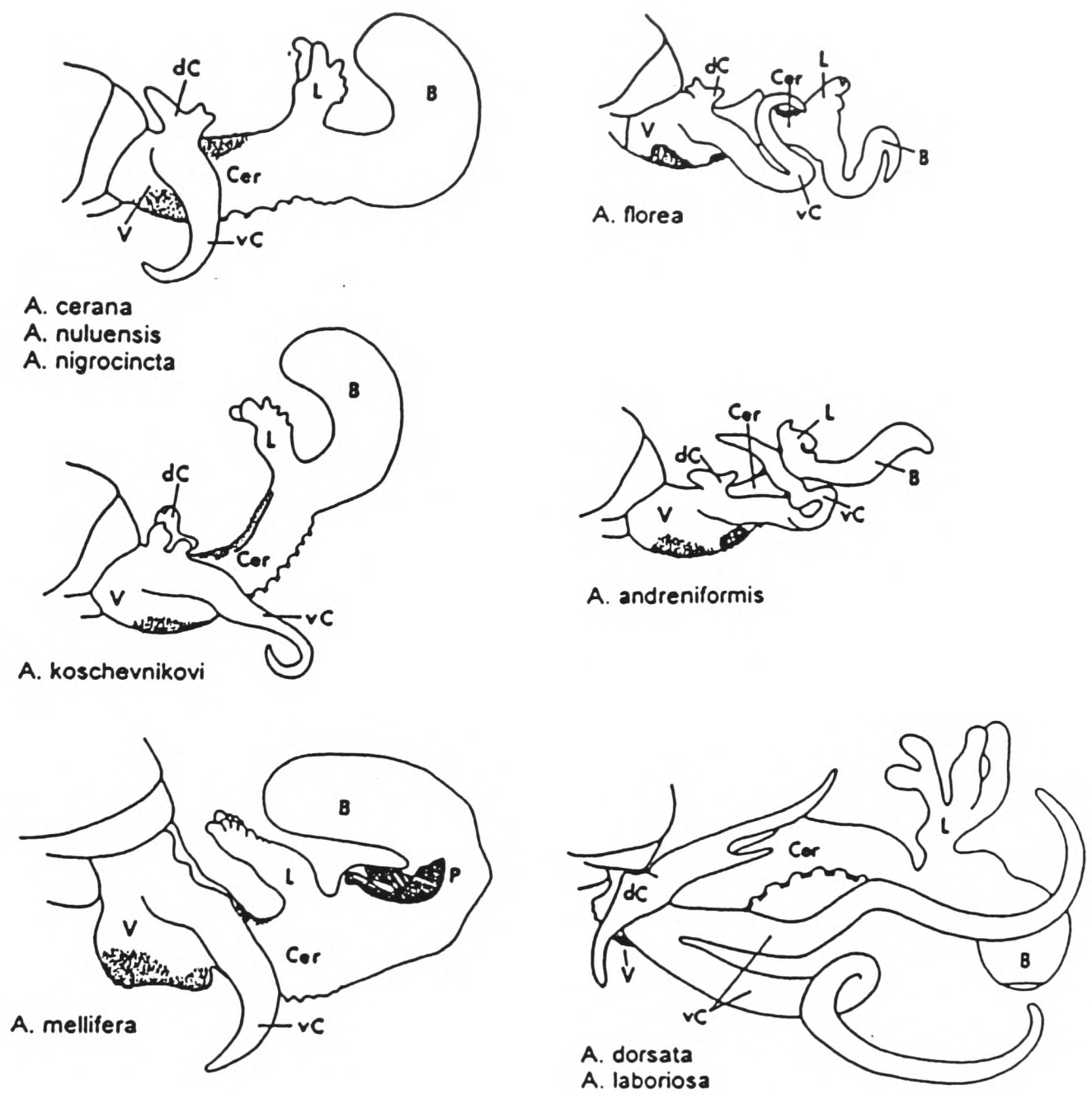


Figure 3: Everted endophalli of nine *Apis* species (lateral view). Symbols for all figures: B: bulbus; Cer: cervix; P: chitinous plates of bulbus; dC: dorsal cornus; L: lobe; V: vestibulum; vC: ventral cornua (Koeniger & Koeniger 2000).

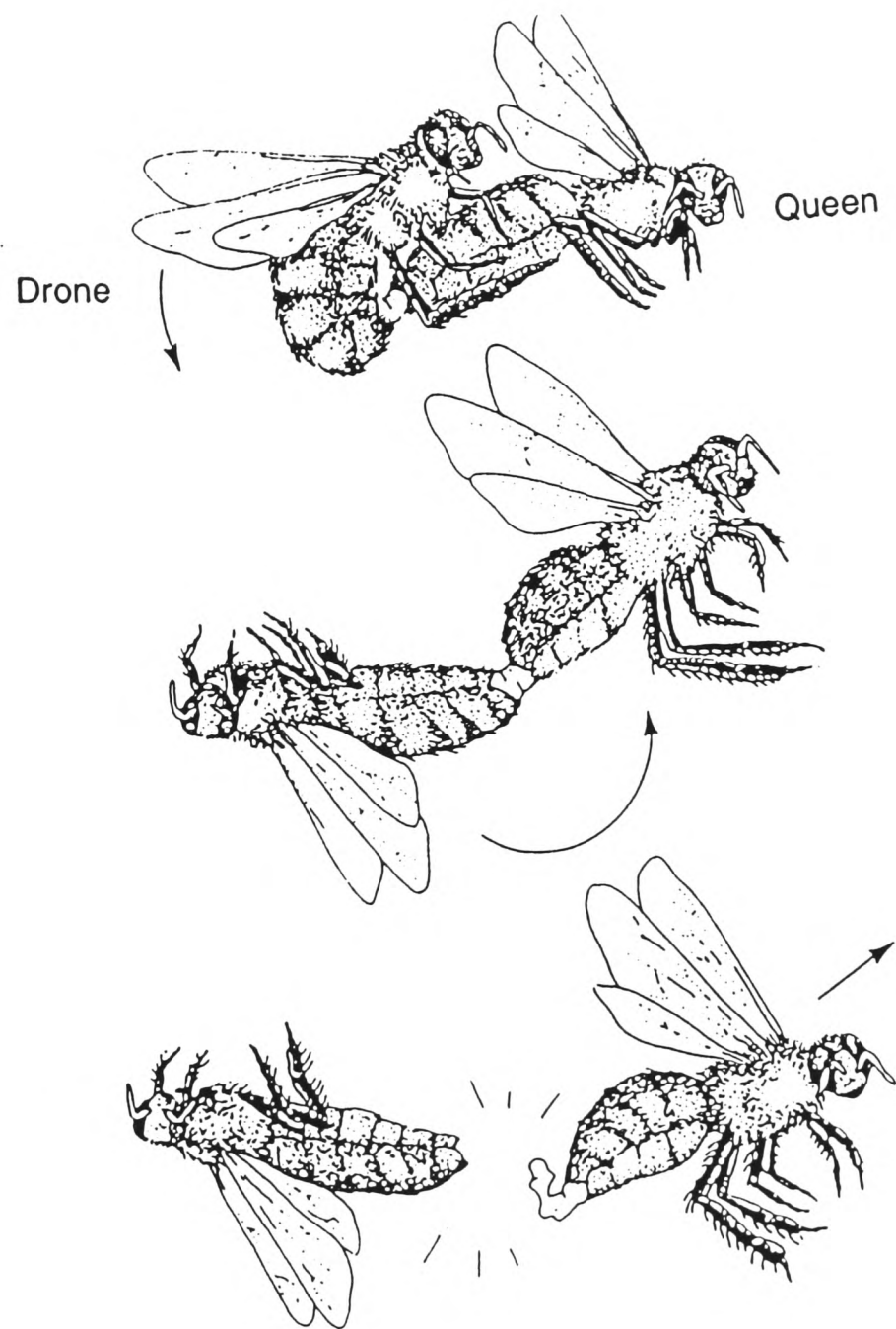


Figure 4: Mating sign (Winston 1987).

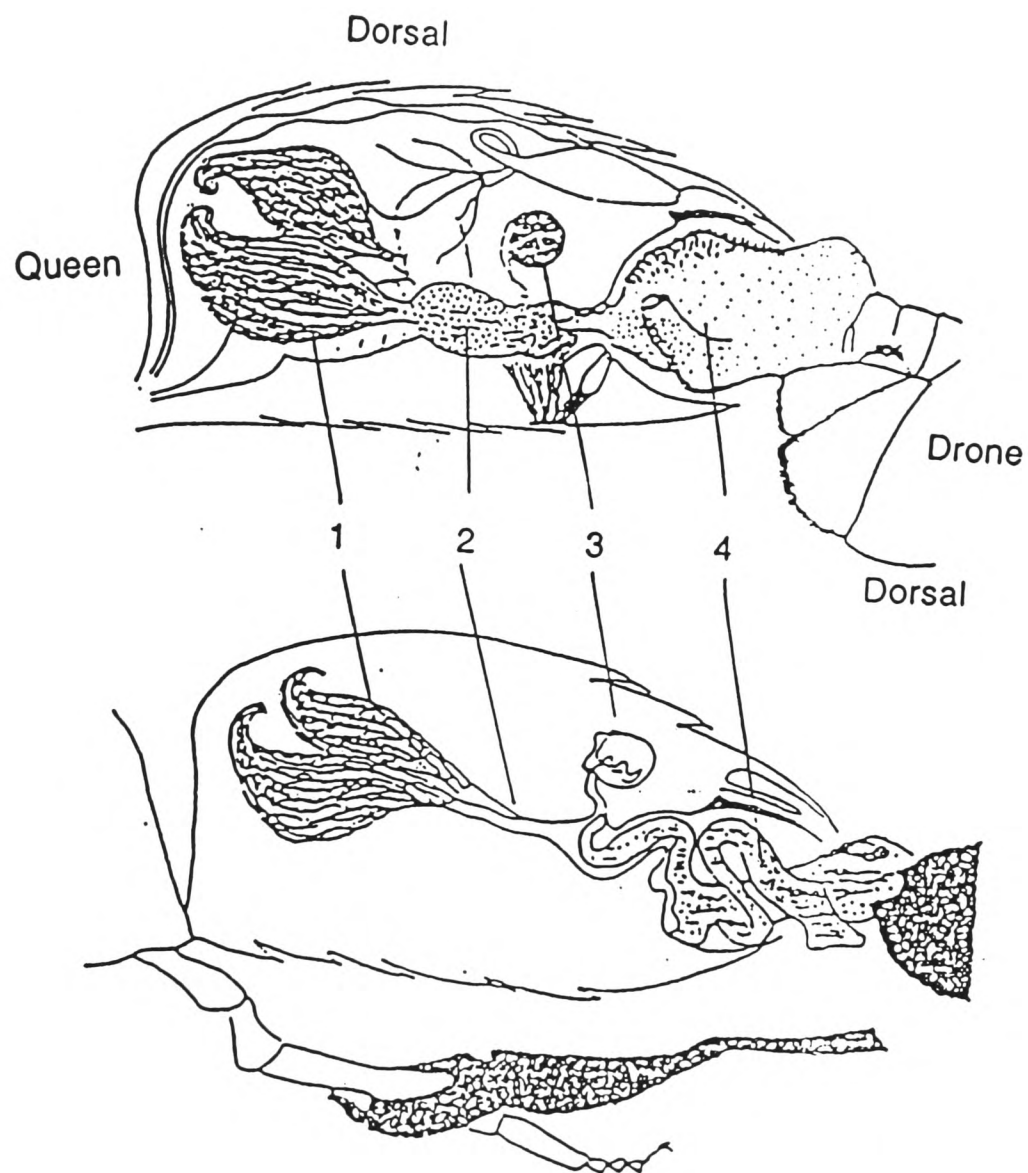


Figure 5: Sperm transfer mechanism in honey bees (Koeniger 1991)

1: Ovary; 2: Oviduct; 3: Spermatheca; 4: Endophallus

Above: in *A. mellifera* and *A. cerana*, drones inject their sperm into the oviducts of the queen.

Below (hypothesised): in *A. florea*, drones transfer their sperm directly into the spermatheca.

“primitiveness” of the open air nesting honey bees seemed to be supported by the claims of Deodikar and Thakar (1966), who reported that the karyotype ($n = 8$) of the open air nesting species were different from those ($n = 16$) of the cavity nesting species. However, later studies (Fahrenhorst 1977) point out that the karyotype of all four honey bee species (*A. mellifera*, *A. cerana*, *A. florea* and *A. dorsata*) are uniform ($n = 16$). For a long time it was thought that the three castes (the queen, drone and worker) of *A. dorsata* developed in the same type of cell and consequently, *A. dorsata* was considered to be the most primitive species of the genus. However, further observations (e.g. Viswanathan 1950; Thakar & Tonapi 1961; Morse & Laigo 1969) show that special cells, the queen cells, are also built in *A. dorsata* colonies. According to Buttel-Reepen (1903), the difference in size between workers and drones or the queen is greater in *A. mellifera* than *A. dorsata*, indicating a higher level of social organisation in the former. However, this contrasts with *A. florea*, where the differences in sizes between castes are greater (Table 2). Dance communications are different among the four species. *Apis florea* workers dance on the horizontal surface of the honey comb, while the other species dance on the vertical surface of the comb. Based on his fundamental discoveries, Lindauer (1956) considered *A. florea* as an ancestral type, *A. dorsata* as an evolved type and *A. mellifera* or *A. cerana*, which perform dances in the darkness of the nest, as the most evolved. However, Koeniger (1976) argued that dance communication depended on the nesting site.

Later, Koeniger & Koeniger (1991) reviewed and discussed the polarity of evolution within the genus. With regard to the mating behaviour and morphology of the male genitalia, they considered the cavity-nesting species (*A. mellifera* and *A. cerana*)

Table 2: Ratio of the size of drone and queen to that of worker within four honey bee species (from Ruttner 1988).

Character	<i>A. florea</i>	<i>A. cerana</i>	<i>A. mellifera</i>	<i>A. dorsata</i>
1/ Head width				
Worker	1	1	1	1
Drone	1.23	1.08	0.99	1.02
Queen	1.43	1.07	1.20	0.98
2/ Wing length				
Worker	1	1	1	1
Drone	1.36	1.25	1.06	1.04
Queen	1.47	1.19	1.31	1.08

nearest to the ancestral condition. Alexander (1991), Willis *et al.* (1992), Lockhart *et al.* (1994), Engel & Schultz (1997) and Oldroyd *et al.* (1998) also proposed phylogenies for the genus. Oldroyd *et al.* (1998) suggested that the enlarged penile bulb, mucus glands (which form the mating signs), and excess sperm production found in the cavity nesting species (*A. cerana*, *A. koschevnikovi* and *A. mellifera*) are likely to be derived characters, whereas the lack of mucus glands and reduced penile bulb observed in the open-nesting species is likely to be ancestral.

***Apis dorsata* and the *Melaleuca* forests in Vietnam**

Vietnam is situated in the Southeast of Asia, an area of great biological diversity as well as extensive forestry. However, studies on wildlife and environment have been limited because of the long wars which were ended in 1975 and, after that, the country's economic difficulties. Scientific information on the forestry ecosystems of the country is generally lacking. Typical forests in the Mekong delta, southern Vietnam, are coastal mangroves and further inland, submerged *Melaleuca* forests. These forests are very important in seashore protection, climate regulation and soil reclamation; they are also good habitats for wildlife. In addition, the forests are important in the national economy as they supply local people with many products: wood for fuel and construction materials, shrimp and fish as food, plants and honey as both food and medicine.

Honey is mostly collected from the Asian giant honey bee, *Apis dorsata*, which migrates into the *Melaleuca* forests during the flowering season. Elsewhere, *A. dorsata* builds its single comb hanging from a tree branch, projecting rock, water tower or the eaves of a building, but in the *Melaleuca* forest they are lured to occupy

man-made supports called rafters (Crane *et al.* 1993; Mardan 1993; Chinh *et al.* 1995a, 1995b; Mulder 1995; Tan & Chinh 1995). The rafter is a tree trunk, which is split lengthways, about 2 m in length and 15 cm in diameter. It is placed on two vertical poles: one pole is about 2 m high and the other 1 m high. The rafter therefore slopes at an angle to the horizontal like the rafter of a house (Figure 6). This beekeeping technique has been a traditional way of life for thousands of people in the area for a few hundred years (Fougeres 1902, cited in Crane *et al.* 1993; Dau 1991).

General objectives

In Vietnam, droughts, floods and typhoons have occurred more often in recent years, which may be a consequence of deforestation and global climate change. A growing awareness of global climate protection and the need for environmentally friendly development have emphasised the value of forest conservation. It is therefore important to understand the relationships within and among the plant, animal, and human communities in the forests. This thesis is aimed at further understanding the Asian giant honey bee, *Apis dorsata*, its relationships to some plants of the *Melaleuca* forest, and the socio-economic factors of people making their living using the rafter beekeeping technique. The findings will help in developing a policy for sustainable exploitation and conservation of the *Melaleuca* forests in southern Vietnam.

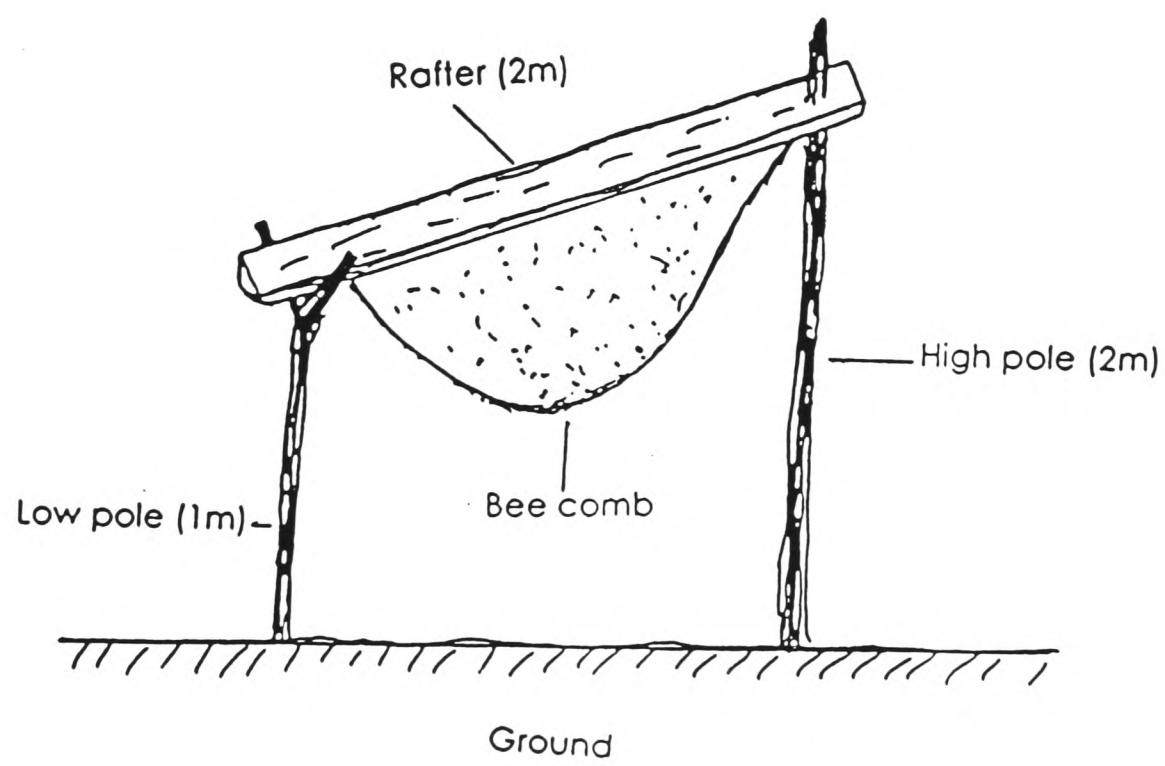


Figure 6: Diagram of rafter and *Apis dorsata* comb.

CHAPTER 2

BIOLOGY OF *APIS DORSATA* IN VIETNAM

Introduction

The *Melaleuca* forests in southern Vietnam supply many products to local people, play important roles in environmental protection, and provide habitats for many wild animals including the Asian giant honey bee, *Apis dorsata*. When the *Melaleuca* flowers bloom, thousands of *A. dorsata* swarms arrive and are lured to build nests on low man-made supports called rafters. The bees are an important part in the ecology of the forests and the income of the local people.

The European honey bee, *Apis mellifera* is the most studied insect because man has collected honey from it for thousands of year. Nowadays, the number of described honey bee species is increasing due to recent studies in the remote areas of Southeast Asia and also further studies on the biology and behaviour of already described species. Ruttner (1988) recognised four honey bee species in the genus, Otis (1997) reported nine and then Michener (2000) proposed eleven species. With more species discovered in the genus *Apis*, the phylogenetic relationship of the species has become more complex and therefore the biology of all species should be well understood. However, *A. dorsata* is the least studied of the four traditionally recognised species and information on its biology is rare and fragmentary. Crane (1993) showed that research on Asian honey bees amounted to only a few percent of that on *A. mellifera*. Among the Asian honey bees, sixty percent of the publications were on *A. cerana* and nearly forty percent were on *A. florea* and *A. dorsata*. Initially, more attention was given to *A. dorsata* but since 1979 there has been more work on *A. florea*, because *A. dorsata* is very defensive and/or too inaccessible for people to carry out research.

In the global awareness of the need for wildlife protection, the conservation of the Asian giant honey bee, *A. dorsata* in the *Melaleuca* forests should be given greater attention. Information on the biology and behaviour of *A. dorsata* is important in bee management for honey production, the conservation of the species, and the conservation of the *Melaleuca* forests, as well as the environment. This chapter contributes information on biology of *A. dorsata* in the *Melaleuca* forest, namely,

- the structure and dimensions of nest and different types of cells;
- the weights of the newly emerged queen, drone and workers in different conditions; and some biometrical features of workers;
- development times of the queens, drones and workers;
- the colony size, queen cells and queen's egg production of the colonies at full development.

Materials and Methods

Study site:

The *Melaleuca* forests in southern Vietnam are located in Asia's tropical monsoon area. The weather is generally hot and humid. The dominant plant species in the forests is *Melaleuca cajuputi* (Myrtaceae), the flowers of which are a very good source of nectar and pollen. This study was carried out in the forestry and fishery farm of Song Trem, Thoi Binh district (longitude 104⁰59' E and latitude 9⁰27' N), Ca Mau province, southern Vietnam from March 2001 to September 2002.

Measurement of bee nests and cells:

Due to the abundance of *A. dorsata* colonies managed by beekeepers, the measurements could be carried out on a large number of colonies. Figure 1 shows the dimensions of the comb and cells to be measured. The width and height of the comb (Figure 1a) were measured on live colonies on the rafters in the forest using a ruler. Callipers were used to measure the comb thickness, the depth of the cell (Figure 1b) and the width of ten continuous cells (Figure 1c) on pieces of combs harvested by beekeepers. The measurement was always carried out three times on a colony. Thus, the number of observations given in the result part is the number of the investigated colonies multiplied by three. Because the diameter of the cell was determined by measuring the width of ten continuous cells, the measurement on drone cells was done only where they concentrated in bands on the comb (the drone brood was scattered irregularly among worker brood or concentrated in bands). Twenty nine queen cells were cut lengthways to measure their maximum inner heights and widths. The volumes of 28 emerged queen cells were measured by dripping water from a micropipette set to an accuracy of 0.01 ml.

Bee weights:

To investigate and compare the weights of bees of different castes and of different conditions, the method was as follows: From each of three *A. dorsata* colonies, about sixty workers on combs were collected randomly: half of which was killed by freezing and weighed soon after using a digital balance (1mg accuracy); and the other half was kept without food in a wire cage (volume of 0.5 - 1.0 litre) for 24 hours to empty the load in their stomach before they were weighed alive. Also from the same three colonies, brood combs were incubated at 35⁰C and newly emerged workers were weighed alive within five hours after emerging. The drone, worker brood and queen

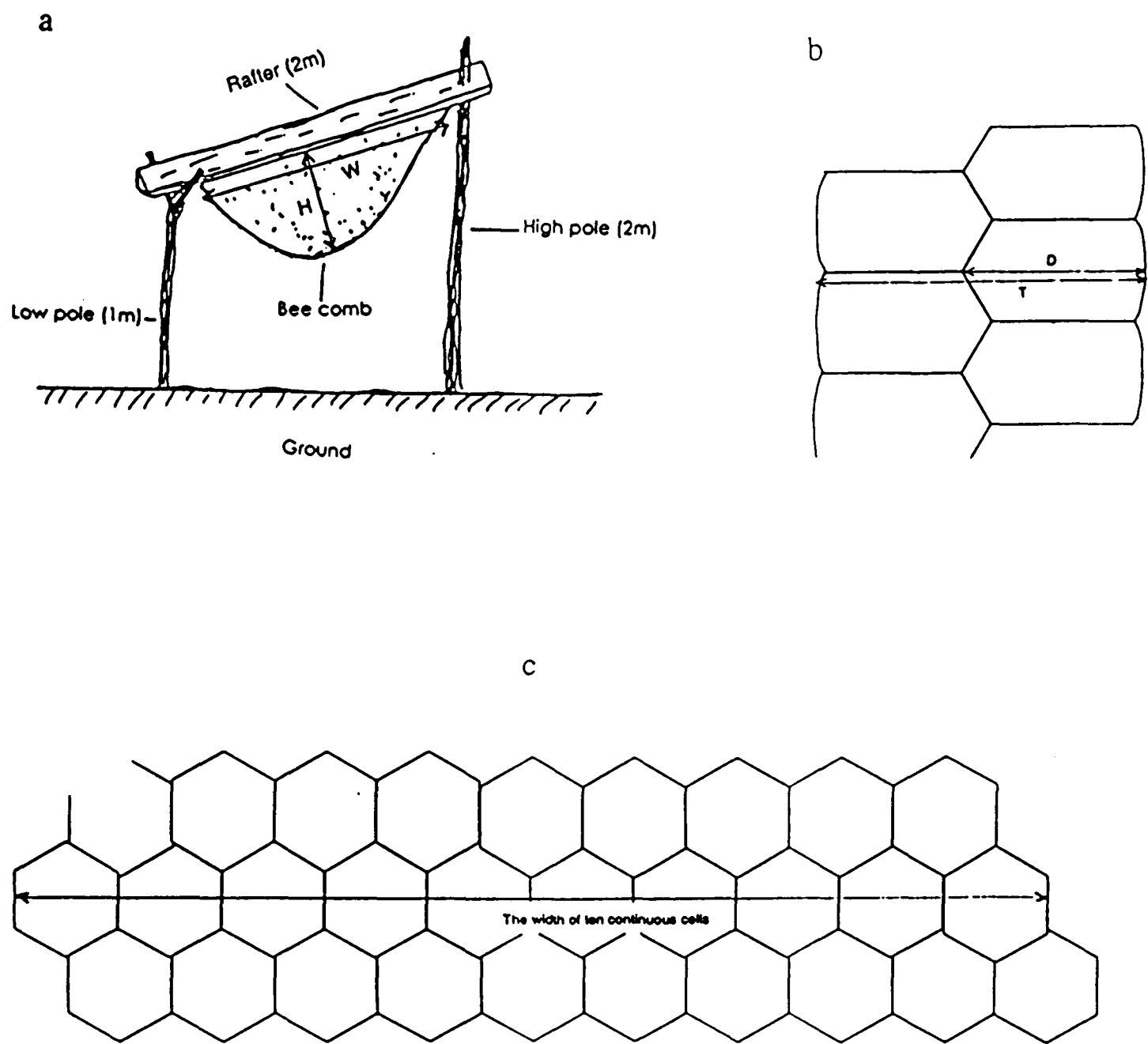


Figure 1: Dimensions of *A. dorsata* comb and cells.

a) The width (W) and height (H) of an *A. dorsata* comb on a rafter.

b) The thickness (T) of the comb and the depth (D) of the cell.

c) The width of ten continuous cells.

cell of another colony were incubated and the newly emerged bees were weighed alive within five hours after emerging.

Measurement of biometric data:

Figure 2 shows the dimensions of biometric features in workers to be measured. From each of eight colonies, the proboscis, wing dimensions and number of hamuli of thirty worker bees were measured. In each of three colonies, the cubital index (see Figure 2b) was measured on thirty worker bees. All measurements of morphological characters generally followed the technique described by Ruttner (1988). Worker bees were collected and put into boiling water so that their proboscis could expand fully. Then the bees were preserved in 70% ethanol until the measurements were carried out. Sizes of proboscis and wing dimensions were measured with accuracy of 0.1 mm using a stereo-binocular microscope (7 - 45 x). Measurements (with accuracy of 0.01 mm) of cubital index and counts of hamuli were obtained using another stereo-binocular microscope (100 x). The microscopes were equipped with eye piece scale and eye piece graticule.

Total development time of worker bees:

Scout bees exploring potential nest sites were observed and the exact time of the occupation of a nest site by a swarm was recorded. Fifteen days after the occupation of the nest site, a small piece of comb containing the oldest sealed brood was collected and placed in an incubator at 35⁰C. The emergence of the first thirty adult bees was then checked every three hours. Total development time from egg to adult of a worker bee was assumed to be the time from the swarm's occupation until the emerging of the worker.

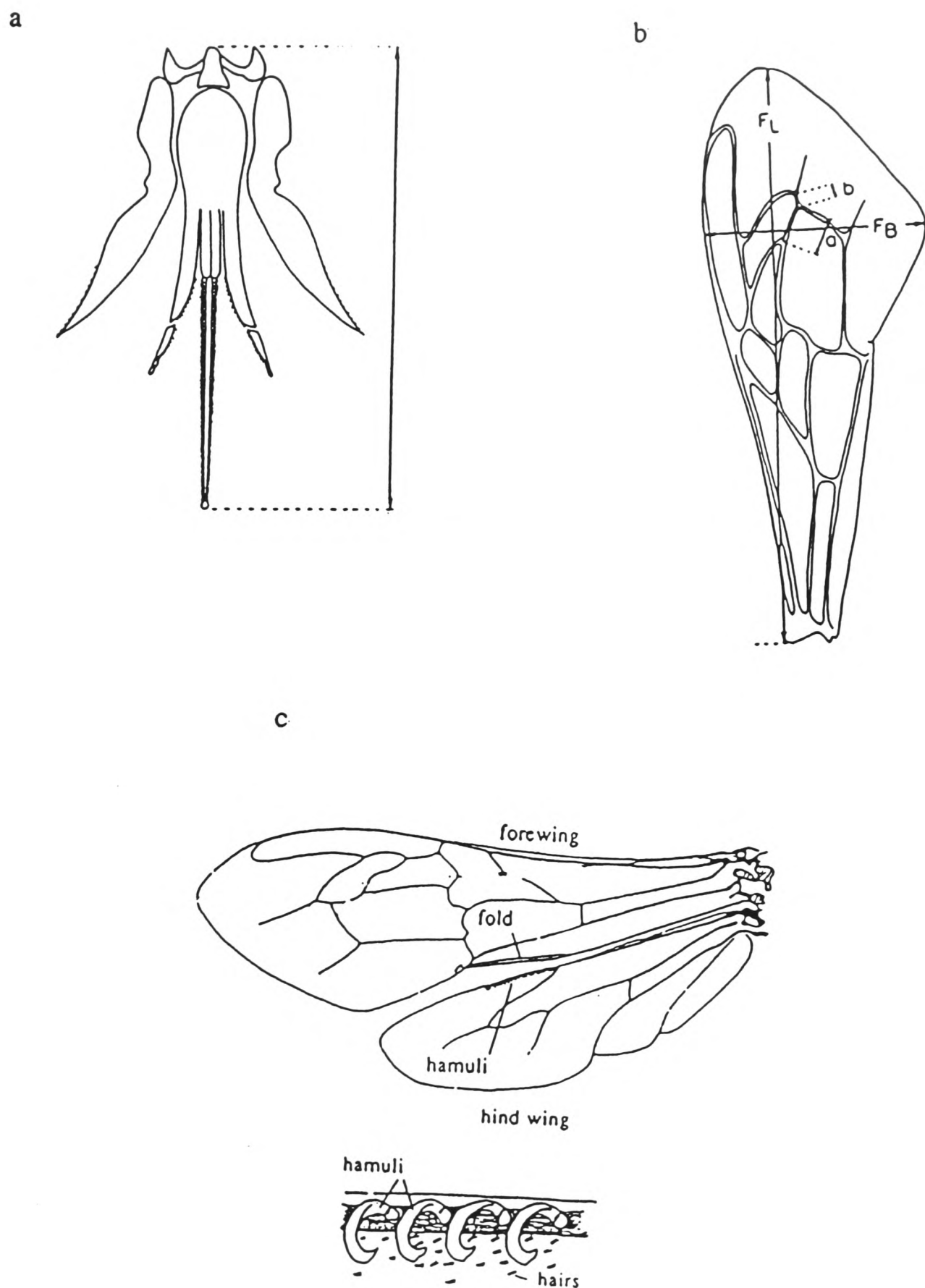


Figure 2: Morphological measurements.

a) The length of proboscis (from Ruttner 1988).

b) The length and width of forewing. Cubital is the a/b ratio (from Ruttner 1988).

c) Wings of bees and wing hooks or hamuli (from Dade 1962).

Development time of worker egg:

In a growing colony of *A. dorsata*, eggs at the lower edge of the comb where there were many newly-built cells nearby were assumed to be newly-laid eggs. A small part of comb containing newly-laid eggs was collected and placed in a 35⁰C incubator. Two days later, the hatching of the first thirty eggs was checked every three hours. The development time of an egg was assumed to be the time from comb collection until the larva hatched.

Development time of sealed worker brood:

A small part of comb containing newly-sealed worker brood (which were just nearby the being-sealed large larvae) was collected and placed in a 35⁰C incubator. Nine days later, the emergence of the first thirty adult bees was checked every three hours. The development time of a sealed brood was assumed to be the time from comb collection until the emergence of the adult bee.

Total development time of drone bees:

A piece of comb which contained thirty-four drone brood scattered among 211 worker brood was collected and incubated at 35⁰C and then the emergence of brood was checked every six hours. The development time of drones was inferred by comparison with that of the workers.

Total development time of the queen bees:

Ten queen cells of a colony together with nearby worker brood cells were incubated at 35⁰C and checked for emergence every three hours. Therefore, the development time of the queen was inferred by comparison with that of the last thirty workers.

Egg laying output of the queen:

The egg laying output per day of the queen was studied on twenty colonies which were going to swarm naturally. A queen's daily egg production is roughly the total number of brood (eggs, larvae and pupae) divided by the development time from egg to adult bee of worker bees. The total number of brood can be calculated by taking the total surface area of brood and dividing it by the surface area of a worker cell. The total surface area of brood (in square millimetre) was estimated using a transparent measuring sheet marked with 50 mm x 50 mm squares. The area of brood to be measured was drawn on a transparent sheet; and then the measuring sheet was used to estimate its total surface area. Figure 3 shows that a worker brood cell is considered as a regular hexagon and its surface area is calculated to be the square of the cell diameter multiplied by 0.8660.

Data presentation, statistics and graphics:

Most results of measurements in the study are given as the MEAN $\pm$ SD (n). The Student's t test, Analyses of Variance and Pearson's correlation were used. All tests are two-tailed. Statistical calculations were performed using MINITAB package version 12.21. The graphics were drawn using MINITAB package version 12.21 and Microsoft Excel 2002 SP-1.

Results

Bee nest and cell dimensions in A. dorsata

The comb of *A. dorsata* is more or less semicircular. The width (which corresponds to the line of attachment to the nest site) is greater than the height. Figures 4, 5 and 6 show the results of measurements on 158 colonies. The width of the *A. dorsata* comb

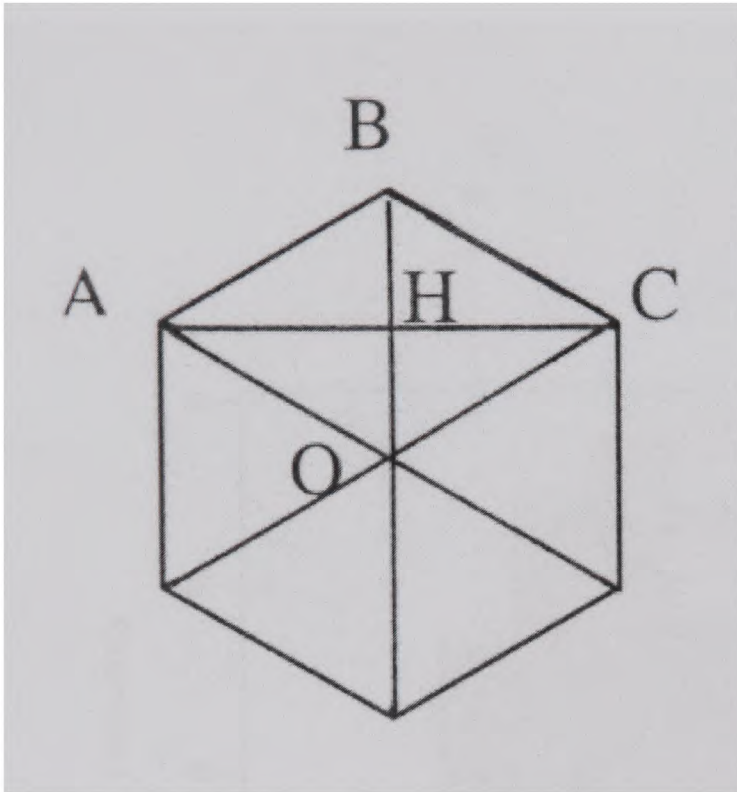


Figure 3: Regular hexagonal surface of a honey bee cell.

The area of the cell equals six areas of the regular triangle AOB = $(3) \times (AH) \times (OB)$
 $= (6) \times (AH) \times (BH) = (6) \times (AH) \times (AH / \sqrt{3}) = (2) \times (\sqrt{3}) \times (AH)^2 = (\sqrt{3}) / (2) \times$
 $(AC)^2 = 0.8660 \times (AC)^2$.

In practice, AC (the cell diameter) is determined by measuring the width of 10 continuous cells and then dividing it by 10.

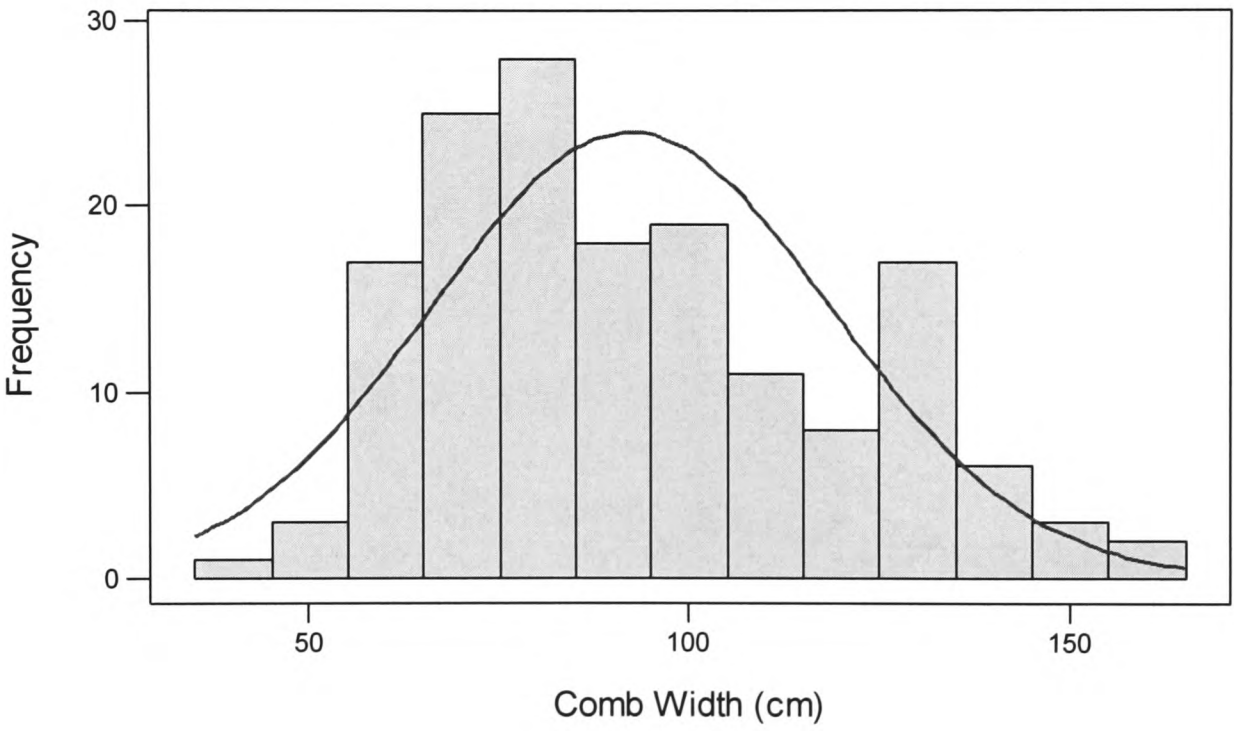


Figure 4: Distribution of the widths of *A. dorsata* combs on man made supports, rafters (n = 158).

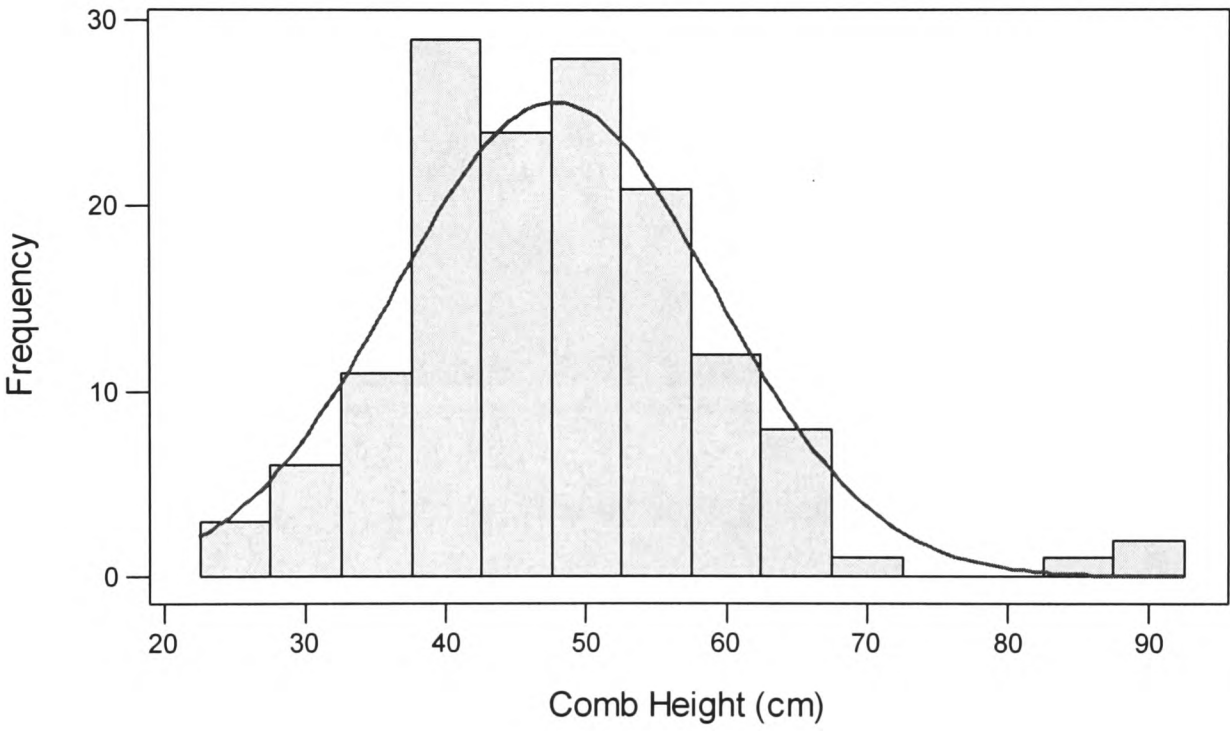


Figure 5: Distribution of the heights of *A. dorsata* combs on rafters (n = 146).

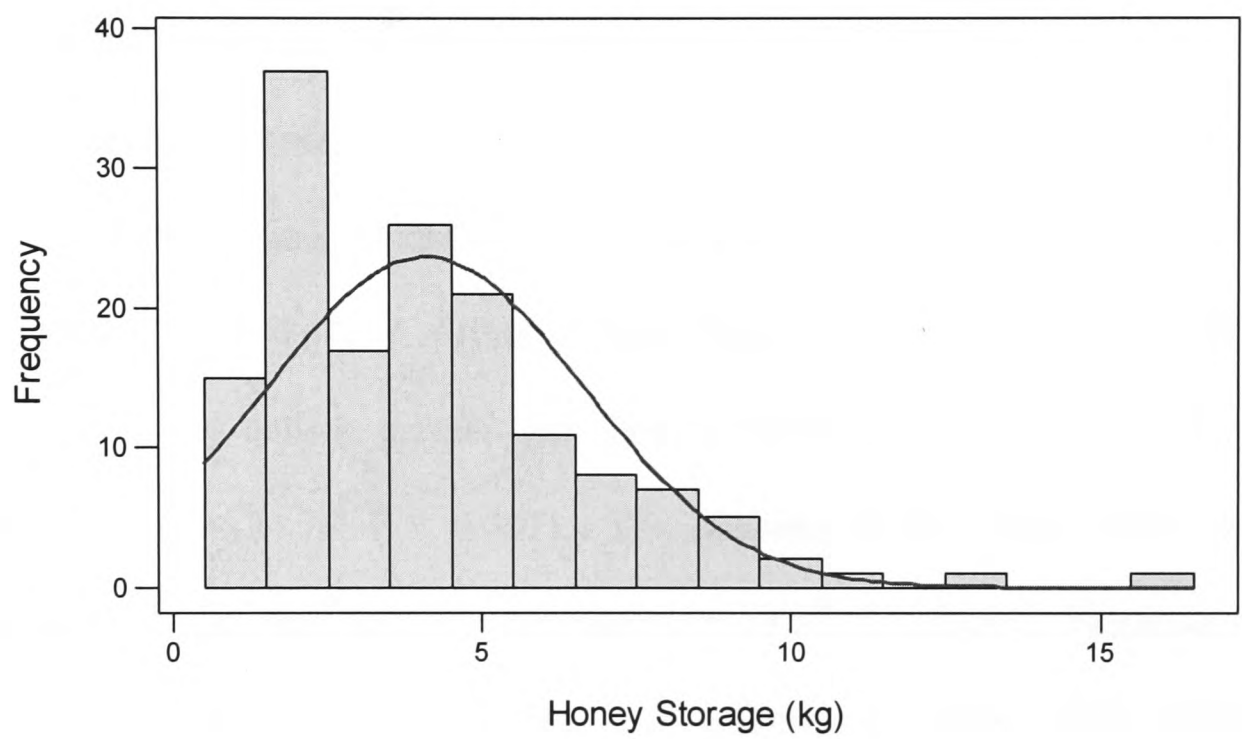


Figure 6: Distribution of the honey storage of *A. dorsata* combs on rafters (n = 152). There are some colonies with the extremely high honey yields. This trend of distribution offers the potential for selection of bee colonies with high honey yields.

was 92.4 ± 26.2 cm ($n = 158$), ranging from 43 to 162 cm; and the height was 47.8 ± 11.4 cm ($n = 146$), ranging from 23 to 90 cm. Honey was usually stored in the highest part of the comb. The honey storage (Figure 6) is not distributed as normally as the size (Figures 4 & 5) of the comb. On average, a colony could store 4.09 ± 2.56 ($n = 152$) kilograms of honey in the comb but the highest is up to 15.7 kg. Next to the honey is the pollen part and the rest of the comb is the brood part. Table 1 shows the dimensions of different types of cells in *A. dorsata* colonies. The honey cell is the largest of the three types of cells. The thickness of the honey part was highly variable in 200 observed colonies. Its range was from the normal thickness of a worker brood comb to 19 cm because of the more storage the thicker. The drone brood comb is much thicker ($t = 4.49$, $P < 0.001$) than that of the worker. The width of ten continuous honey cells is greater than those of drone ($t = 16.77$, $P < 0.001$) and of worker cells ($t = 24.76$, $P < 0.001$). The diameter of the drone cell is also very significantly larger than that of the worker ($t = 13.83$, $P < 0.001$). Moreover, the cell size was also very different among 110 colonies measured. The width of ten continuous worker cells varied from 52.3 to 61.0 mm; and the difference among the colonies is highly significant (one-way ANOVA, $F_{109, 220} = 9.09$, $P < 0.001$). In drone brood the capping of the cell was domed and elevated, so the drone cell is very much deeper than the worker cell ($t = 9.97$, $P < 0.001$).

Bee weights and biometric data

Table 2 shows the weight of worker bees in some conditions and of the queen and drone. The difference between the randomly collected workers and those with empty stomachs is very highly significant ($t = 15.44$, $P < 0.001$); therefore, a normal worker

Table 1: Some data on the dimensions of different types of cells in *A. dorsata*.

	No. colonies investigated	Mean $\pm$ SD (n)	Range
Comb thickness (mm)			
Worker brood part	75	33.1 $\pm$ 2.5 (225)	28 - 38
Drone brood part	30	37.1 $\pm$ 1.6 (90)	34 - 41
Width of 10 continuous cells (mm)			
Honey	30	63.9 $\pm$ 3.0 (90)	58 - 70
Worker	110	55.7 $\pm$ 1.7 (330)	52 - 61
Drone	30	58.1 $\pm$ 1.4 (90)	55 - 61
Cell depth (mm)			
Worker	75	17.4 $\pm$ 1.5 (225)	16 - 22
Drone	30	19.0 $\pm$ 0.4 (90)	18 - 20

Table 2: Weights in milligrams of *A. dorsata* workers in some conditions, drones and the queens. From each of three *A. dorsata* colonies, sixty workers on combs were collected randomly: half of which was weighed right away at an accuracy of 1mg, and the other half was kept without food for 24 hours to empty the load in their stomach before weighing. Also from the same three colonies, brood combs were incubated at 35⁰C and newly emerged workers were weighed within a few hours after emerging. Drone, worker brood and queen cells of a colony were incubated and the newly emerged bees were weighed.

	Mean $\pm$ SD (n)	Range
Randomly collected worker		
Stomach normal	150.0 $\pm$ 22.5 (90)	107 - 212
Stomach empty	107.4 $\pm$ 13.2 (90)	80 - 149
Newly emerged workers	157.4 $\pm$ 17.0 (90)	111 - 188
Newly emerged bees in same colony		
Worker	159.9 $\pm$ 15.5 (30)	110 - 177
Drone	168.5 $\pm$ 10.4 (30)	151 - 191
Queen	272.0 $\pm$ 40.1 (9)	217 - 327

bee can weigh 40% more than a worker with an empty stomach. The weight of the newly-emerged bee is highly significantly different from the randomly collected bee ($t = 2.46$, $P = 0.015$). Moreover, the origin (colony) of the bees also affects their weights. The weights of newly-emerged worker bees in the three colonies (161.1 ± 8.3 mg ($n = 30$), 142.2 ± 18.7 mg ($n = 30$) and 169.0 ± 8.8 mg ($n = 30$); respectively) are highly significant (one-way ANOVA, $F_{2,87} = 34.53$, $P < 0.001$). The weight of a newly emerged drone is greater than that of a worker from the same colony ($t = 2.52$, $P = 0.015$). A virgin queen weighed much more than a worker ($t = 8.2$, $P < 0.001$) or a drone ($t = 7.67$, $P < 0.001$).

Table 3 shows some biometric data of *A. dorsata* worker bees in the *Melaleuca* forest in comparison with *A. dorsata* in other countries and with other honey bee species.

Development time of A. dorsata worker, drone and the queen

Figure 7 gives the emergence time of drones compared with that of workers. On average, drones emerged 4.0 days later than workers. Figure 8 demonstrates the emergence time of young queens and workers. It shows that not all brood in queen cells was of the same age, implying that the mother queen laid eggs in the queen cells at different times. I assume that the egg which emerged into the first virgin queen was laid at the same time as the nearby worker eggs; therefore, the development time of a queen is estimated to be about 3.2 days shorter than that of a worker. Data on the development time of the queen, worker and drone of *A. dorsata* are shown in Table 4. Observations on dozens of emerging virgin queens of *A. dorsata* showed that in contrast to *A. mellifera* and *A. cerana*, there was no lid on the top of the queen cell

Table 3: Some biology of *Apis dorsata* workers in Vietnam in comparison with *A. dorsata* elsewhere and other honey bee species.

Character	<i>A. dorsata</i> of this study	Extracted from Ruttner (1988)		
		<i>A. dorsata</i>	<i>A. mellifera</i>	<i>A. florea</i>
Cell diameter (mm)	5.23 - 6.10	5.35 - 5.64	4.62 - 5.51	4.25 - 4.80
Weight of unloaded worker (mg)	107.4 ± 13.2 (90)	118.1	77.2	43.8
Length of proboscis (mm)	6.53 ± 0.23 (240)	6.45	6.11	5.40
Size of forewing (mm)				
Length	12.96 ± 0.26 (240)	12.5 - 13.5	7.64 - 9.70	7.27 - 9.02
Width	4.50 ± 0.15 (240)	-	-	2.8 - 3.1
Size of hind wing (mm)				
Length	8.91 ± 0.22 (240)	-	-	-
Width	2.90 ± 0.14 (240)	-	-	-
Number of wing hooks	25.7 ± 1.9 (240)	24.3	21.7	16.9
Cubital index (a/b)	9.01 ± 3.32 (90)	7.25	1.82	3.98

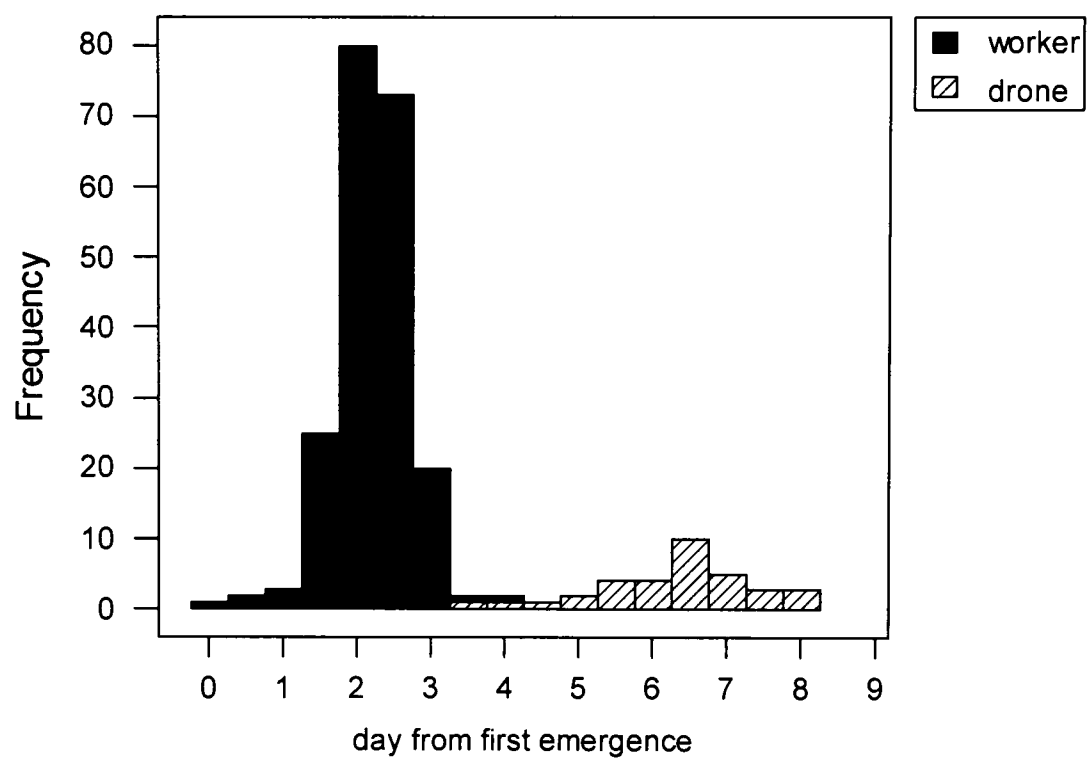


Figure 7: Comparison of the emergence time of drones with that of nearby worker bees. A piece of comb which contained thirty-four drone brood scattered among 211 worker brood was collected and incubated at 35⁰C and then the emergence of brood was checked every six hours.

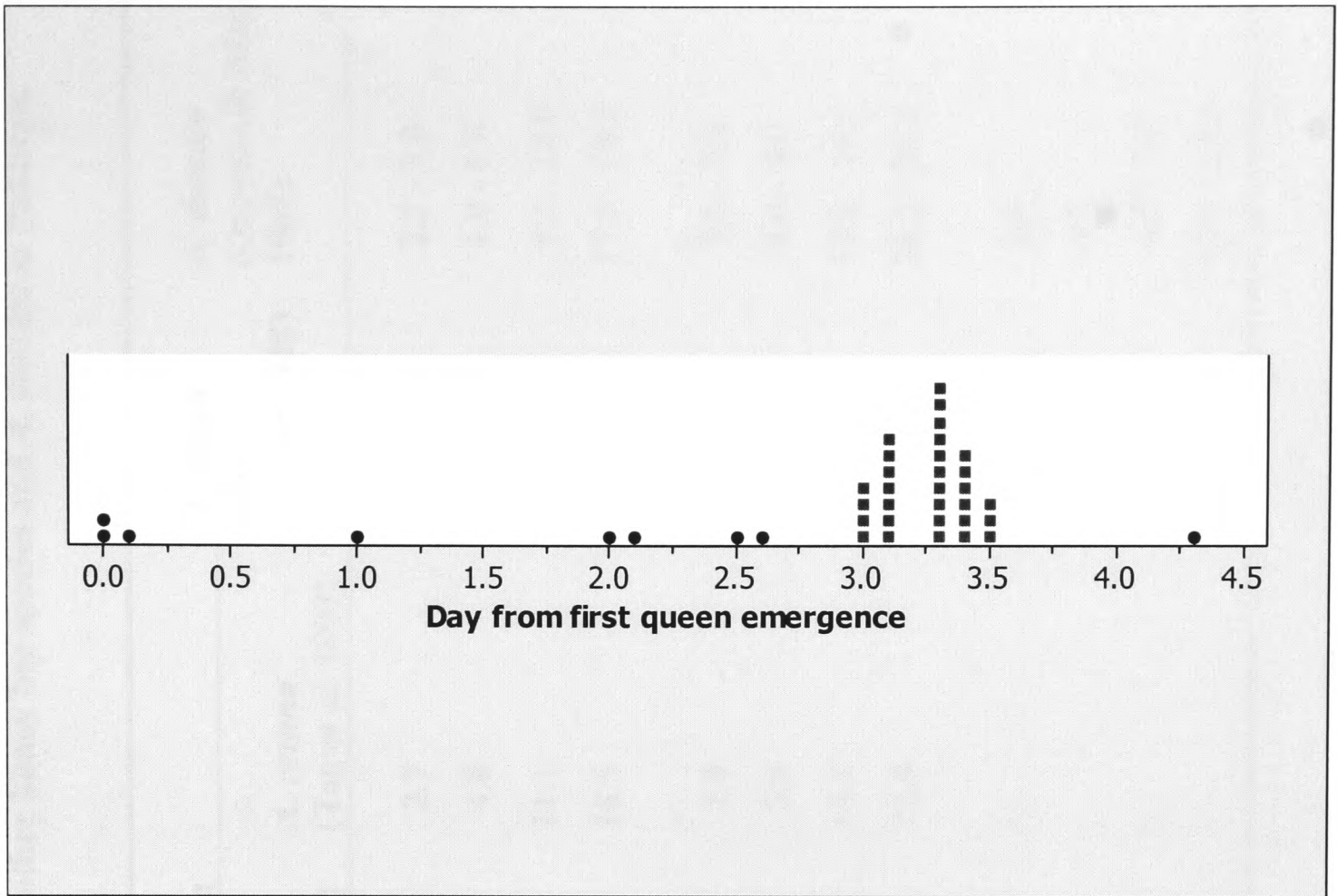


Figure 8: Comparison of the emergence time of nine virgin queens with that of the last thirty nearby worker bees. Queen cells of a colony together with nearby worker brood cells were incubated at 35⁰C and checked for emergence every three hours. The symbol ● represents a queen and ■ a worker.

Table 4: Development time (days) of *A. dorsata* in comparison with other honey bee species and *A. dorsata* in Pakistan.

		Southern Vietnam				<i>A. dorsata</i> (this study)	<i>A. mellifera</i> (Tan <i>et al.</i> 1993)	<i>A. cerana</i> (Tan <i>et al.</i> 1993)	<i>A. florea</i> (after Ruttner 1988)	<i>A. dorsata</i> (Qayyum & Ahmad 1967)
Worker:	Egg	2.9 ± 0.1 (30)	2.9	2.7	3.0	2.5 - 3.0				
	Open brood	5.6	5.8	4.8	6.4	4.0 - 5.0				
	Sealed brood	11.2 ± 0.2 (30)	11.8	11.1	11.2	9.5 - 12.0				
	Total	19.7 ± 0.1 (30)	20.5	18.5	20.6	17.5 - 19.5				
Drone:	Egg	-	3.0	2.8	3.0	2.5 - 3.0				
	Open brood	-	6.7	5.9	6.7	4.0 - 5.0				
	Sealed brood	-	14.7	14.1	12.8	13.5 - 15.5				
	Total	23.7	24.4	22.8	22.5	21.5 - 23.5				
The queen:	Egg	-	-	-	-	2.0				
	Open brood	-	-	-	-	4.5				
	Sealed brood	-	-	-	-	6.5 - 7.0				
	Total	16.5	-	-	-	13.0 - 13.5				

after the virgin queen had emerged; *Apis dorsata* virgin queens perhaps chew off the cap to emerge.

The colony size, queen cells and queen's egg production of the colony at full development

Data on colony size, number of queen cells and egg production from thirty-two colonies at full development are shown in Table 5. All of the natural queen cells were at the lower edge of the comb. There is a strongly positive relationship between the size of the colony and the number of the queen cells reared: $r = 0.520$, $P = 0.002$, $DF = 30$ (Figure 9). High and narrow queen cells, which are similar in shape to the queen cells of *A. mellifera* and *A. cerana*, were observed in a few colonies; but short and broader queen cells were more frequent. In the former case, the maximum inner height and width of a queen cell were 28.1 ± 0.7 mm ($n = 16$) and 8.5 ± 0.4 mm ($n = 14$), respectively; so the ratio of height to width could be as high as 3.3. In the latter case, the maximum inner height and width were 22.6 ± 1.6 mm ($n = 13$) and 12.4 ± 1.4 mm ($n = 13$); so the ratio reached only 1.8. The average volume of a queen cell was found to be 1.300 ± 0.159 ml ($n = 28$).

Discussion

The smallest colony recorded on rafters of beekeepers was 43 cm wide but smaller colonies were sometimes observed in the forest. They are not managed because very little honey is stored and almost all colonies less than 20 cm in width are usually queenless and will die out. The size of the colony is rather similar to those reported in other areas (see Ruttner 1988). Table 5 presents the average width and height of an *A.*

Table 5: Some biological data of the *A. dorsata* colonies at full development.

Colony	Width (cm)	Height (cm)	No. queen cells	Daily egg production
1	140	64	15	1000
2	116	57	9	800
3	88	58	7	600
4	90	48	8	800
5	125	66	10	800
6	118	57	14	1000
7	91	52	6	500
8	130	62	14	900
9	117	61	11	800
10	141	64	15	1000
11	110	64	9	700
12	91	52	7	600
13	104	62	9	700
14	129	57	12	900
15	120	47	8	900
16	135	56	10	1400
17	118	52	7	1100
18	162	59	10	1300
19	134	56	11	1600
20	118	53	11	1300
21	134	54	10	-
22	122	54	8	-
23	112	65	9	-
24	130	57	8	-
25	130	54	11	-
26	130	54	9	-
27	107	50	8	-
28	150	62	11	-
29	115	48	10	-
30	105	60	10	-
31	142	56	8	-
32	114	52	5	-
Mean $\pm$ SD	120.9 $\pm$ 17.6	56.6 $\pm$ 5.3	9.7 $\pm$ 2.4	940 $\pm$ 290

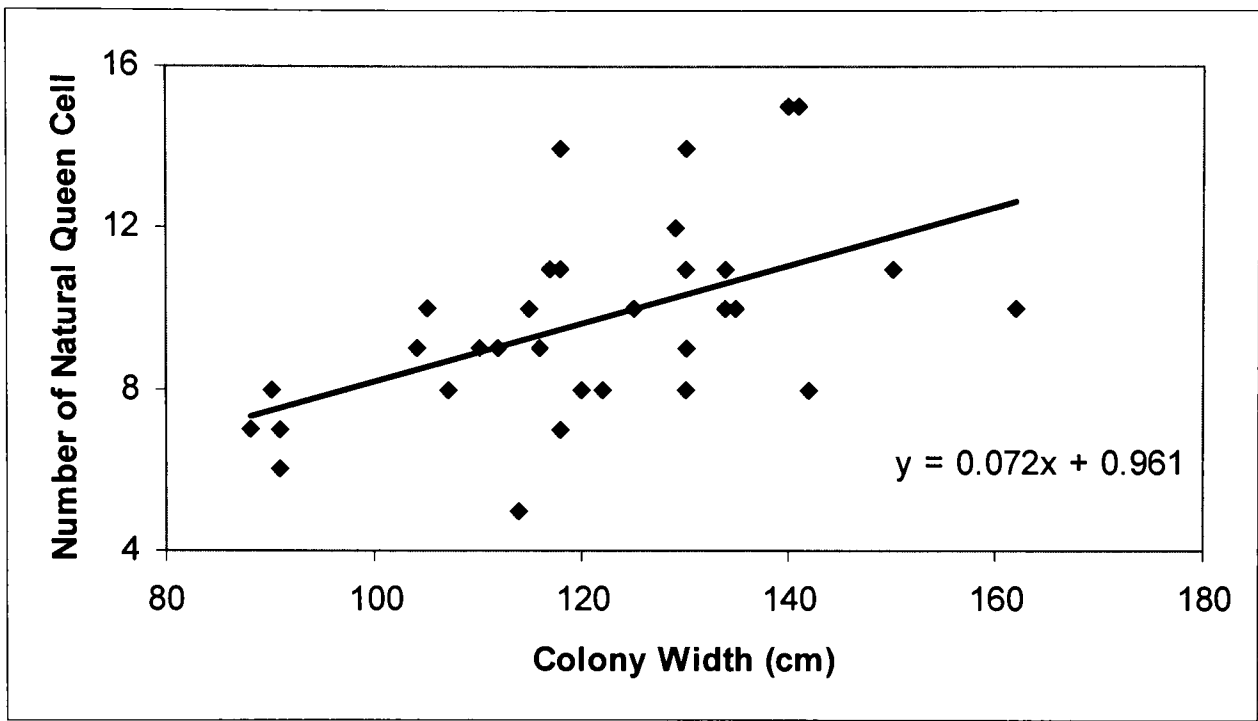


Figure 9: Relationship between the width of the colony and the number of queen cells in the colony ($r = 0.520$, $P = 0.002$, $DF = 30$).

dorsata colony when the colony has developed fully and built queen cells prior to swarming; therefore, these data are more representative for mature colonies than those given in Figures 4 and 5.

Honey is heavy, so the honey cells are usually at the highest part of the comb, attached to the support. When more honey is collected, the depth of the honey cells is increased by the bees for more storage and for stronger attachment. The average honey yield of a colony in the *Melaleuca* forest of Vietnam is the similar to those reviewed by Ruttner (1988) in other countries. Moreover, in my research area, beekeepers harvest the honey about 20-30 days after initial bee occupation and they can harvest 2-3 times from the same colony. Figure 6 shows that there are some colonies with extremely high honey yields and if this has a genetic basis these colonies have high potential for selection in breeding programmes.

To weigh an *A. dorsata* colony without destroying it, the following technique was used with a colony measuring 157 cm x 68 cm. The honey and pollen parts of the colony were cut off and weighed: they were 13.3 and 3.8 kg; respectively. All the bees were caught, weighed then released back to the colony; the bee weight was 11.8 kg. The brood comb was measured and its weight was estimated via many bee combs which were sometimes collected by beekeepers. Although subject to some error, the weight of the brood comb was estimated to be 9 kg; therefore, the weight of the colony was as high as 38 kg. With this great weight, an *A. dorsata* colony requires a strong nest site, which will be studied in the next chapter.

The results of this study confirm that the cells for honey storage, for drone brood and worker brood of *A. dorsata* are different in size. The honey cell is the largest and its depth can vary greatly due to the storage volume required. The worker and drone brood cells are similar, being hexagonal and horizontal but they differ in diameter and depth. Moreover, the capping of the drone cell is distinguishable. Until now, the difference in diameter between the two types of brood cells has not been confirmed. This study shows that they are statistically significant although the drone cell is only 1.04 times wider than the worker cell. This slight difference is not easy to be distinguished in practice, especially when the drone cells are scattered among the worker cells. In other honey bee species, the ratio in diameter of drone to worker cells is much greater. According to Ruttner (1988, p.81 and p.132), the ratios in *A. mellifera*, *A. cerana* and *A. florea* are 1.33, 1.13 and 1.59, respectively.

In an *A. dorsata* colony, a newly-emerged worker bee weighs a little more than a randomly-collected one; but the weight of the latter varies more due to the contents (pollen, nectar or water) in its stomach, perhaps. The comparison of the normal workers and the empty stomach workers shows that a worker can contain a load of about 40 mg, occupying nearly 40% of its weight. The results of my study also show that the weights of the queen, drones and workers are very different. The ratio of the queen: drone: worker is 1.70: 1.05: 1.00 in this study. Koeniger & Koeniger (1993) investigated and compared the weights of all three castes in *A. dorsata*, *A. mellifera*, *A. cerana* and *A. florea* in Thailand. Figure 10 compares the queen: drone: worker ratios in four honey bee species. It shows that the difference among the three castes in *A. dorsata* is the smallest.

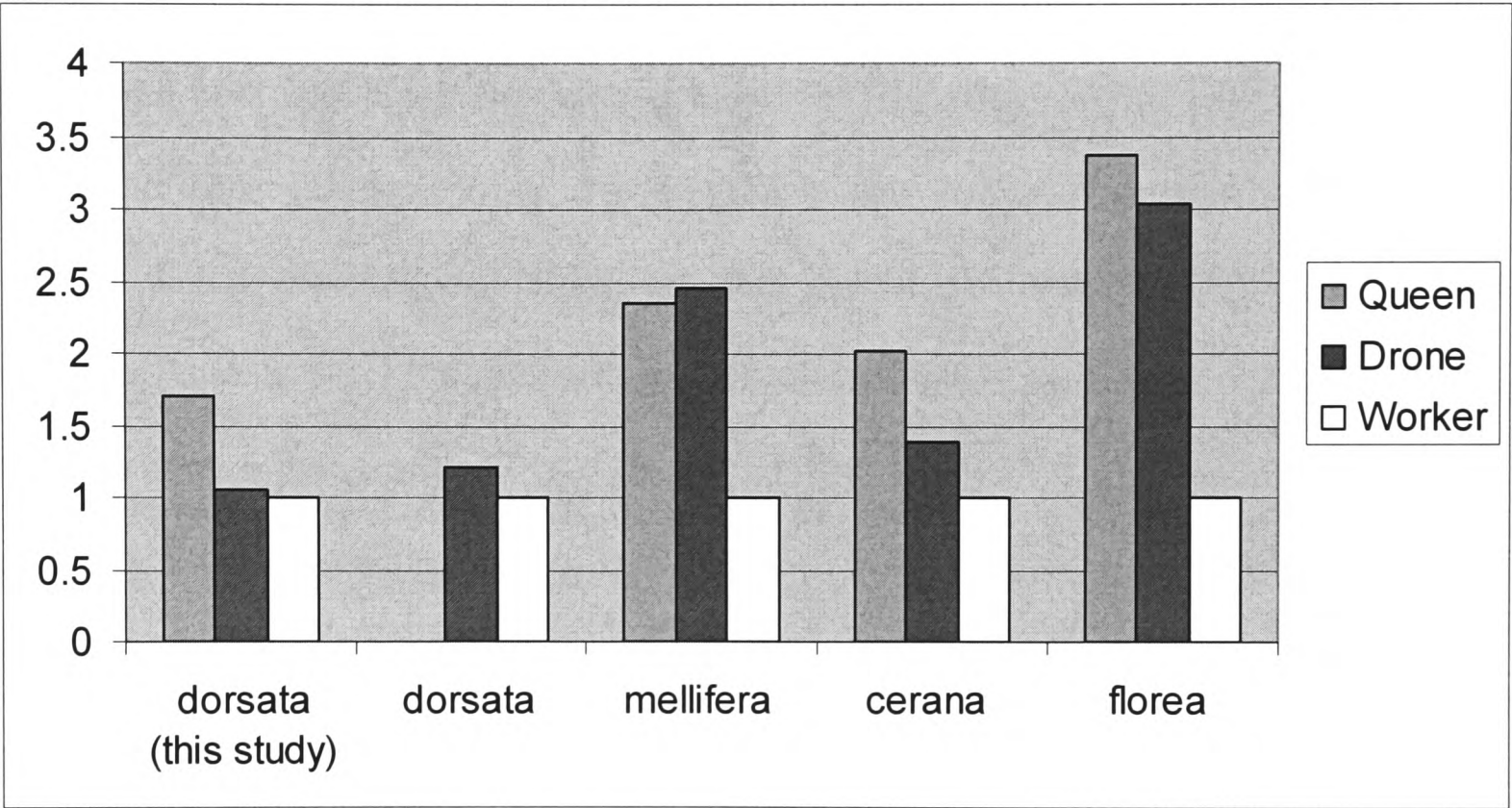


Figure 10: Weight ratios of the queen: drone: worker in four honey bee species.
Data are from this study and Koeniger & Koeniger (1993), who did not record *A. dorsata* queens. All bees in this study and queens in Koeniger & Koeniger (1993) were newly emerged.

In honey bee taxonomy, differences in behaviour are more important than those of morphology; e.g. the race of *A. cerana* in Himalaya or Japan is much bigger in size than those of *A. mellifera* in tropical Africa. However, morphological characteristics of worker bees as well as sizes of worker cells are still important. Moreover, morphological characteristics can be distinct among sub-species. For bee breeders in Europe, *A. mellifera carnica* can be differentiated from *A. mellifera mellifera* by their cubital index (Ruttner 1988). In America, beekeepers could discriminate the Africanised bees from the European race in the field by measuring the width of ten continuous cells (Rinderer *et al.* 1986). *Apis cerana cerana* from the North of Vietnam and *A. cerana indica* from the South can be differentiated by their cell diameters (Binh & Tan 1994). Because such detailed studies to the level of subspecies have not been implemented in *A. dorsata*, a collection of these morphological data is necessary for future studies. Data in Table 3, which are in the range of data reviewed by Ruttner (1988), are the first account for *A. dorsata* in Vietnam.

Development time from egg to adult of the queen, worker and drone bee of different honey bee species are compared in Table 4. *Apis mellifera* and *A. cerana* have been studied in many locations (reviews in Ruttner 1988 & Crane 1990) including southern Vietnam (Tan *et al.* 1993), but to my knowledge, the data on *A. dorsata* of this study are only the second study after Qayyum & Ahmad (1967). In southern Vietnam *Apis dorsata* needs a shorter time than *A. mellifera* but longer than *A. cerana* to develop. Actually, the total development time of 19.7 days for worker bees in my study is the duration from the bee swarm's occupation of nest site to the emergence of the first worker bees. It is longer than the real development time of a worker because the time between occupation and the queen's laying is not known. However, according to experienced rafter beekeepers, this time duration was less than a day. Ruttner (1988)

wrote that if an *A. dorsata* swarm started building a nest, comb construction was rather rapid. Koeniger & Koeniger (1980) reported a swarm to construct a good portion of comb during a night. The development times of many other honey bee species are still not available.

Like other honey bee species, *A. dorsata* produces natural queen cells when the colony develops fully. Although natural queen cells of *A. dorsata* have been observed and reported recently (e.g. Viswanathan 1950; Thakar and Tonapi 1961; Morse and Laigo 1969), this study is perhaps the first to rear *A. dorsata* queen cells on purpose. The queen cells can be elongated like those of *A. mellifera* and *A. cerana*, but the broader shape is more often observed. The reason for this phenomenon is not yet known. In comparison with worker and drone cells, the queen cell is bigger in size, special in shape and vertical in direction. In general, the number and position of queen cells in *A. dorsata* are not much different from those in other honey bee species.

The number of eggs laid per day by the queen depends on the age of the queen, the strength and condition of a colony, external circumstances, species and sub-species. Egg laying capacity of the queens has been measured in *A. mellifera*, *A. cerana* and *A. florea* (reviewed in Ruttner 1988; Crane 1990). However, no information is available at present for other honey bee species including *A. dorsata*. The data presented here is the egg laying capacity of the queens in the colonies about to swarm and is therefore assumed to be the highest level of egg production for an *A. dorsata* queen.

In Table 6, I extract and compare some key aspects of the reproductive biology of different honey bee species. The periods of mating flights of different honey bee

species are separate and that of *A. dorsata* is close to sunset. The duration of queen mating flights in *A. dorsata* seems shorter than those of other species but the *A. dorsata* queen normally practices multiple mating flights; therefore, the total mating time is longer and this goes along with its extreme level of polyandry. Like the temperate *A. mellifera* and *A. cerana* colonies which need to develop quickly after hibernation, the tropical *Apis dorsata* colony could have the same great egg production (up to 1600 eggs/day) to restore the number of bees lost during the migration. With regard to the appearance of mating signs and mechanism of sperm transfer, two groups can be partitioned in the genus *Apis*. Group 1 comprises *A. mellifera*, *A. cerana* and *A. koschevnikovi*. These species have mating signs which are formed on the queen after mating. During the mating, drone bees eject their sperm into the oviducts of the queen, and then 24 hours later, the sperm move into the spermatheca of the queen. Group 2 currently comprises only *A. florea*, which has no mating signs and in which sperm are transferred directly from drones into the spermatheca of the queen. *Apis andreniformis*, which is similar to *A. florea* in many features of morphology and behaviour, as well as the sperm transfer mechanism, is similar to the species of group 1 in the mating signs. The giant honey bee, *A. dorsata* is similar to the species of group 1 in their body size but more similar to *A. florea* in nest structure, nesting behaviour and the lack of a mating sign. The sperm transfer mechanism in *A. dorsata* has never been studied and according to Koeniger & Koeniger (1991, 2000) it is not easy to predict based on the genitalia of *A. dorsata* drone. This kind of study is difficult but necessary in the future.

Table 6: Some key comparative aspects of the reproductive biology of some honey bee species.

Except noted, data cited are extracted from Koeniger & Koeniger (1991, 2000).

¹Tan *et al.* (1999), ²Koeniger *et al.* (1994a), ³Rinderer *et al.* (1993), ⁴Koeniger *et al.* (2000), ⁵After Oldroyd *et al.* (1998), ⁶This study, ⁷Ruttner (1988).

Although the drone flight time of *A. dorsata* in Vietnam was not firstly studied it is preferably cited. Although those of *A. cerana* and *A. florea* below were not the first studies, they were cited for easy comparisons with *A. koschevnikovi* and *A. andreniformis*; respectively from the same locations.

Character	<i>A. dorsata</i>	<i>A. mellifera</i>	<i>A. cerana</i>	<i>A. koschevnikovi</i>	<i>A. florea</i>	<i>A. andreniformis</i>
Time of drone mating flight	18.08 - 18.40 ¹	12.00 - 17.00	14.00 - 16.15 ²	16.45 - 18.30 ²	14.00 - 16.45 ³	12.15 - 13.45 ³
Duration of queen mating flight (minute)	15.4 ± 4.3 (14) ¹	15.8 - 21.0	20 - 39	19 ²	18 - 30	19 - 23 ⁴
Queen’s multiple mating flights	common ¹	sometimes	sometimes	-	-	-
Mating signs	no ¹	yes	yes	yes ²	no	yes ⁴
Sperm transfer mechanism	-	oviducts	oviducts	oviducts	spermatheca	spermatheca ⁴
No. drones mating with a queen determined by DNA method	26.7 ⁵	13.8 ⁵	18.0 ⁵	-	8.0 ⁵	13.5 ⁵
Egg production per day	500 - 1600 ⁶	1400 - 2000 ⁷	300 - 2000 ⁷	-	350 ⁷	-



Plate 1: An *A. dorsata* comb without bees.

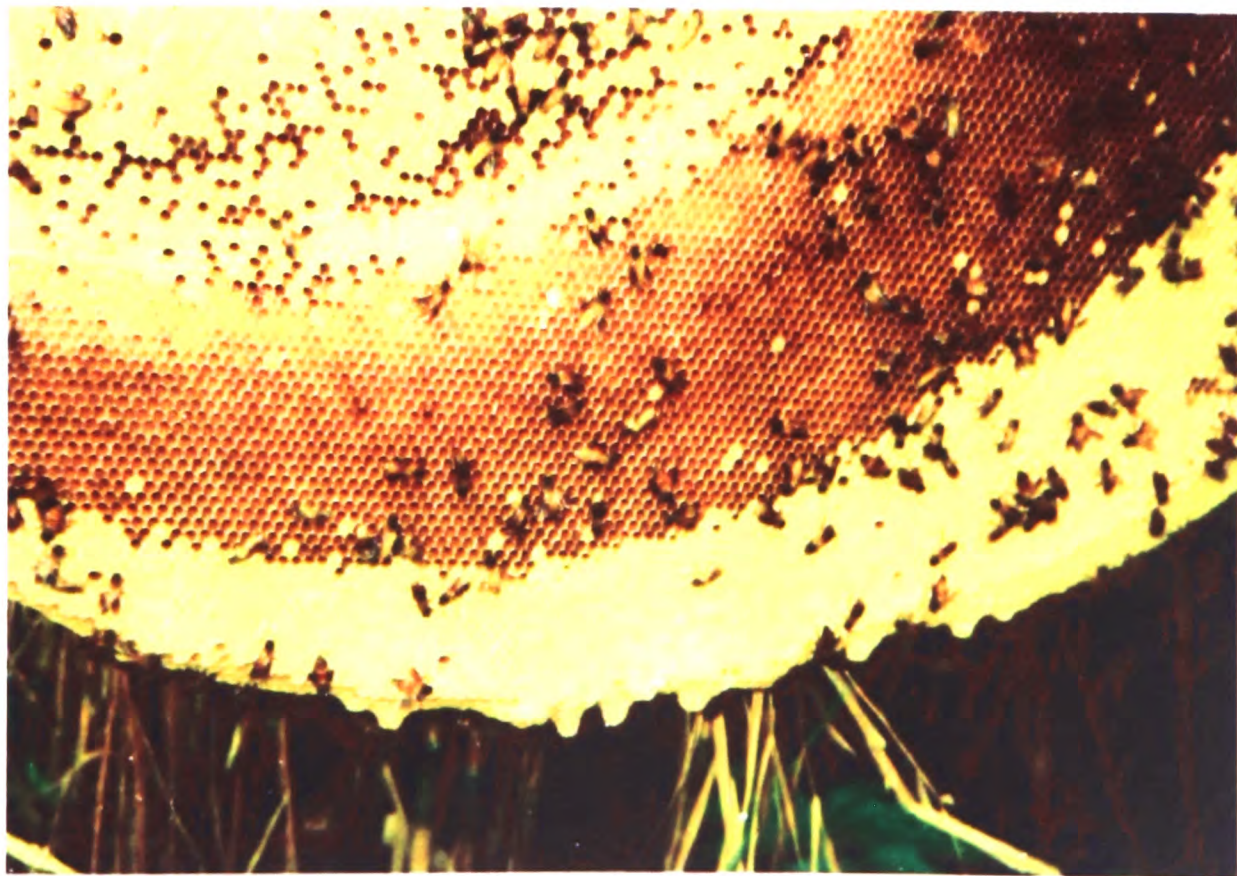


Plate 2: The queen cells are at the lower edge of the comb.



Plate 3: Queen cells in a 35⁰C incubator.



Plate 4: A virgin queen is emerging from queen cell.

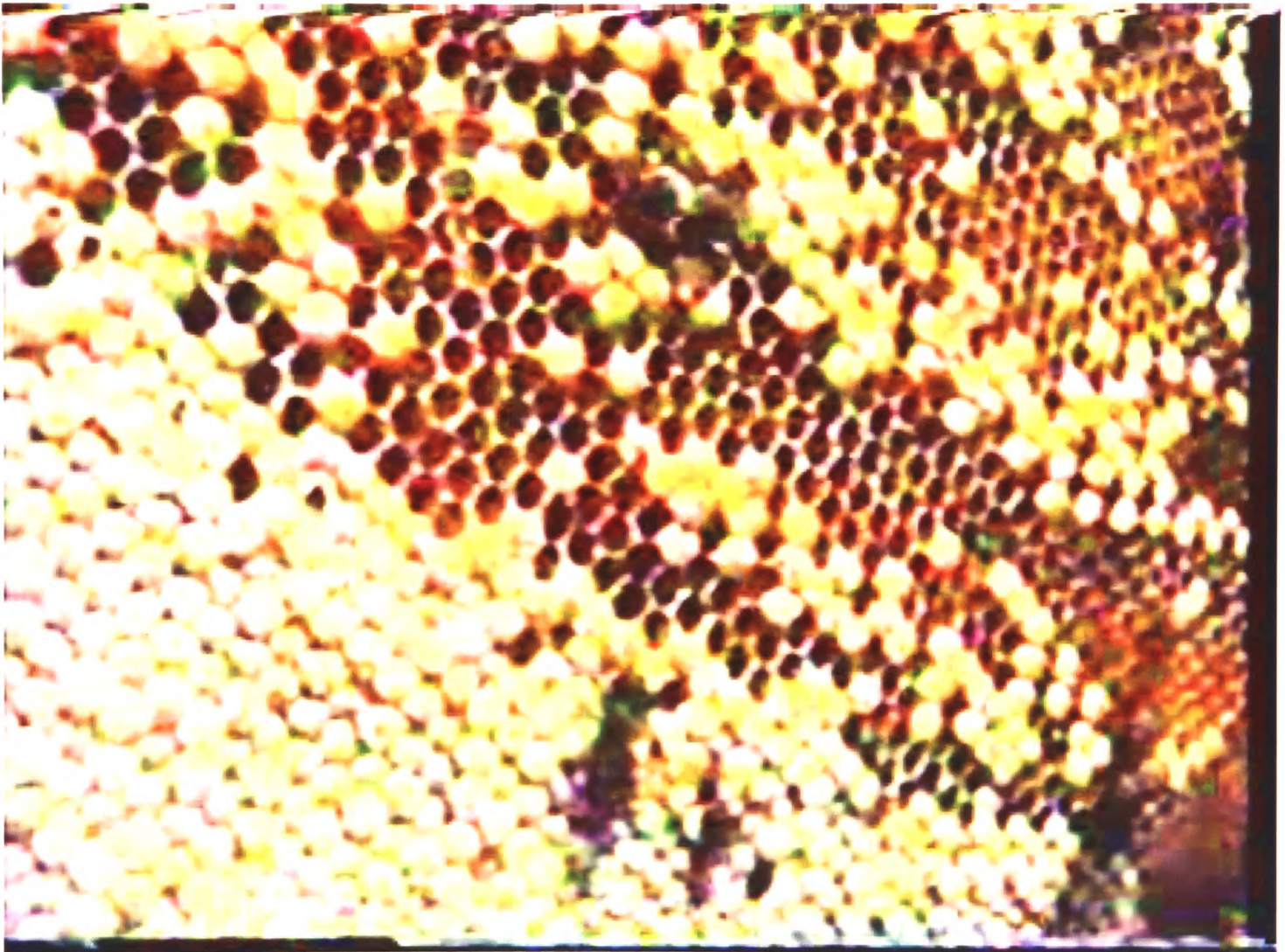


Plate 5: Drone brood (upper right) are scattered among worker brood and were still sealed after the worker brood had emerged.

CHAPTER 3

NEST SITE SELECTION IN *APIS DORSATA*

Introduction

Selection of a new home is crucial for the survival and reproduction of many animals. Studies on nest site selection in the European honey bee, *Apis mellifera* were initiated in Germany by Lindauer (1961) and then studied in much more detail in the United States (e.g. Seeley 1977, 1982; Seeley & Morse 1978; Visscher *et al.* 1985; Camazine *et al.* 1999; Seeley & Buhrman 1999, 2001). These studies show that in order to select a nest site, hundreds of scout bees go out to hunt, check dozens of nest sites, and then convey information to nest mates via dances. After complex information processing, a unanimous decision is made and the whole swarm takes off to the new nest site. Seeley & Morse (1978) demonstrated that selection criteria in *A. mellifera* were the volume, the height, the direction, the entrance position and the entrance area of the nest cavity. Properties which were not important were the shape of the cavity, the shape of the entrance, and the draughtiness or the dryness of the cavity. Visscher *et al.* (1985) also found *A. mellifera* swarms to prefer cavities with beeswax from previous colonies. Some preliminary studies on nest site selection have been carried out in *A. cerana* (Inoue *et al.* 1990 & Hossain *et al.* 1992). Studies on nest site selection in *Apis dorsata* have been of a preliminary and fragmentary nature (e.g. Nandi & Mahabal 1974; Deodikar *et al.* 1977; reviews in Ruttner 1988 & Crane 1990; Reddy & Reddy 1993).

Domestication of the Asian giant honey bee, *A. dorsata* was once thought to be impossible because of its nesting and defensive behaviours. However, many advances

have been made in the management of this good honey producer and some techniques are successful (summarised in Crane 1999; Mahindre 2000). In southern Vietnam, *Apis dorsata* as well as the two dwarf honey bees, *A. florea* and *A. andreniformis*, are native to the submerged *Melaleuca* forests. Elsewhere, *A. dorsata* builds its single comb hanging from a tree branch, projecting rock, water tower or the eaves of a building, but in the *Melaleuca* forest man-made supports called rafters are mostly used. The rafter is a tree trunk, which is split lengthways, about 2 m in length and 15 cm in diameter. It is placed on two vertical poles: one pole is about 2 m high and the other 1 m high. The rafter therefore slopes at an angle to the horizontal like the rafter of a house (Figure 1). The rafter is always erected at the edge of a quiet open space in the *Melaleuca* forest with its higher end pointing to the open space (Figure 2).

When *Melaleuca* flowers bloom, thousands of *A. dorsata* swarms arrive. It is usually observed that many swarms settle on trees; then after time they leave to occupy rafters and build their new nests. In *Apis mellifera*, bee scouts explore and select the best new site among many choices (authors cited above). If the same is true for *A. dorsata*, what are the scout bees examining? In practical rafter beekeeping, not all rafters (hereafter “nest sites”) become occupied by bee colonies. The occupation rate is 48.1% on average but ranges from 18 - 76% (data in Chapter 6). According to the literature on *A. dorsata*, findings from the European honey bee, beekeepers’ experiences and my observations, I supposed that the properties of the nest sites that are probably important in the nest site selection would be direction, diameter, slope, open space, aggregation, remnant of beeswax, length, height, the material and nature of the nest sites. In this study, many observations, investigations and experiments on nest site selection of this species were carried out to test these hypotheses. The

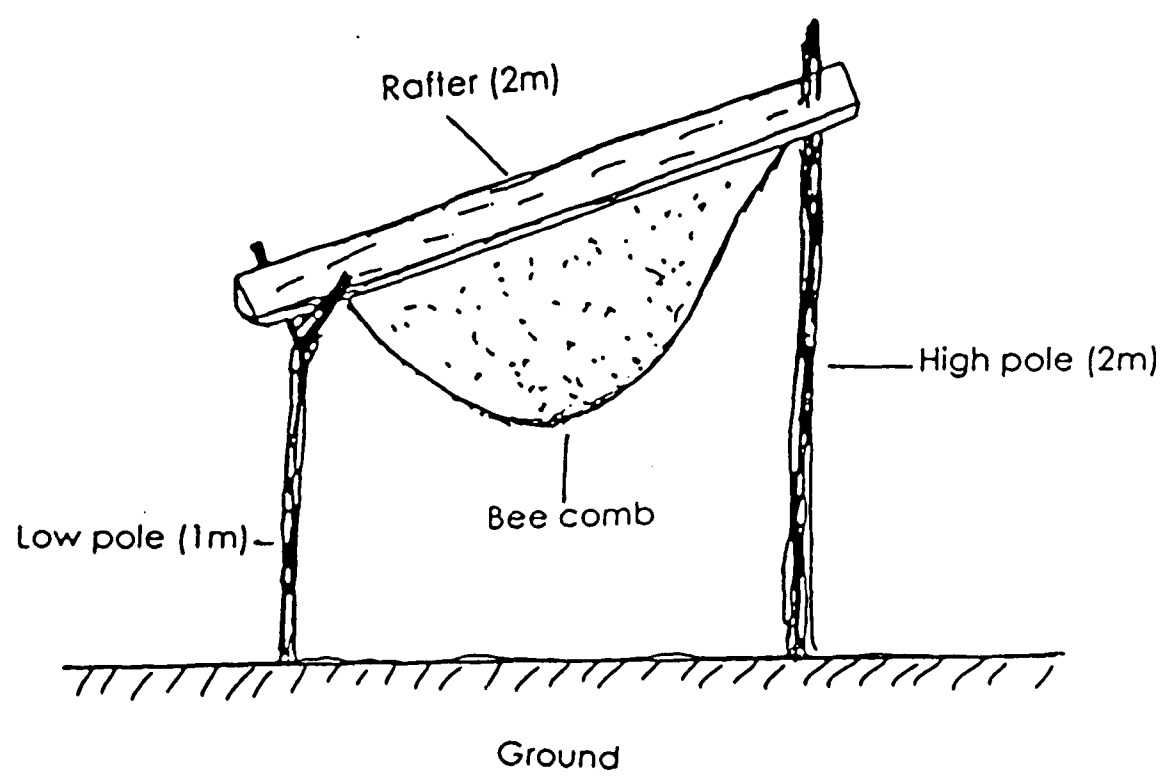


Figure 1: Diagram of rafter and *Apis dorsata* comb.

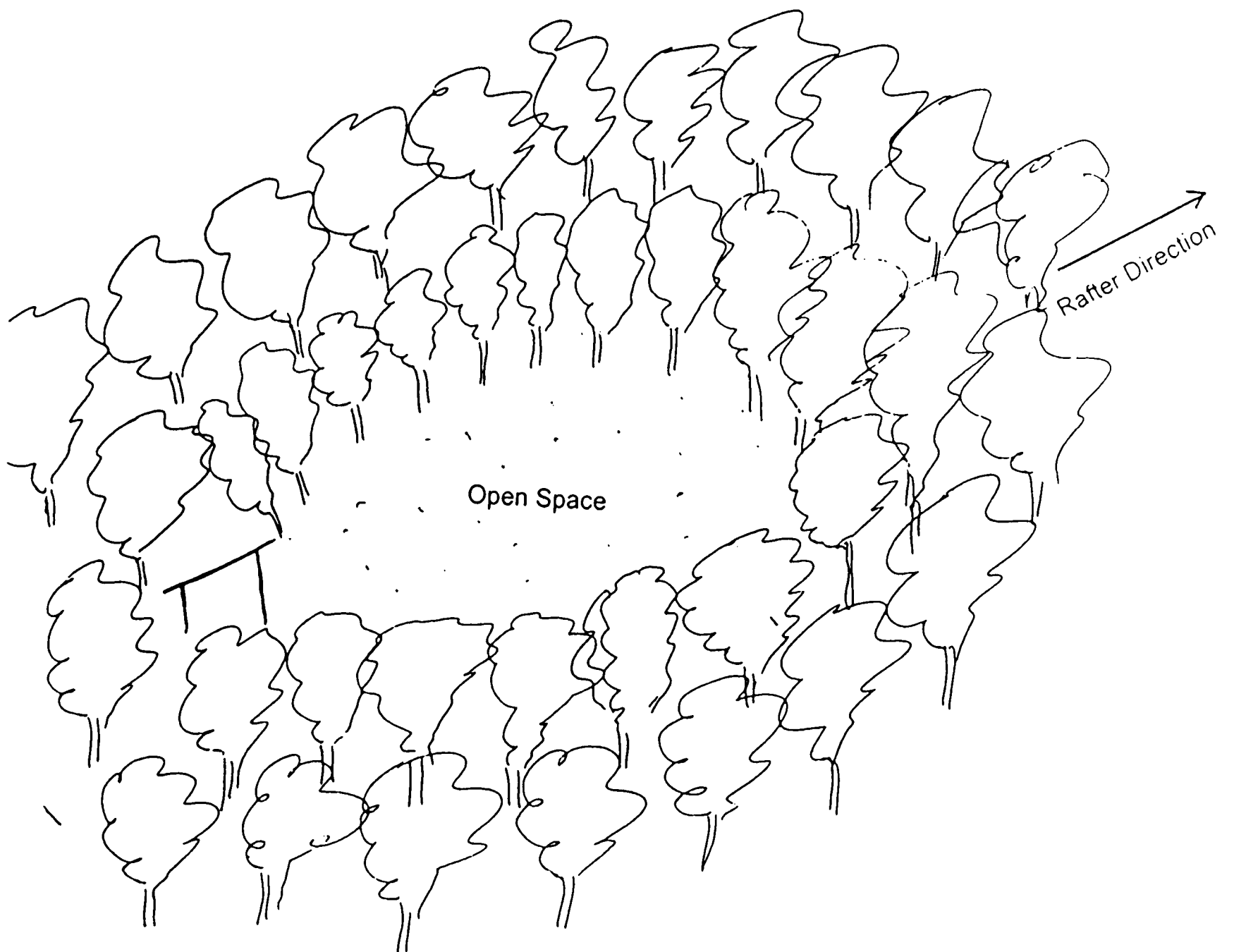


Figure 2: A rafter is erected at the edge of an open space in the forest.

- The higher point of the rafter is directed to the open space.
- The slope of the rafter was determined by measuring the distance between the two poles (b), which was then divided by the rafter length between the two poles (a). The slope (α) was calculated from $\cosine \alpha = (b/a)$.
- The open space in front of the rafter was considered to be a circle and was characterized by its diameter .

objective is to determine what properties of the nest sites are (and are not) nest site selection criteria in the Asian giant honey bee, *Apis dorsata*. The results will allow beekeepers to make their nest sites more attractive to bee swarms.

Materials and Methods

Study site:

This study was carried out in the *Melaleuca* forest of Song Trem farm, Thoi Binh district (longitude 104°59' E and latitude 9°27' N), Ca Mau province, southern Vietnam mainly from March 2001 to September 2002, although some data collected in 1993 - 1994 (Tan *et al.* 1997) were included in the analysis. There are two seasons in the year in the *Melaleuca* forests: the dry season from December to April and the rainy season from May to November. *Melaleuca cajuputi* (Myrtaceae) is the dominant plant species and its flowers are a very good source of nectar and pollen. The tree can bloom from December to September but the two flowering peaks are from February to April and from June to August. The bees start to arrive in the area in December, peak in February or March and stay until May. In May, a major part of the colonies fly away, but again start to return in June and peak in July. After that the colonies depart again in late September. At other times of the year, some *A. dorsata* colonies can be found in the *Melaleuca* forests, but honey is stored in small amounts.

Scout bee observations:

Observations of scout bees were made at eight nest sites. Their behaviour was observed and bee numbers present were counted every five minutes. In some cases a video recording was made until the nest site was occupied or abandoned.

Investigations of nest site properties:

In total, the direction, diameter, slope to the horizontal, and area of the open space in front of 507 occupied and unoccupied nest sites were recorded. The direction of the nest site was determined using a compass. The slope of the nest site was calculated by measuring the distance between the two poles (b), which was then divided by the nest site length between the two poles (a). The slope (α) was calculated from $\cosine \alpha = (b/a)$. The open space in front of the nest site was considered to be a circle and was characterised by its diameter.

Experiments on nest aggregation:

Following the results of the above study, another experiment was carried out. At each of ten similarly-sized open spaces (8 - 9 m diameter), four nest sites were erected: one facing between NW - NE, one NE - SE, one SE - SW and the other SW - NW. The experimental nest sites were 2 m long, 13 -14 cm in diameter and erected at a slope of 30 degrees. All of the open spaces were located in a forest plot of about one hectare and thus all were easily in the range of searching bees (Figure 3). The bee occupations were recorded every one or two weeks for the three following seasons; i.e. the rainy season of 2001, the dry season of 2002 and the rainy season of 2002.

Relationships among the size of A. dorsata colonies and the nest site diameter:

Data on the colony width, height and honey storage in Chapter 2 were used to analyse the relationships among the sizes of the comb. In this study, the widths of sixty three colonies and the corresponding diameters of their nest sites were measured to analyse the relationship between the width of the colony and the diameter of the nest site.

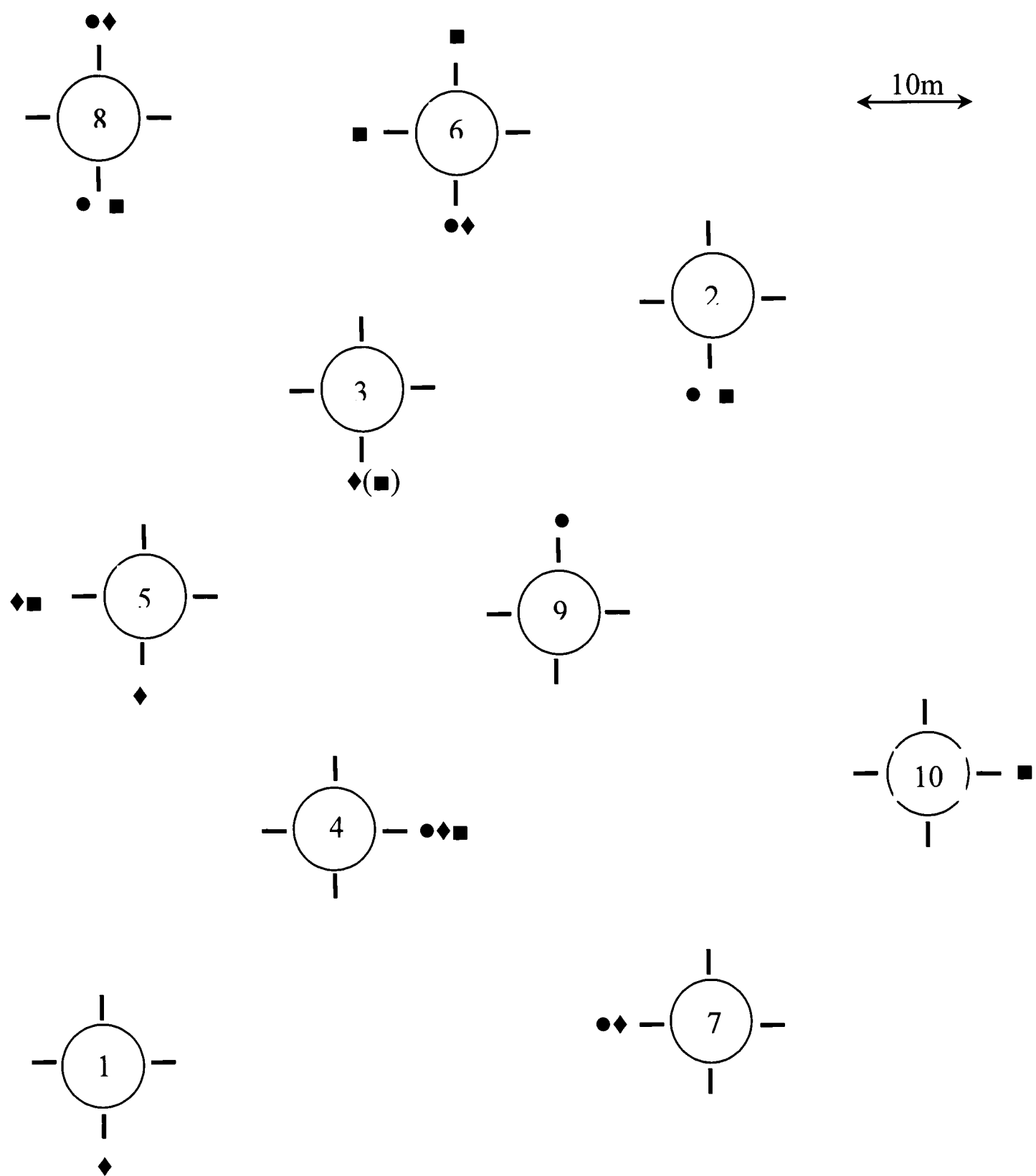


Figure 3: Relative positions of 40 experimental rafters and 10 open spaces in a plot of *Melaleuca* forest and their occupations by bees.

At open space 3, a colony occupied in dry season 02 and stayed until rainy season 02.

Legends: ○ open space — rafter

●, ◆ and ■ occupation by bees in rainy season 01, dry season 02 and rainy season 02, respectively.

Statistics and graphics:

Discriminant Analysis and Logistic Regression were applied to analyse the effects of properties of nest sites on the occupation of nest sites by bees. Chi-square tests were used for comparisons of proportions, binomial test and testing for goodness of fit. If the comparison of more than two proportions was significant, a Tukey-type multiple comparison test was applied to compare pairs of proportions (Zar 1999: 559 - 561). To test the relationship between two variables of *A. dorsata* nests, Pearson's correlation was used. Statistics were processed using SPSS Package Release 9 and Minitab Package Release 12.21 and graphics were drawn by Microsoft Excel 2002 SP-1. All tests were two tailed.

Results

Exploration of potential nest sites by A. dorsata scout bees

Six nest sites were explored by scout bees (less than 10 individuals) for a period of time (as long as 135 minutes), but were not occupied by the swarms. By contrast, a few scout bees explored two other nest sites; the number increased to tens and hundreds and thousands and, ultimately, each nest site was occupied with a swarm.

Scout bees initially explored a nest site, repeatedly landing and taking off. They spent some time crawling on it but mostly they flew up and down the length of the nest site on both sides. The scouts also flew out to check the immediate vicinity.

The effects of the direction, diameter, slope and open space in front of the nest sites on the occupation by bees

Table 1 show that the occupation rate of nest sites was 46% ($n = 507$) on average. Beekeepers erected their nest sites facing all directions and the directions of the nest sites do not affect the occupation of the nest sites by bees (Discriminant Analysis, $F_{1,505} = 0.795$, $P = 0.373$). The diameters of the nest sites ranged from 9 to 17 cm and they affect very strongly the bee occupation ($F_{1,505} = 22.067$, $P \ll 0.001$). The investigated nest sites were sloping from 6 to 39 degrees to the horizontal and their slopes also affect strongly the occupation of the nest sites by bees ($F_{1,505} = 7.573$, $P = 0.006$). The open space in front of the nest sites was a categorical variable and coded 1 or 2 if its diameter was not larger or larger than 25 m, respectively. The bee occupation of the nest sites is very strongly affected by the size of the open space ($F_{1,505} = 35.888$, $P \ll 0.001$). However, in the case the open space in front of the nest site was not larger than 25 m, it was a continuous variable, ranging from 3 to 25 m; and its effect on the bee occupation is not significant ($F_{1,460} = 0.248$, $P = 0.619$).

The chance of a nest site to be occupied or unoccupied by a bee swarm is predicted by its discriminant score (D) as the following linear equation (Logistic Regression Analysis):

$$D = -6.103 - 0.0000068 * \text{DIRECTION} + 0.238 * \text{DIAMETER} + 0.037 * \text{SLOPE} + 1.963 * \text{OPENSOURCE}$$

If $D < 0.5$, the nest site is predicted not to be occupied by a bee swarm.

If $D > 0.5$, it is predicted to be occupied by a bee swarm.

Table 1: The effects of the direction, diameter, slope and open space in front of the nest sites on the occupation by bees. In total, data on 231 occupied and 246 unoccupied nest sites were collected.

	Range	Mean	SD	Discriminant Analysis
<i>Direction (degrees)</i>				
Occupied	5 - 280	84.4	39.7	F _{1, 505} = 0.795; P = 0.373
Unoccupied	0 - 345	88.1	51.4	
<i>Diameter (cm)</i>				
Occupied	10 - 17	12.7	1.5	F _{1, 505} = 22.067; P << 0.001
Unoccupied	9 - 17	12.1	1.5	
<i>Slope (degrees)</i>				
Occupied	6 - 36	24.3	6.1	F _{1, 505} = 7.573; P = 0.006
Unoccupied	6 - 39	22.7	7.0	
<i>Open Space Diameter</i> (coded 1 if ≤ 25 and 2 if > 25 m)				
Occupied		1.17	0.38	F _{1, 505} = 35.888; P << 0.001
Unoccupied		1.02	0.15	

Moreover, the correlation coefficients between the discriminant score and the three variables: slope, diameter and open space in front of nest sites are 0.360, 0.614 and 0.783, respectively. Therefore, among these three properties of nest sites, the occupation of the nest site by a bee swarm depends most on the open space and least on the slope.

In traditionally practical beekeeping of the study area, the diameter and the slope of the nest sites can be divided into some ranges and the corresponding occupation rates are shown in table 2.

The effects of the nest site aggregation and the beeswax of the previous colony on the occupation by bees

Results are shown in Figure 3. There were a total of 22 occupations on the nest sites during the three continuous seasons. In open space 3, a colony had occupied in the dry season and stayed until the rainy season 2002. In the rainy season 2001 there were five isolations and one aggregation, in the dry season 2002 six and one; and in the rainy season 2002 also six and one. In total, 17 cases of isolation and 3 cases of aggregation were observed. Chi square test (the expected numbers were 12.8 and 7.2, respectively) shows that there is no statistical difference between isolation and aggregation in nesting ($\chi^2 = 3.828 < \chi^2_{0.05} = 3.841$; DF = 1; P > 0.05).

Figure 3 also demonstrates the effects of remnants of beeswax on the bee occupation. At the beginning of the dry season 2002, there were seven nest sites with, and 33 nest sites without, beeswax from the previous colonies. In that season, four colonies

Table 2: Some ranges of the diameter and slope of the nest sites and their corresponding occupation rates.

	No. nest sites	Occupation (%)	Conclusion
<i>Diameter (cm)</i>			
9 - 10	54	28 a*	$\chi^2 = 20.289$ DF = 3 P<0.001
11 - 12	215	40 ab	
13 - 14	188	51 bc	
15 - 17	50	66 c	
* Two occupations with different letters are significant: a & b, P<0.05; a & c, P<0.01			
<i>Slope (degrees)</i>			
6 - 13	36	33 ab	$\chi^2 = 17.512$ DF = 4 P = 0.002
13 - 20	102	37 a	
20 - 27	210	44 ab	
27 - 34	127	60 c	
34 – 39	30	33 abc	
		b & c, P < 0.05; a & c, P < 0.01	

occupied the nest sites with beeswax and other four colonies occupied the nest sites without beeswax. Then at the beginning of the rainy season 2002, numbers of nest sites with beeswax and without beeswax became 11 and 29, respectively. After that, four and three colonies occupied the nest sites with and without beeswax; respectively. Therefore, the occupation rates on the nest sites with and without remnants of beeswax were a total of 8/18 and 7/62, respectively, which are statistically significant ($\chi^2 = 6.04$; after Yates's correction $\chi^2 = 4.55$, DF = 1, $P < 0.05$). The results also re-confirm that the direction of the nest site does not affect the bee occupation. The numbers of occupations on nest sites facing North, East, South and West were 9, 5, 4 and 4, respectively. They are not significant ($\chi^2 = 0.561$, DF = 3, $P > 0.05$).

Relationships among the width, height, honey storage of A. dorsata colonies and the nest site diameter

As shown in Chapter 2, the comb of *A. dorsata* is more or less semicircular. The width (which corresponds to the line of attachment to the nest site) is greater than the height, ranging from 43 to 162 cm ($n = 158$). The height of the comb was from 23 to 90 cm ($n = 146$). The relationship between the height and the width of *A. dorsata* comb is strongly positive ($r = 0.721$, DF = 144, $P < 0.001$) as shown in Figure 4. Honey was usually stored in the highest part of the comb, and ranged from 0.5 to 15.7 kg per harvest ($n = 152$). Figure 5 shows that there is also a strongly positive relationships ($r = 0.662$, DF = 150, $P < 0.001$) between the width and the stored honey of a bee comb. There is no relationship between the diameter of the nest site and the width of the bee comb ($r = -0.065$, DF = 61, $P = 0.615$) as shown in Figure 6.

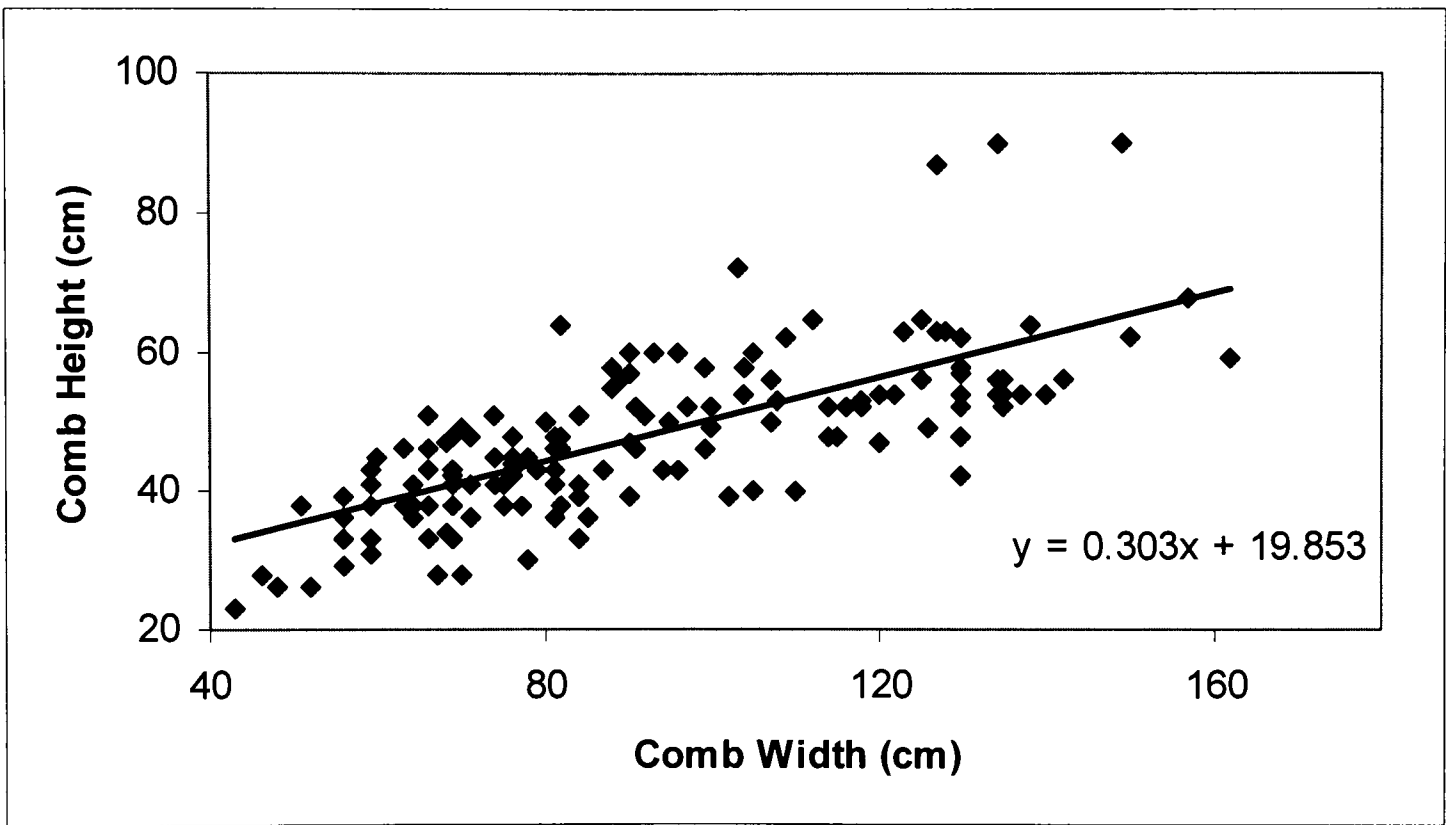


Figure 4: Relationship between the width and the height of the colony
($r = 0.721$, $DF = 144$, $P < 0.001$).

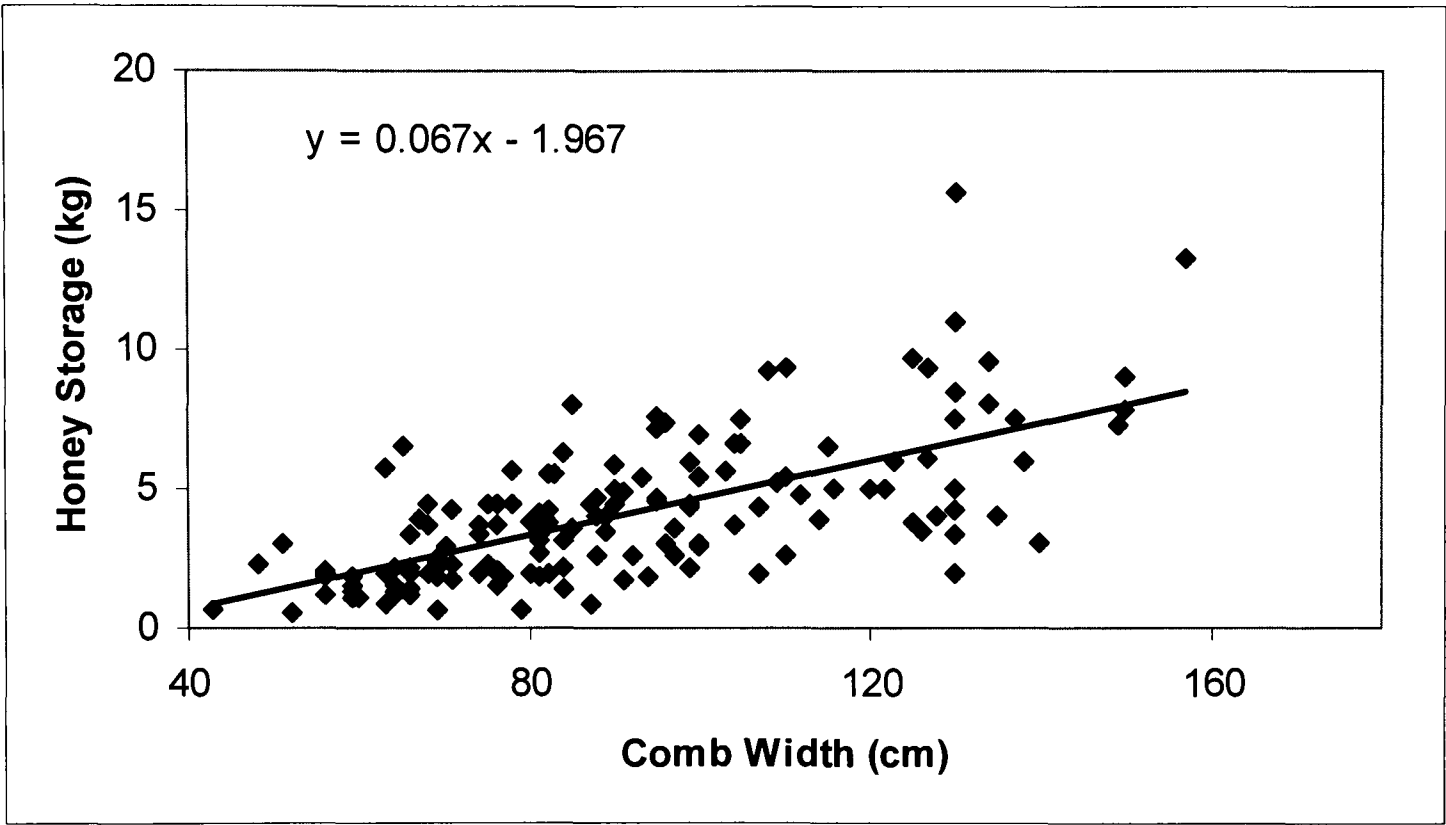


Figure 5: Relationship between the width of the colony and the honey storage
($r = 0.662$, $DF = 150$, $P < 0.001$).

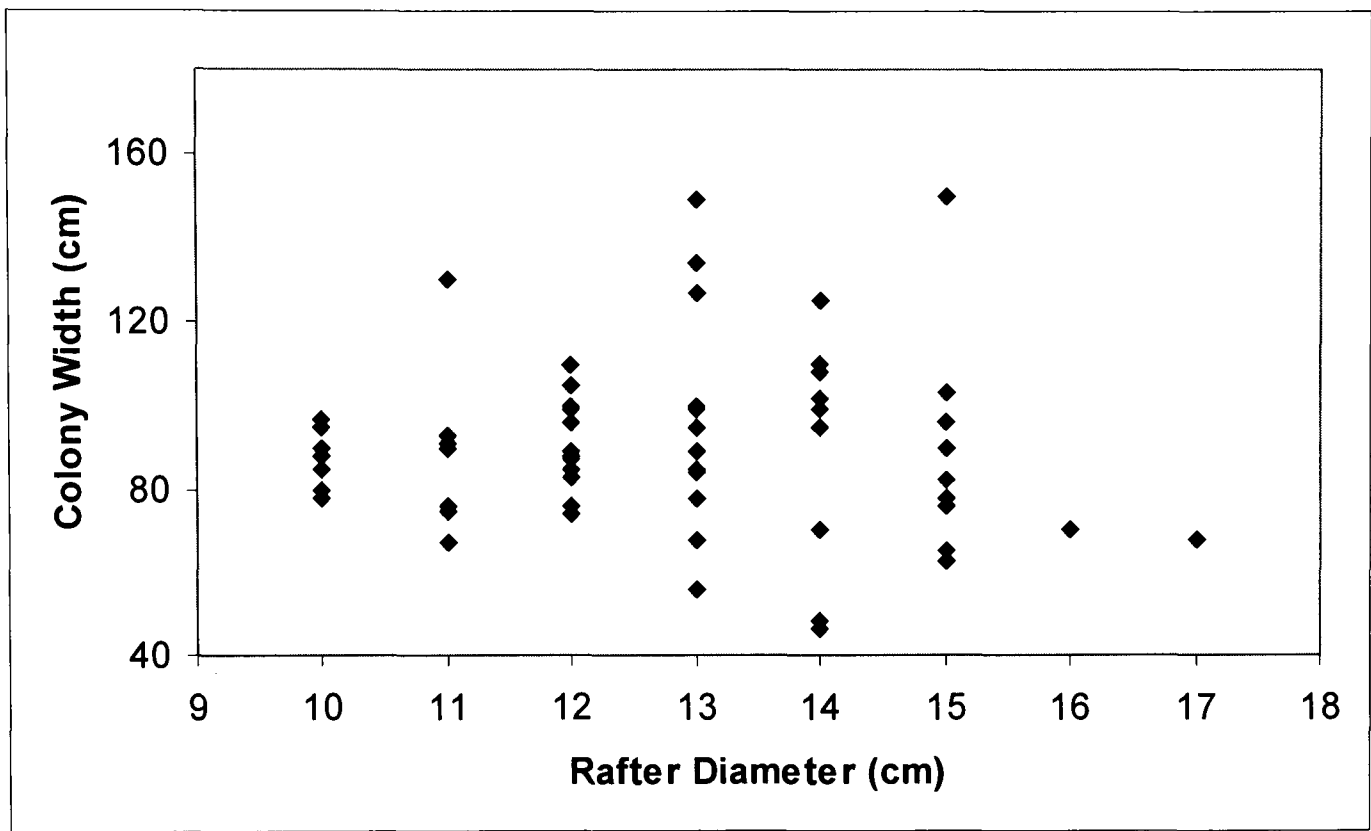


Figure 6: Relationship between the diameter of nest site and the width of colony
($r = - 0.065$, $DF = 61$, $P = 0.615$).

Discussion

When *A. dorsata* swarms arrive in an area, they commonly settle on trees for as long as a few days. This allows scout bees to explore and select the best new house among many choices.

In the European honey bee, *A. mellifera*, scout bees explore potential nest sites before occupation and the best nest sites are usually visited by more scouts than the other nest sites (Lindauer, 1961; Seeley, 1977; Camazine *et al.*, 1999; Seeley & Burman, 2001). Although the preferred properties of a nest site for *A. dorsata* are different from *A. mellifera*, they demonstrate similar behaviours in the selection of potential nest sites to ensure colony development and survival. Before occupying a nest site, scout bees explored it thoroughly and it appears from this study that the decision to occupy a nest site is related to the number of scout bees inspecting it.

Criteria in nest site selection of A. dorsata

Bees tended to choose strong nest sites: the bigger the rafter, the higher the occupation rate. The smallest diameter the bees will accept is not known, but the nest site should be able to bear the weight of a colony at its full development. In my research area, beekeepers seldom make their rafters with a diameter of less than 9 cm. In respect of the locally traditional knowledge, *Melaleuca* trees of this size are maybe at the minimum strength necessary for a nest site. Reddy & Reddy (1989) found that the *A. dorsata* nest density decreased correspondently with the decrease in the diameter of tree branch, and no nests were found on branches with a diameter of less

than 6 cm. In natural nest sites, the relationship between support strength and occupation rate is positive up to a certain limit. Very much stronger nest sites, that could easily bear the biggest colonies, are not preferred. To study the relation between the weight of the colony and the strength of the nest site, the correlation between the width of colonies and the diameter of nest sites was tested because the width, the height and the honey storage of the colony were positively correlated. There is no correlation at all as shown in Figure 6. Both the big and the small colonies prefer the strong nest sites for their future full development. In the European honey bee, *A. mellifera*, Seeley (1977) found that the preference of nest cavity volume was independent of the swarm size. In the cavity-dwelling ant *Leptothorax curvispinosus*, Pratt & Pierce (2001) discovered a slightly positive relation between colony size and volume of nest.

Apis dorsata colonies usually build nests on sloping branches of trees but no information on preferred slopes have been collected. Morse & Laigo (1969) and Chakrabarti & Chaudhuri (1972) reported that when trees were used, bees built their combs on slanting branches. Ahmed & Abbas (1985) found 39 of 60 *A. dorsata* colonies on horizontal branches of trees and the remaining colonies on slanting branches. According to Reddy & Reddy (1989) nests are not commonly found on vertical tree branches. In my study, the bees prefer nest sites with a slope between 27 and 34°, possibly because they find it easier to fly into the open air and to store honey. However, when it is too high the comb is liable to fall off.

Ruttner (1988) and Crane (1990) write that there should be a clearly open way or an open space in front of the comb so that the bees can fly out into the open. In the

Melaleuca forest, nest sites with a very large open space in front of them (its diameter is larger than 25 m) have higher occupation rate. Some explanations for this may be that flight access is easier; the bees avoid predators on nearby trees or simply that these sites are more easily discovered by scout bees. Very large open spaces result from forest fires or from felling trees for wood and agriculture. In addition, nest sites are sometimes placed at the edge of the forest and these open spaces are also considered as very large.

In addition to the diameter, the length of the nest site is probably important. Nest sites should be long enough for a full development of the colony. Figure 4 shows the maximum width of an *A. dorsata* comb was 162 cm. Therefore, it is suggested that in the range of less than 162 cm, the bee swarms prefer the longer nest site. However, above this length limit which could easily accommodate the colony, no preference is shown. According to Seeley & Morse (1978), a temperate *A. mellifera* swarm selects a cavity of 40 to 100 litres because it is large enough to accommodate the colony at full development and it is small enough for bees to regulate the nest temperature. Meanwhile, *A. dorsata* in the tropics selects the support bigger than 9 cm and about 2 m long to bear its colony at full development and honey storage; very big and very long supports are also selected.

It is known that the Asian giant honey bee, *A. dorsata* migrates seasonally (reviews in Ruttner 1988 and Crane 1990; Thapa *et al.* 1999; Neumann *et al.* 2000; Paar *et al.* 2000). When plants stop flowering, bee colonies abscond and when they bloom again, the bee swarms come back, and then many supports are re-occupied. The results in Figure 3 demonstrate this phenomenon: among total 22 occupations on the nest sites

eight were re-occupied. Why are some nest sites of the previous colonies reoccupied? This behaviour of *A. dorsata* is still not yet understood. I propose three hypotheses for this phenomenon. First, they are reoccupied by the same colonies. Second, they are reoccupied because they are the favoured nest sites that any colony prefers. And third, they are reoccupied because the remnants of beeswax present that the sites have been successfully occupied previously. Moenkkonen *et al.* (1999) reported that an animal could use other cues in habitat selection because it reduced the cost of finding a nest site. In this study, because all experimental rafters were standardised, the second hypothesis could be rejected. Therefore, it is possible that the nest sites are reoccupied by the same colonies genetically and/or behaviourally (first hypothesis), or by the remnants of beeswax, the signal for a good nest site (third hypothesis).

Thapa *et al.* (1999) analysed the DNA of worker bees in colonies that had occupied every year, a window frame of a high building in Thailand. The results showed that there was no relationship among the colonies and it seemed that the bees did not return to their natal nest after migration. In contrast, Neumann *et al.* (2000) carried out similar work at five nest sites in Malaysia. At one nest site, they found the colony occupying in 1997 to be the same colony (and same queen) as that occupying in 1995; and at the other two nest sites they found two colonies in 1997 to be daughters of the colonies in 1995. In addition, Paar *et al.*, (2000) studied eight nesting sites in India. At one site, they found the same colony led by the same queen returned twice. At other two nesting sites, the same colonies with the same queens also returned once. If home site fidelity is the behaviour of the species, it is possibly still affected by two factors. First, the ratio of the arriving bee swarms to the available nest sites in the area: the more swarms or the fewer nest sites there are, the lower the chance of reoccupation by

the same colony. And second, the returning time of the bee swarm: if it returns too late, its home nest site may have been occupied by another swarm. Nevertheless, according to Neumann *et al.* (2000) and Paar *et al.* (2000), a few colonies must have returned to their home nesting places. How had these colonies identified their natal nest sites? I propose two hypotheses. First, genetically, the bees locate the position of their home nest site. Two, chemically, the bees can detect their substances on the nest site when they return. These hypotheses should be tested in the future. In *A. mellifera*, Visscher *et al.* (1985) reported that bee swarms preferred previously occupied cavities, too.

The properties which do not seem to be important in selection of A. dorsata

This study demonstrates that the direction of a nest site was not a criterion in nest site selection by *A. dorsata*. In the *Melaleuca* forest of Southern Vietnam, the rafters are less than 2 m high from the ground level and the nests are protected from winds by nearby vegetation. Therefore winds do not strongly affect the combs. Moreover, wind directions change during the year: they usually come from the Northeast (from December to April) then from the Southwest (from May to November); and sometimes from the East and the West. If the nest sites are not affected by the winds, the bees may build their combs facing all directions. Indeed, according to my personal observations on some big trees and projecting rocks which are usually protected from strong winds, *A. dorsata* combs face many different directions. The preference for certain directions by *A. dorsata* colonies as reported earlier in some places might be due to the direction of strong winds in these locations. For example, Nandi & Mahabal (1974) reported nesting behaviour in relation to local wind directions.

The sun has been reported as being important in nest site selection by honey bees. Indeed, Seeley & Morse (1978) report that swarms of *A. mellifera* prefer nest sites with the entrances facing the South, from which they can receive the warm sunshine. This is, however, for the bees in the temperate zone of the northern hemisphere. In the tropics, it is not known whether bees like or dislike direct sunshine. But, in the *Melaleuca* forest of Vietnam, the sun moves overhead from the South direction to the North during December to June and *vice versa* during June to December. Hossain *et al.* (1992) found that the entrances of 56% of *A. cerana* nests in Chittagong region of Bangladesh faced southward because the cold winds came from the North.

It has been reported that many *A. dorsata* colonies aggregate on the same tree, building or projecting rock (Morse & Benton 1967; Seeley *et al.* 1982; Reddy & Reddy 1989; reviews in Ruttner 1988 & Crane 1990). However, the results in my experiment show that the presence of other colonies was not a criterion in nest site selection by *A. dorsata*. As studied in many other animals, if the advantages of aggregation outweigh the disadvantages, we may expect that the former is the normal behaviour. In *A. dorsata*, the advantages could be an inter-colony defence and the multiple mating of a virgin queen. In fact, when an *A. dorsata* colony was provoked to attack an enemy, nearby colonies on the same tree or rock could take their part (but Seeley *et al.* (1982) did not observe this). Living in groups of many colonies, the mating of a virgin queen with drones from other colonies is perhaps easier. Moritz *et al.* (1995) and Oldroyd *et al.* (1996) found that *A. dorsata* exhibited the highest polyandry of honey bee species and Tan *et al.* (1999) showed that *A. dorsata* virgin queens perform multiple mating flights. It is possible that because *A. dorsata* nests in

the open air and often migrates in the tropics and subtropics of Asia, the species faces many predators and challenges in their environment. The queen performs multi-mating flights and mates with many drones to produce a genetically diverse worker population.

However, the two advantages are not so clear. An *A. dorsata* colony is very defensive and attack by hundreds of hornet-sized worker bees can chase away most mammals. Seeley *et al.* (1982) report that, unlike *A. cerana*, which nests in cavities, or *A. florea*, which nests in dense bushes, *A. dorsata* nests in the open air because of its effective defensiveness. In addition, living in groups of colonies does not necessarily increase the chance of multiple mating because the queen and/or drones of *Apis* can fly out for a long distance to mate; e.g. 1 - 17 km in *A. mellifera* (Peer, 1957), up to 500 m in *A. cerana* (Punchihewa *et al.*, 1990), and at least a few hundred metres in *A. dorsata* (Koeniger *et al.*, 1994b). Otherwise, disadvantages in aggregation of many *A. dorsata* colonies are recognisable. The first is competition for food. Plants usually flower seasonally and the lack of food is a serious problem at the end of the flowering season. Tropical honey bees usually abscond and migrate; the shortage of food at the end of flowering must be a reason. The second disadvantage is the lack of nest sites. Competition for nest sites is common in many animals and this could occur when a large number of *A. dorsata* colonies arrive in an area. A third disadvantage to living in large groups is the transmission of diseases and parasites.

Comparing the advantages (benefits) with the disadvantages (costs) of aggregation by *A. dorsata* colonies, a normal behaviour of aggregation of *A. dorsata* colonies would not be expected. In fact, although aggregation of *A. dorsata* is frequently reported

and also observed by myself, separate nesting of *Apis dorsata* is also very common in the Philippines (Morse & Laigo 1969), Sri Lanka (Koeniger & Koeniger 1980), India (Ahmed & Abbas 1985) and some other countries (reviews in Ruttner 1988). If the crucial properties of the nest sites selected by *A. dorsata* swarms are considered, suitable nest sites are limited. First, the support must be strong and long enough. Second, the nest site must have a very clear way to the open air. And third, it should not be exposed to very strong winds. Because nest sites with such properties are not very common and because the number of bee colonies is perhaps much more than that of suitable nest sites, it has been easily found in nature that many *A. dorsata* colonies do aggregate on a tree, rock or building. In this study bee swarms were given the choice of aggregation or isolation and the result shows that neither aggregation nor isolation was preferred. It might be that the different ecological conditions result in the different nesting behaviours of *A. dorsata*. When *A. dorsata* colonies nest at exposed, high nest sites, they are aggregative and when nesting in well hidden, low places such as the *Melaleuca* forest, they are isolated. However, until a similar experiment is carried out in those places, my study suggests that aggregation may not be a normal behaviour of *A. dorsata* colonies. Aggregation behaviour in nesting has not been reported in other honey bee species.

In my research area, trees are about 15 cm in diameter and have no big branches. Fallen and slanting trees are occasionally present. High man-made constructions are rare. Therefore, the bee swarms have no option except to choose man-made rafters for nesting. In other places where there are trees, rocks and man-made constructions (i.e., water towers, monuments and the eaves of buildings), *A. dorsata* colonies build their

nests on any supports regardless of whether they are natural or man-made. Table 3 shows the numbers of *A. dorsata* nests on natural and man-made supports.

With regard to the height of the nest sites, many researchers (reviews in Ruttner 1988) found that *A. dorsata* colonies build their nests on very high supports. Some have proposed that this could be a normal behaviour of the species to avoid terrestrial predators. However, nesting on emergent tall trees or rocks can expose them to strong winds and many flying predators; such as, birds, bats and wasps. If we consider the criteria in nest site selection of the species again, low trees are not usually suitable. In urban areas, there are both high and low nest sites available but colonies on the low nest sites are usually disturbed or destroyed by humans; as a consequence, nesting by *A. dorsata* on the high nest sites is common. On the contrary, only low nesting *A. dorsata* colonies are present in my research area and some other areas (Chakrabarti & Chaudhuri 1972): the reason is that there are no high trees with big branches for bees to nest on. Ruttner (1988) review shows that colonies on both high and low nest sites are usually reported in many other areas. Therefore, the height of the nest site might not be a criterion in nest site selection by *A. dorsata*.

Table 3: Number of colonies/nesting sites recorded on natural and man-made supports.

Authors	Natural supports	Man-made supports
Nandi & Mahabal (1974)	31 colonies	113 colonies
Deodikar <i>et al.</i> (1977)	1018 colonies	843 colonies
Reddy (1983)	140 colonies	200 colonies
Reddy <i>et al.</i> (1986)*	2 nesting sites	2 nesting sites
Reddy & Reddy (1987)*	2 nesting sites	2 nesting sites
Venkatesh & Reddy (1990)*	4 nesting sites	4 nesting sites
Reddy & Reddy (1993)*	3 nesting sites	7 nesting sites

**Note: The number of colonies at a nesting site was not mentioned by these authors*



Plate 1: A nest site is being checked by some scout bees (see the bees in the next figure).



Plate 2: The scout bees are checking the nest site.

CHAPTER 4

POLLINATION ECOLOGY OF *APIS DORSATA* IN THE *MELALEUCA* FOREST

Introduction

The *Melaleuca* forests of Vietnam are located in the tropical monsoon area of Asia. They are named the *Melaleuca* forests because the dominant (more than 90%) plant species is *Melaleuca cajuputi* (Myrtaceae), which is suited to acidic soil in coastal areas (Brinkman & Xuan 1991). The second most abundant and important plant to honey bees is the palm tree, *Nypa fruticans* (Thunb.) Wurmb. (Palmae), which usually grow along the banks of the river and the canals.

The forests supply local people with many products: wood for fuel and construction materials, shrimp and fish as food, cajuput oil as medicine, and honey as both food and medicine. The forests are also important in environmental protection, e.g. in the regulation of water and climate and reclamation of acidic soil, and also by providing habitat for wildlife (Brinkman & Xuan 1991; Crane *et al.* 1993; Mulder 1995). They once covered a surface area of 250,000 ha, but now only 70,000 ha remains because there is an increasing need for land for homes and farming. However, in recent years, the area of replanted *Melaleuca* forests has tended to increase due to a large demand for *Melaleuca* wood for construction.

Floral diversity in the *Melaleuca* forest is great. A survey by Hung & Tan (1999) identified 228 plant species belonging to seventy six families in the *Melaleuca* forest of Ca Mau province. According to Duc (1991), vertebrate fauna is also abundant;

many mammals and birds have been identified but some species have been disappearing year after year. Information on insects in the *Melaleuca* forest is lacking. In a national workshop on the rehabilitation and management of the *Melaleuca* forest, Le Dien Duc (1991), on behalf of the organising committee wrote “no information is available on insect fauna supported by the *Melaleuca* canopy. It is clear that this is still unknown to science”.

Melaleuca flowers are a very good source of nectar and pollen for local honey bees (the Asian giant honey bee, *Apis dorsata* and the two dwarf honey bees, *A. florea* and *A. andreniformis*) as well as many other insects. When *Melaleuca* flowers bloom thousands of migratory *A. dorsata* swarms arrive, and when the flowers finish the bee colonies depart (Crane *et al.* 1993; Mardan 1993; Chinh *et al.* 1995a, 1995b; Mulder 1995; Tan & Chinh 1995; Chapters 3 & 6 of this thesis).

Because the preservation of *Melaleuca* forests is necessary for future sustainable development in Vietnam, the plants and insects in the forests, as well as their relationships, should be well understood. This chapter is aimed at investigating the following:

1. the rewards of pollen and nectar of the two main bee plants, *Melaleuca cajuputi* Powell (Myrtaceae) and *Nypa fruticans* (Thunb.) Wurmb. (Palmae);
2. the insect visitations to flowers of *Melaleuca cajuputi* and *Nypa fruticans*;
3. the daily flight activities of *A. dorsata* colonies in relation to the rewards of *Melaleuca* and *Nypa* flowers.

Materials and Methods

Study site:

The study was carried out in the forestry farm of Song Trem, Thoi Binh district (Longitude 104°59' E and Latitude 9°27' N), Ca Mau province, Vietnam from March 2001 to June 2002. The farm covers an area of 10 079 ha, of which 6500 ha is covered with *Melaleuca* forest. The dry season of the year is from December to April and the rainy season from May to November. In dry days of April and May 2001, the temperature was about 28 - 30°C at 06.00 h; it increased, peaked at 35 - 37°C at 14.00 h and then decreased to 30 - 32°C at 18.00 h. Relative humidity varied conversely, being higher than 90% at 06.00 h, 60 - 70% at 14.00 h and 80 - 90% at 18.00 h. In January 2002 the average temperature was about five degrees lower but the daily fluctuation was the same.

Reward of Melaleuca cajuputi flowers:

Melaleuca flowers can bloom from December to September but the two flowering peaks are from February to April and from June to August. Flowers are grouped into inflorescences comprising from 10 to 50 small flowers. Initial study in April and May 2001 showed that a *Melaleuca* tree can flower at any time of the day but more flowers start early in the morning. Most trees and almost all the flowers of a tree release pollen but not all of them secrete nectar. A flower lasts for about five days and its nectar volume mainly varies with the time of day. The collection of pollen and nectar reward data was very difficult due to heavy rains in the rainy season. Therefore, the data for this study was collected in the dry season 2002 on five *Melaleuca* trees, which were near to the farm office and secreted nectar. The measurements were

carried out every two hours (06.00 h - 18.00 h) on flowers which started opening early in the morning.

Pollen release was quantified following the method of Stone *et al.* (1996) with some modifications. It is as follows:

Pollen release of *Melaleuca* flowers was quantified using the relative abundance of pollen available on the inflorescence surface every two hours throughout the duration of flowering. Each inflorescence (sampled once only) was rolled lightly across the adhesive side of a piece of clear adhesive tape. This piece of tape was then stuck to a glass slide (1 inch x 3 inch) and kept until pollen grains were counted. For counting, the piece of tape on the slide was cut into twelve parts, each of which was placed over a haemocytometer and the number of pollen grains was counted using a microscope. The data recorded were the average number of pollen grains counted on a square millimetre of the haemocytometer for a tree at a given time.

Nectar volume in all (10 - 50) flowers of the inflorescence from each tree was measured using a micropipetter for disposable capillary pipettes (BRAND Micro Pipetter Cat.-No. 25900, Rudolf Brand GMBH + Co., Germany). The data recorded were the average volume in a flower of a tree at the given time. Sugar content of the nectar was measured using three different hand-held refractometers (N-1E for sucrose range 0.0 to 32.0%, N-2E for range 28.0 to 62.0% and N-3E for range 58.0 to 90.0%, Atago Co. Ltd., Japan) which are suitable for measuring different sugar contents on flowers during the day.

Reward of *Nypa fruticans* flowers:

Nypa fruticans palms usually flower from December to June. Explorative investigations also show that a flower of *Nypa fruticans* starts opening before dawn and finishes by sunset. Therefore, in 2002 pollen release of ten *Nypa* trees near to the farm office was quantified using the relative abundance of pollen available on the inflorescence surface every hour from 05.00 h to 18.00 h. The method described above for *Melaleuca* was applied.

Pollen grains of some *Melaleuca* and *Nypa* flowers were collected in the morning to measure their sizes (to be nearest 2.4 micrometer) using a binocular-stereo microscope (400 x) with an eye piece scale and an eye piece graticule.

Insect visitations to flowers:

On *Melaleuca* flowers, the investigations were carried out on fourteen groups of inflorescences. Every hour throughout the flowering duration, insect visitations were quantified by counting the number of insects on the group of selected inflorescences for fifteen minutes. The insects on flowers were captured using a hand net and brought to the Oxford University Museum of Natural History for identification. *Nypa* pollen grains are very attractive to insects and many are observed collecting pollen on opening inflorescences at all times of the day. Therefore, insect visitation was quantified by counting numbers of insects on the group of selected inflorescences once every hour. The counts were done on twenty-nine groups of inflorescences. The insects on flowers were captured using an aspirator or forceps and also brought to the Oxford University Museum of Natural History for identification.

Flight activities of A. dorsata colonies and their correlations to flower rewards:

The number of bees flying out of the colony was counted for five minutes, then after a five minute break the number of bees flying in was counted for another five minutes. Counts were done hourly from 06.00 h to 18.10 h at two colonies, each colony for five separate days. Correlations between the bee flight and the rewards of *Melaleuca* and *Nypa* flowers were analysed using the counts of bee flights and the measurements of pollen/nectar rewards present at the corresponding times.

Statistics and graphics:

Most data collected in this study are not normally distributed, so the nonparametric tests Kruskal-Wallis, Friedman, Wilcoxon signed-rank and Spearman's correlation were applied. ANOVA was used for the analyses of the sugar content and the bee flights (because their distributions are normal). Kolmogorov-Smirnov tests (Sokal & Rohlf 1995) were applied to analyse the distributions of visitors on flowers during different times of the day. All tests are two tailed. Most statistical analyses were performed using MINITAB package version 12.21. Graphics were drawn using MINITAB package version 12.21 and Microsoft Excel 2002 SP-1.

Results

Nectar volume of Melaleuca cajuputi

Nectar volume of *Melaleuca* flowers is very variable. Table 1 shows the mean volume of nectar present in a *Melaleuca* flower during flowering. On average the

Table 1: The volume (µl) of nectar present in a *Melaleuca* flower. For each tree, nectar in all (10 - 50) flowers of the inflorescence was measured. The last column shows the mean for five trees. The number in brackets shows the percentage on the maximum volume of the day.

Day & Time	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5	Mean
Day 1:						
06.00 h	4.5	3.8	6.5	0.2	0.0	2.97 (100)
08.00 h	4.4	2.6	3.8	0.2	1.5	2.50 (84)
10.00 h	3.6	1.6	1.2	0.0	1.1	1.49 (50)
12.00 h	0.5	0.8	1.2	0.0	0.1	0.53 (18)
14.00 h	0.2	0.0	0.3	0.1	0.0	0.13 (4)
16.00 h	0.3	0.5	1.0	0.0	0.8	0.50 (17)
18.00 h	0.0	0.4	0.3	0.0	0.4	0.23 (1)
Day 2:						
06.00 h	1.8	0.0	4.1	0.0	1.2	1.43 (95)
08.00 h	0.0	0.0	2.0	0.6	4.9	1.50 (100)
10.00 h	0.0	0.5	0.0	0.0	2.0	0.49 (33)
12.00 h	0.0	0.0	0.0	0.0	0.2	0.04 (3)
14.00 h	0.0	0.0	0.0	0.0	0.0	0.00 (0)
16.0 h	0.0	0.0	0.0	0.0	0.0	0.00 (0)
18.00 h	0.0	0.0	0.0	0.1	0.0	0.02 (1)
Day 3:						
06.00 h	0.6	0.4	0.3	0.1	0.2	0.33 (26)
08.00 h	0.6	0.0	1.0	0.0	4.8	1.28 (100)
10.00 h	0.7	0.1	0.0	0.0	0.0	0.16 (12)
12.00 h	0.0	0.0	0.0	0.0	0.0	0.00 (0)
14.00 h	0.0	0.0	0.0	0.0	0.3	0.06 (4)
16.00 h	0.0	0.0	0.0	0.0	0.0	0.00 (0)
18.00 h	0.0	0.0	0.0	0.0	0.0	0.00 (0)

Day 4:

06.00 h	0.1	0.4	0.2	0.0	0.1	0.15 (50)
08.00 h	0.3	0.0	0.0	0.0	1.2	0.30 (100)
10.00 h	0.0	0.0	0.1	0.0	0.0	0.02 (7)
12.00 h	0.0	0.0	0.0	0.0	0.0	0.00 (0)
14.00 h	0.0	0.0	0.0	0.0	0.0	0.00 (0)
16.00 h	0.0	0.0	0.0	0.0	0.0	0.00 (0)
18.00 h	0.0	0.0	0.0	0.0	0.0	0.00 (0)

tree secreted as much as 3 micro-litres of nectar per flower in the early morning of the first day and seemed to stop on the fourth day. The fluctuation of the volumes present are very highly significant among the days (Kruskal-Wallis test, $H = 29.91$, $DF = 3$, $P < 0.001$) and among the time of the day ($H = 35.75$, $DF = 6$, $P < 0.001$) but not significant among the investigated trees ($H = 6.03$, $DF = 4$, $P = 0.197$). The sugar contents of nectar are shown in Table 2. While the nectar volume varies greatly by both day and time, the sugar content in nectar does not vary by day but does vary by time of the day. For example, the sugar content of nectar at 06.00 h is not different statistically among the three days (one-way ANOVA, $F_{2,9} = 1.57$, $P = 0.260$); and the variations in sugar contents of nectar from 06.00 h to 18.00 h in the first day are very highly significant (one-way ANOVA, $F_{6,20} = 60.29$, $P < 0.001$).

The results demonstrate that the nectar was secreted in the largest volume (3 μl) with the lowest sugar content (10.5%) in the early morning. The volume became lower and the sugar content gradually higher; and then it dropped to the lowest (0.13 μl) with the sugar content highest (54.7%) in the early afternoon. In the early evening, nectar was secreted again but the volume was small. In the following three days, the same pattern of nectar fluctuation was repeated but the amounts were less and less (1.5, 1.3 and 0.3 μl at early mornings, respectively). Therefore, the sugar value of the nectar, defined as the volume multiplied by the sugar content, in the first day is demonstrated in Figure 1. It shows that on average a flower secreted about 31 μg of sugar in early morning, kept on secreting to reach the maximum of 42 μg at about 10.00 h, and decreased gradually during mid-day partly due to the collection of insects. In early evening nectar is secreted again and the sugar value increases slightly.

Table 2: Sugar content (%) of *Melaleuca* nectar. An asterisk (*) shows the content could not be measured due to too small amount of nectar.

Day & Time	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5	Mean
Day 1:						
06.00 h	10	9	11	12	*	10.5
08.00 h	11	9	12	17	11	12.0
10.00 h	26	30	28	*	28	28.0
12.00 h	48	42	46	*	63	49.8
14.00 h	51	*	59	54	*	54.7
16.00 h	43	44	39	*	48	43.5
18.00 h	*	27	25	*	32	28.0
Day 2:						
06.00 h	10	*	11	*	21	14.0
08.00 h	*	*	12	22	14	16.0
10.00 h	*	60	*	*	49	54.5
12.00 h	*	*	*	*	50	50.0
14.00 h	*	*	*	*	*	*
16.00 h	*	*	*	*	*	*
18.00 h	*	*	*	37	*	37.0
Day 3:						
06.00 h	9	16	15	16	18	14.8
08.00 h	16	*	17	*	17	16.7
10.00 h	30	*	*	*	*	30.0
12.00 h	*	*	*	*	*	*
14.00 h	*	*	*	*	52	52.0
16.00 h	*	*	*	*	*	*
18.00 h	*	*	*	*	*	*

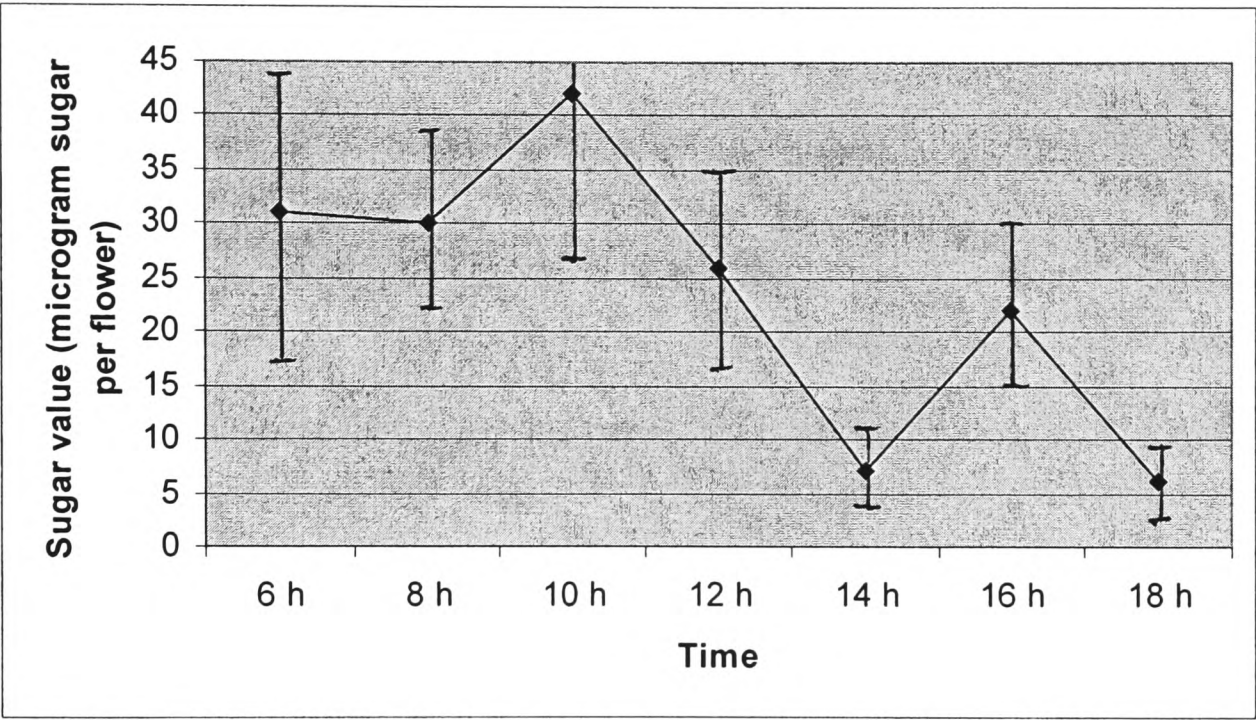


Figure 1: Fluctuation of sugar value, defined as the volume multiplied by the sugar content, of a *Melaleuca* flower during the first day. The points are the multiplications of the mean values from Table 1 and Table 2.

Pollen release of Melaleuca cajuputi and Nypa fruticans

Figure 2 shows the numbers of pollen grains counted per square millimetre during five days (108 hours) of flowering of *Melaleuca* flowers. When flowers start to bloom, pollen grains are released in small numbers (20% in comparison with the maximum release). The number increases and about eight hours later, when the flowers open completely, the release of pollen is at its maximum. After that the release tends to go down gradually and finishes by the end of the fifth day (108 h) because of the loss, partly by collectors. The numbers vary very greatly from the start to the end of the flowering (Friedman test, $S = 130.39$, $DF = 34$, $P < 0.001$) but they are not statistically different among the trees ($S = 2.77$, $DF = 4$, $P = 0.598$). Pollen grains of *Melaleuca cajuputi* flowers are white in colour and triangular in outline. The size of the grain was $17.5 \pm 1.1 \mu\text{m}$ ($n = 30$).

Nypa fruticans flowers bloom in a day. Table 3 shows the counts of pollen grains released by flowers during their flowering. Flowers start to bloom and release pollen very early in the morning when the sun has not risen. The pollen release increases and reaches the peak of 100% at 09.00 h. Then the number of pollen grains on flowers tends to go down partly due to collectors and the release finishes by sunset. The availability of pollen grains on flowers is very highly significant among time of the day (Friedman test, $S = 62.15$, $DF = 13$, $P < 0.001$) and not significant among trees ($S = 6.41$, $DF = 9$, $P = 0.699$). Pollen grains of *Nypa fruticans* flowers are orange in colour and round in outline. The size was $44.7 \pm 2.4 \mu\text{m}$ ($n = 30$).

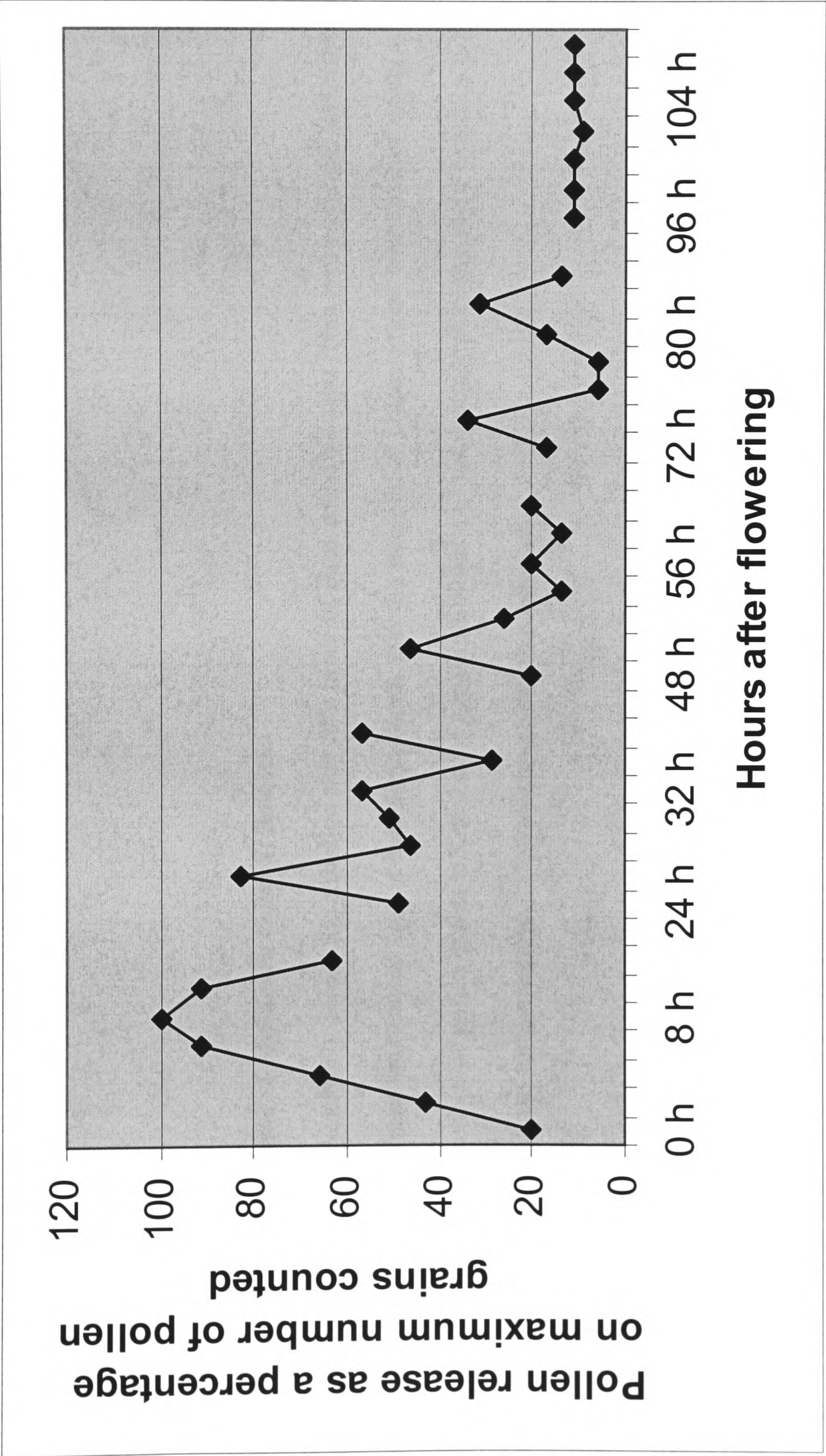


Figure 2: Pollen release of *Melaleuca cajuputi* flowers (see legend on next page).

Figure 2 (cont.): Pollen release of *Melaleuca cajuputi* flowers.

Each inflorescence was rolled slightly across the adhesive side of a piece of clear adhesive tape. This piece of clear adhesive tape was then cut into twelve parts, each of which was placed over a haemocytometer and the number of pollen grains was counted using a microscope. Data recorded was the average number of pollen grains counted on a square millimetre of the haemocytometer for a tree at a given time (day time only). A point on the graph shows the percentage on the maximum number counted.

Table 3: Number of *Nypa* pollen grains counted per square millimetre during flowering (see legend in Figure 2).

Time	Tree										Mean
	1	2	3	4	5	6	7	8	9	10	
05.00 h	5	0	0	6	1	3	3	3	2	0	2.3 (12)
06.00 h	25	7	19	5	1	9	16	9	11	15	11.7 (64)
07.00 h	18	25	34	8	3	8	28	17	7	11	15.9 (86)
08.00 h	13	17	7	14	29	16	16	14	17	9	15.2 (83)
09.00 h	57	14	16	18	14	27	7	17	6	8	18.4 (100)
10.00 h	6	20	12	16	31	12	6	11	12	14	14.0 (76)
11.00 h	4	24	16	12	23	12	9	8	6	6	12.0 (65)
12.00 h	4	28	6	7	28	9	4	13	4	6	10.9 (59)
13.00 h	2	10	10	3	5	9	19	9	6	10	8.3 (45)
14.00 h	6	3	8	6	3	14	9	24	4	2	7.9 (43)
15.00 h	0	4	7	7	4	12	6	5	8	10	6.3 (34)
16.00 h	10	4	7	7	5	17	3	10	6	3	7.2 (39)
17.00 h	5	4	4	3	9	4	1	2	4	2	3.8 (21)
18.00 h	3	3	3	2	4	3	5	4	3	4	3.4 (18)

Insects visiting Melaleuca cajuputi and Nypa fruticans flowers

Insects visiting *Melaleuca* flowers comprised honey bees (*Apis dorsata* and *A. florea* - Apidae), carpenter bees (*Xylocopa auripennis*, *X. aestuans* and *Xylocopa* sp. - Apidae), cleptoparasitic bees (*Thyreus* sp., Apidae), solitary bees (*Ceratina* sp. - Apidae and *Megachile* sp. - Megachilidae), halictid bees (*Nomia* sp., *Pseudapis* sp., *Lasioglossum* sp. and *Homalictus* sp. - Halictidae), colletid bees (*Hylaeus* sp. - Colletidae), syrphid flies (Syrphidae), wasps (*Vespa affinis*, *V. tropica* and *Polistes* sp. - Vespidae and unidentified species in Scoliidae), butterflies (Lepidoptera), beetles (Coleoptera), and bugs (Hemiptera). Table 4 shows the numbers of pollinators visiting flowers in fifteen minutes. They visited flowers only in the first two days of flowering. Much more visitations were on the 1st day than on the 2nd day (Wilcoxon signed-rank test, $W_s = 105$, $n = 14$, $P < 0.001$). The visitations also varied greatly with time of the day (Kruskal-Wallis test, $H = 123.11$, $DF = 12$, $P < 0.001$) and in different inflorescences ($H = 63.42$, $DF = 13$, $P < 0.001$). Seventy-two per cent of pollinators visited flowers before noon. Although more than 20 species visited *Melaleuca* flowers, the two honey bee species, *A. dorsata* and *A. florea* accounted for about 20% and 23% of total number, respectively.

Visitor species on *Nypa fruticans* flowers were not as diverse as those on *Melaleuca cajuputi*. Visitations of the four visitor groups (i.e. *A. dorsata*, *A. florea*, halictid bees and syrphid flies) are shown in Table 5. Bees of the Halictidae were very common on *Nypa* flowers. They started visiting at 06.00 h, increased gradually, peaked at 08.00 h and then decreased gradually until 15.00 h. Flies of the Syrphidae were often observed on *Nypa* flowers, too. They visited flowers mainly from 07.00 h to 10.00 h

Table 4: Insect visitations to the inflorescences of *Melaleuca* flowers in 15 minutes.

		6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	Total
Inf. 1	1st day	0	0	0	15	5	5	1	14	9	10	10	17	0	86
	2nd day	0	0	0	13	7	10	6	7	7	5	7	9	0	71
Inf. 2	1st day	0	3	1	14	3	9	2	18	12	9	8	0	0	79
	2nd day	0	1	0	7	3	5	2	3	2	4	8	0	0	35
Inf. 3	1st day	0	2	6	2	1	4	0	0	0	0	0	0	0	15
	2nd day	0	0	5	5	2	0	0	0	0	0	0	0	0	12
Inf. 4	1st day	0	3	11	2	3	2	0	0	0	0	0	0	0	21
	2nd day	0	0	1	8	3	0	0	0	0	0	0	0	0	12
Inf. 5	1st day	0	3	5	5	7	0	0	0	0	0	0	0	0	20
	2nd day	0	1	3	0	0	0	0	0	0	0	0	0	0	4
Inf. 6	1st day	0	5	9	1	3	2	2	0	0	0	0	0	0	22
	2nd day	0	3	2	0	0	0	0	0	0	0	0	0	0	5
Inf. 7	1st day	0	8	5	0	0	0	0	0	0	0	0	0	0	13
	2nd day	0	4	0	0	0	0	0	0	0	0	0	0	0	4
Inf. 8	1st day	0	0	12	16	4	0	0	0	0	0	0	0	0	32
	2nd day	0	0	3	5	0	0	0	0	0	0	0	0	0	8
Inf. 9	1st day	0	6	1	4	0	0	0	0	0	0	0	0	0	11
	2nd day	0	2	0	0	0	0	0	0	0	0	0	0	0	2
Inf. 10	1st day	2	13	10	9	7	13	12	0	0	0	0	0	0	66
	2nd day	0	2	2	3	3	2	3	0	0	0	0	0	0	15
Inf. 11	1st day	0	35	20	6	20	20	17	6	6	0	0	0	0	130
	2nd day	0	5	5	2	5	35	29	0	0	0	0	0	0	81
Inf. 12	1st day	0	26	12	8	6	8	4	3	2	0	0	0	0	69
	2nd day	0	19	10	3	0	5	3	0	0	0	0	0	0	40
Inf. 13	1st day	0	9	10	9	9	8	2	4	2	0	0	0	0	53
	2nd day	0	10	6	7	0	5	3	0	0	0	0	0	0	31
Inf. 14	1st day	0	2	9	6	6	7	3	5	3	0	0	0	0	41
	2nd day	0	2	2	3	0	2	1	1	0	0	0	0	0	11
Total		2	164	150	153	97	142	90	61	43	28	33	26	0	989

Table 5: Insect visitations to *Nypa* flowers during their flowering.

Numbers of insects on a group of selected inflorescences were counted once every hour. Data presented is the total number of insects counted at 29 groups of inflorescences.

	5 h	6 h	7 h	8 h	9 h	10 h	11 h	12 h	13 h	14 h	15 h	16 h	17 h	18 h	Total
<i>A. dorsata</i>	110	134	181	62	18	6	2	1	0	0	0	0	0	0	514
<i>A. florea</i>	0	0	3	2	10	19	13	12	12	11	6	1	0	0	89
Halictid bees	0	9	35	43	39	31	19	9	3	4	2	0	0	0	194
Syrphid flies	0	0	6	26	31	12	11	6	1	1	0	0	0	0	94
Total	110	143	225	133	98	68	45	28	16	16	8	1	0	0	891

with the highest number at 09.00 h. Some wasps, such as *Vespa tropica* and *V. affinis* (Vespidae), were sometimes observed on *Nypa* flowers. An analysis of the frequency distributions of four visitors across the day shows very high significances (Table 6).

Figure 3 shows the distributions of both honey bee species (*A. dorsata* and *A. florea*) on both flowers by time of the day. *Apis dorsata* visited *Nypa* flowers in large numbers before dawn and reached a peak at 07.00 h. After that the number of the bees dropped sharply and after 11.00 h, there were no *A. dorsata* on *Nypa* flowers. On *Melaleuca* flowers, *Apis dorsata* visitations were mainly from 07.00 h to 09.00 h, peaked at 09.00 h and then dropped dramatically. In the afternoon, visitations of *A. dorsata* increased and finished before sunset. *Apis florea* started on *Melaleuca* flowers with the peak at 07.00 h and then seemed to decrease during the rest of the day. On *Nypa* flowers, *Apis florea* bees collected pollen rather late, with their peak number at 10.00 h; then the numbers tended to decrease but were still large in the afternoon and stopped at 18.00 h. Some comparisons of the distributions of the two honey bee species on the two plants during time of the day are shown in Table 7.

Flying activities of A. dorsata colonies and their relationships to flowers' rewards

Table 8 shows the number of bees flying out and in during ten observational days in the two investigated colonies. *Apis dorsata* bees in the *Melaleuca* forest mainly foraged in the morning. They started early and peaked at 09.00 h (about 590 bees flying out or in per five minutes). After that the number decreased gradually and the least number (sixty six bees per five minutes) was counted at the end of the day. The numbers of bee flights were highly significantly different during the day

Table 6: D value and significance of Kolmogorov-Smirnov two sample test to compare the frequency distributions of visitor groups on *Nypa* flowers (data in Table 5).

Comparison	D value	Significance
<i>dorsata</i> & <i>florea</i>	0.8913	P<0.001
<i>dorsata</i> & halictid	0.6000	P<0.001
<i>dorsata</i> & syrphid	0.8268	P<0.001
<i>florea</i> & halictid	0.4809	P<0.001
<i>florea</i> & syrphid	0.5017	P<0.001
halictid & syrphid	0.2268	P<0.01

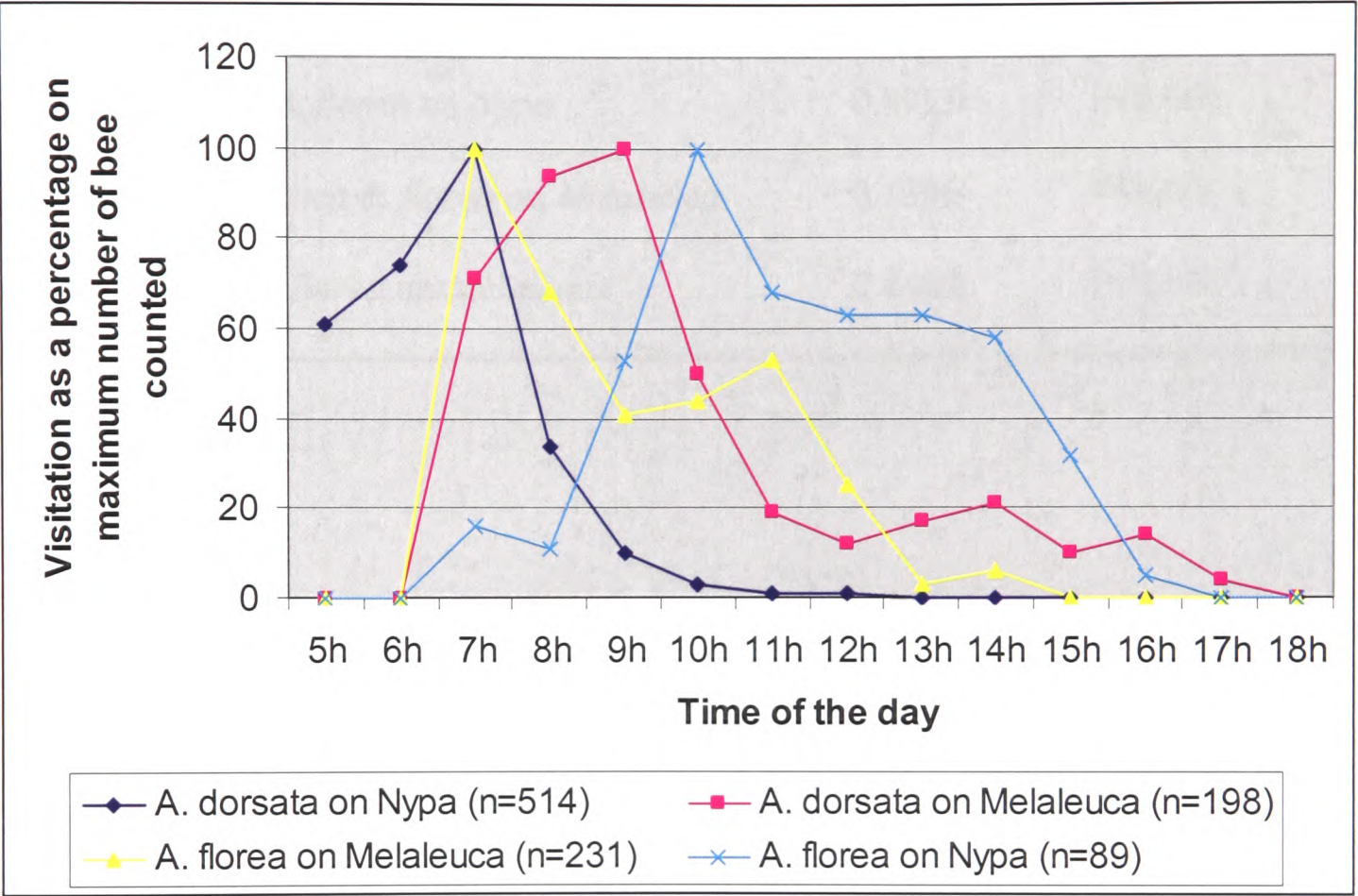


Figure 3: Visitations of *A. dorsata* and *A. florea* to *Melaleuca* and *Nypa* flowers during time of the day. On *Melaleuca*, number of bee visitations to the selected inflorescences in 15 minutes was counted. On *Nypa*, number of bees on the selected inflorescences was counted once every hour. In total, 14 groups of *Melaleuca* inflorescences and 29 groups of *Nypa* inflorescences were observed.

Table 7: D value and significance of Kolmogorov-Smirnov two sample test to compare the frequency distributions of *A. dorsata* and *A. florea* on *Melaleuca* and *Nypa* flowers (data from Figure 3).

Comparison	D value	Significance
<i>dorsata</i> on <i>Nypa</i> & <i>dorsata</i> on <i>Melaleuca</i>	0.6551	P<0.001
<i>dorsata</i> on <i>Nypa</i> & <i>florea</i> on <i>Nypa</i>	0.8913	P<0.001
<i>dorsata</i> on <i>Melaleuca</i> & <i>florea</i> on <i>Melaleuca</i>	0.1356	P<0.05
<i>florea</i> on <i>Nypa</i> & <i>florea</i> on <i>Melaleuca</i>	0.4462	P<0.001

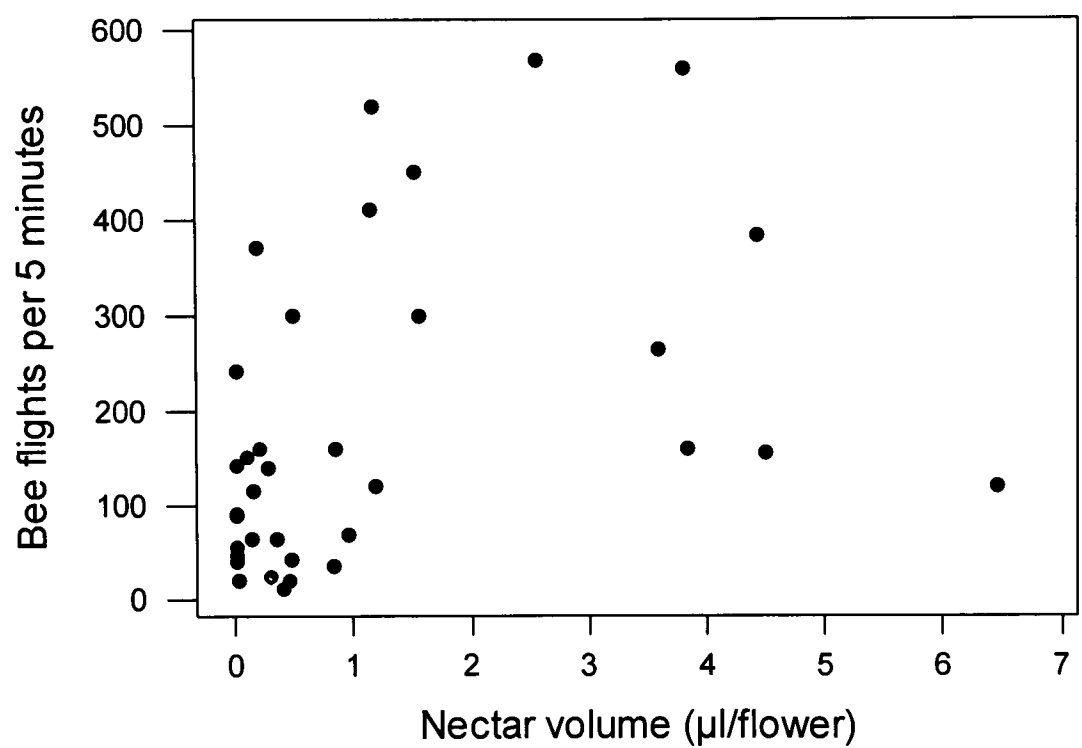
Table 8: Number of flights per five minutes in two *A. dorsata* colonies, each colony counted for 5 days.

		6 h	7 h	8 h	9 h	10 h	11 h	12 h	13 h	14 h	15 h	16 h	17 h	18 h	
Col. 1	Out flight	155	620	385	568	265	122	300	228	159	146	140	68	39	
		160	250	570	600	300	315	160	188	142	140	43	20	10	
		120	200	560	650	520	350	120	100	64	143	68	39	24	
		115	580	370	750	243	107	47	99	151	120	92	66	20	
		88	800	450	700	412	115	65	55	56	58	35	16	20	
	In flight	120	180	300	600	220	160	220	190	170	155	155	70	31	
		115	480	380	650	290	230	112	161	145	182	74	38	13	
		100	160	230	620	570	320	160	90	86	89	77	57	12	
		100	550	270	750	320	110	87	90	93	140	98	57	25	
		65	300	600	650	450	181	115	77	76	77	37	25	30	
Col. 2	Out flight	156	365	475	540	420	62	30	*	*	*	*	*	*	
		104	84	700	420	243	237	191	*	2	33	42	65	110	
		82	240	190	520	400	318	139	168	144	82	141	129	86	
		120	173	615	440	300	221	20	160	217	165	67	70	280	
		207	132	416	650	400	95	120	216	260	180	127	77	44	
	In flight	93	208	665	364	292	72	65	65	*	*	*	*	*	
		98	82	132	500	342	300	200	200	*	22	24	50	66	123
		82	265	134	574	532	472	250	250	152	156	103	161	107	113
		87	165	215	600	440	237	250	250	167	232	150	96	89	160
		204	180	251	600	450	175	148	148	238	250	199	106	102	48
Mean	118.6	300.7	395.4	587.3	370.4	210.0	140.0	148.7	134.7	121.4	89.4	64.5	66		

(one-way ANOVA, $F_{12,233} = 45.61$, $P < 0.001$). However, there are no significant differences between the bee flights of the two colonies (one-way ANOVA, $F_{1,244} = 0.01$, $P > 0.05$), and between the out and in flights (one-way ANOVA, $F_{1,244} = 0.22$, $P > 0.05$). Figures 4 - 8 show the correlations of *A. dorsata* flight activity with the rewards of *Melaleuca* and *Nypa* flowers. There was a strongly positive relationship between the foraging activity of *Apis dorsata* colonies and the nectar volume present in *Melaleuca* flowers (Spearman test, $r_s = 0.504$, $DF = 33$, $P = 0.002$). However, its correlation with the sugar content of the nectar was weak and negative ($r_s = -0.405$, $DF = 25$, $P = 0.036$). With the sugar value, the relationship to bee flight was strong and positive ($r_s = 0.411$, $DF = 33$, $P = 0.014$). There was also a very strongly positive correlation between bee flight and pollen release of *Nypa* ($r_s = 0.432$, $DF = 121$, $P < 0.001$) but no relationships were found with the pollen release of *Melaleuca* flowers ($r_s = -0.150$, $DF = 33$, $P = 0.391$).

Discussion

Despite the floral diversity of the submerged forest, *Melaleuca cajuputi* is very important for insects living on flower rewards because it is completely dominant in the forest and its nectar and pollen are abundant. The time of its flowering appears to cause the arrival or departure of *A. dorsata* colonies in the area (Nam 1959; Crane *et al.* 1993; Mardan 1993; Tan & Chinh 1995; Chapters 3 & 6 of this thesis). The role of *Melaleuca* trees in beekeeping has also been reported in Florida, USA (Robinson 1980) and Malaysia (Kiew & Muid 1991), but no studies on pollen and nectar reward have been published.



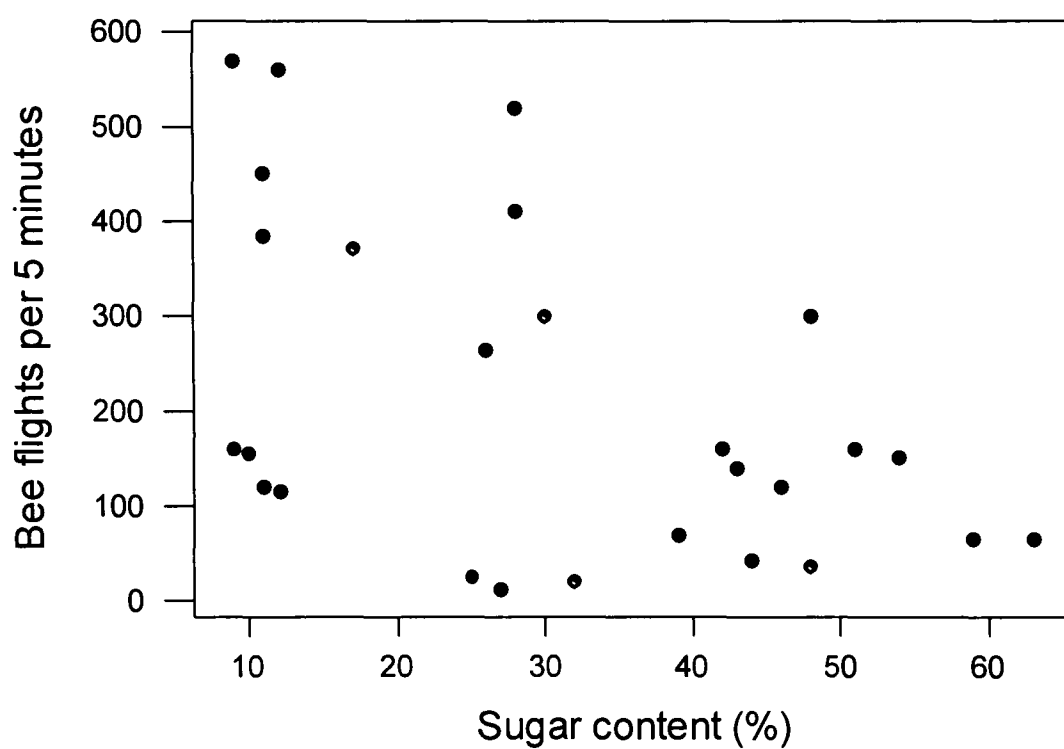


Figure 5: Correlation between the flight activity of *A. dorsata* and the sugar content of nectar in *Melaleuca* flowers (Spearman test, $r_s = -0.405$, $DF = 25$, $P = 0.036$). The data for analysis were the sugar contents of 27 samples of nectar measured in day 1 (Table 2) and the corresponding out-flights of colony 1 (Table 8).

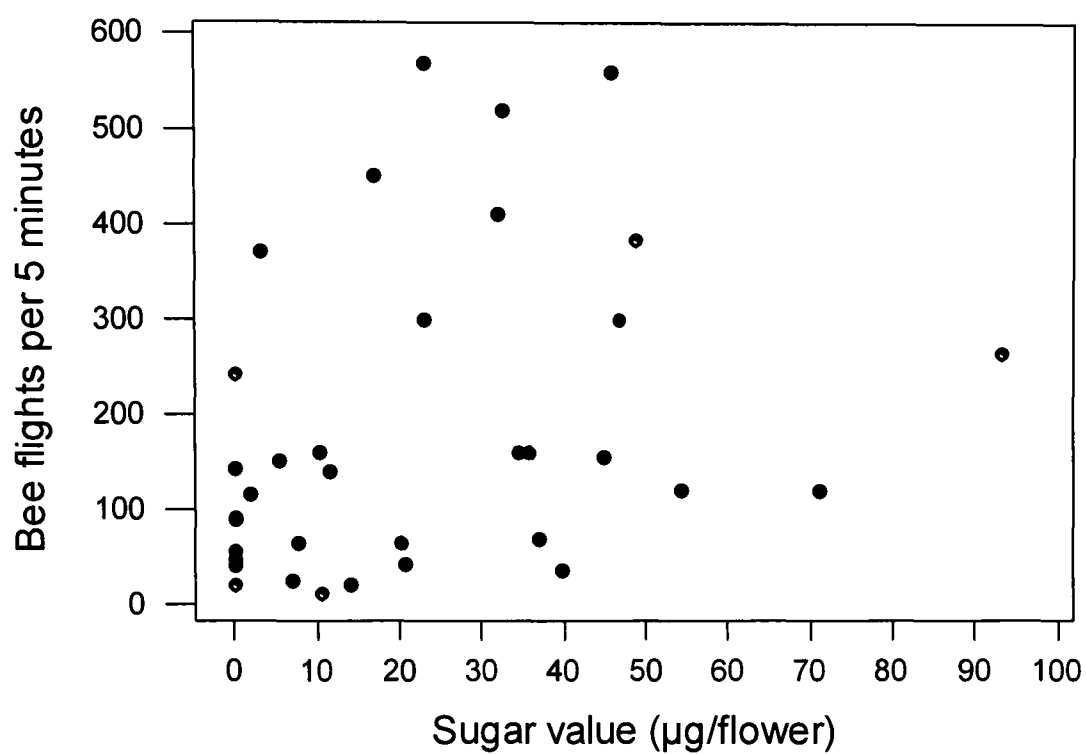


Figure 6: Correlation between the flight activity of *A. dorsata* and the sugar value of a *Melaleuca* flower (Spearman test, $r_s = 0.411$, $DF = 33$, $P = 0.014$). The data for analysis were the sugar value of 35 samples of nectar in day 1 (resulted from Tables 1 & 2) and the corresponding out-flights of colony 1 (Table 8).

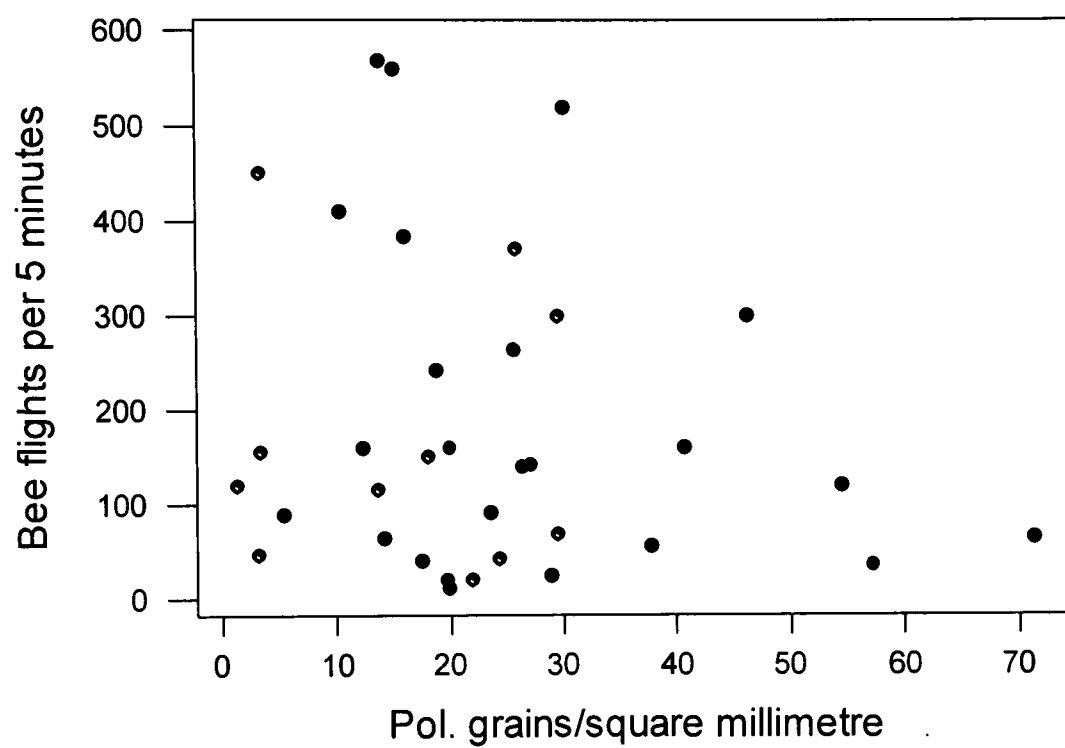


Figure 7: Correlation between the flight activity of *A. dorsata* and the release of pollen by *Melaleuca* flowers (Spearman test, $r_s = -0.150$, $DF = 33$, $P = 0.391$). The data for analysis were 35 counts of pollen release (from 0 h to 12 h after opening) in Figure 2 and the corresponding out-flights of colony 1 in Table 8.

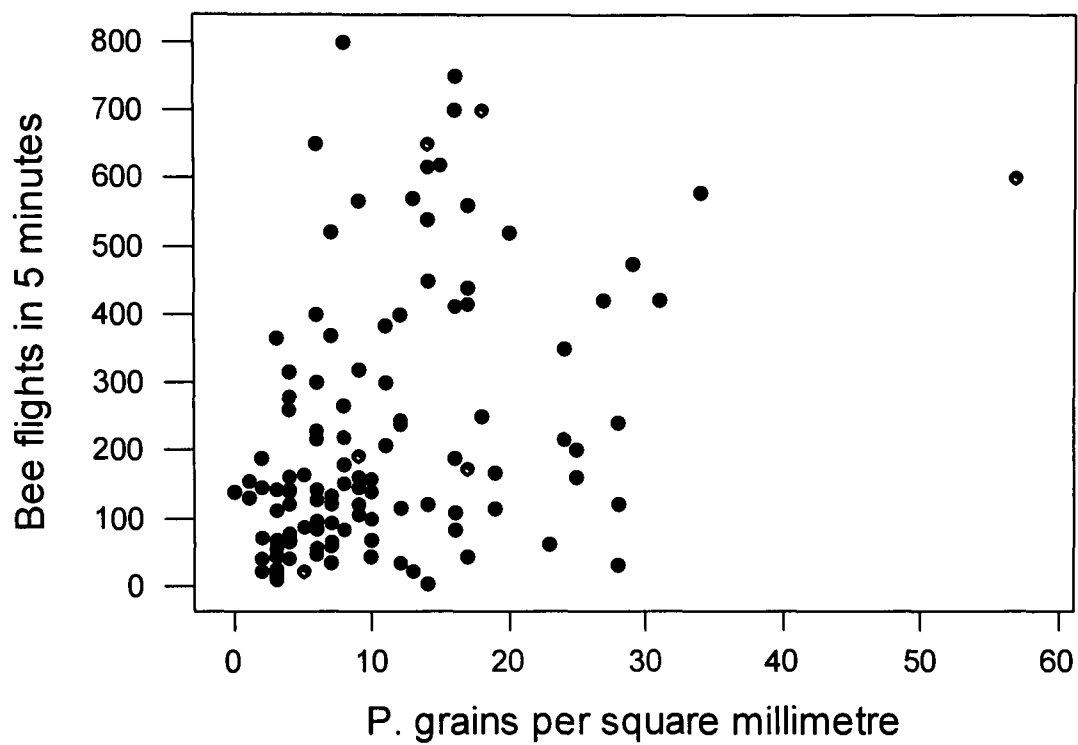


Figure 8: Correlation between the flight activity of *A. dorsata* and the release of pollen by *Nypa* flowers (Spearman test, $r_s = 0.432$, $DF = 121$, $P < 0.001$). The data for analysis were 123 out-flights of two colonies in Table 8 and the pollen release at the corresponding time in Table 3.

As shown in Table 1, the data on nectar volume presented are the means of 10 - 50 flowers in the investigated inflorescences of *Melaleuca*. During measurements in the field, I realised that the flowers in an inflorescence secreted different amounts of nectar, ranging from 0 to 8.9 μl per flower. Why do some flowers secrete a lot of nectar and others secrete little? Nectar is necessary to attract pollinators but it also consumes a lot of energy. Bell (1986) predicted that plants should be able to grow a proportion of flowers without any nectar, which thus escape the costs of nectar production, while gaining the benefits of insect pollination because most visitors either can not discriminate or would lose too much time attempting to do so. Gilbert *et al.* (1991) showed that 75 - 85% flowers of *Cerithe major* L. (Boraginaceae) are relative low nectar producers. Possibly, flowers of *Melaleuca cajuputi* show the same strategy; but it is not clear to me why many *Melaleuca cajuputi* trees secrete very little nectar although they look as normal as the investigated trees.

The fluctuation in the volume and sugar content of *Melaleuca* nectar over the day may be dependent on the temperature. Early in the morning, nectar is secreted in high volume and low sugar content. When the sun rises, the temperature increases and the humidity decreases; so the water in nectar evaporates. In the early evening, the air becomes cooler and the trees secrete nectar again increasing the volume and decreasing the sugar content. Flowers of *Melaleuca* can exist for about five days but nectar secretion is greatest during the first day and almost stops by the fourth day. In the five trees investigated, nectar secretion was not different statistically and neither was the pollen release. However, it may not be certain that the nectar and pollen rewards of different trees in the forest are the same.

The nectar of *Melaleuca* flowers seems more attractive to *A. dorsata* foragers than the pollen does as demonstrated in Figures 4 and 7. The peak flight of an *A. dorsata* colony was at 09.00 h which was also near the time when *M. cajuputi* flowers provided the largest sugar value; the analysis in Figure 6 shows this strong positive correlation. After 10.00 h nectar becomes less “valuable”; and moreover, it becomes too dry for bees to collect and the correlation becomes weakly negative (Figure 5). Visitations of bees and other insects must facilitate the pollination of *Melaleuca* trees because of their flowers’ structure: tens of flowers group into an easily accessible inflorescence and their pistils elevate. The results of this study also suggest that the nectar of *Melaleuca* flowers seems more attractive to *A. dorsata* than the pollen of *Nypa* does. At 09.00 h, *Nypa* pollen release is at the maximum and the *Melaleuca* nectar value is also at peak; but *A. dorsata* shifts from the former to the latter. Flowers of *Melaleuca cajuputi* attract more insect species than those of *Nypa fruticans* because *Melaleuca* provides both pollen and nectar. Stone *et al.* (1996) also found greater diversity of pollinators on pollen-and-nectar flowers than on pollen-only flowers in an *Acacia* community in Africa. Although the *Melaleuca* flower could provide pollen for five days and nectar for three days, the pollinators were observed to forage mainly on the first two days, especially the first day: in the abundance of food source, the flowers providing higher value rewards were preferred.

Nypa fruticans does not provide nectar but its pollen is attractive to many insects. Its pollen grains are rather large; and the inflorescences are so big and strong that the insects can land on the inflorescence and collect pollen easily. *Apis dorsata* is attracted to the flowers in large number even when the sun has not risen. Although the insects never visited the female flowers, their activities of pollen collection could drop

pollen grains down to the female flowers. In addition, Uhl & Moore (1977) studied various characteristics of the inflorescence (morphology, anatomy, occurrence of raphides and tannins, growth patterns, phenology and vectors) of palm trees (*Thrinax*, *Phoenix*, *Nypa*, *Ptychosperma*, *Bactris* and *Asterogyne*) in relation to mode of pollination. They reported that palms had previously been considered predominantly anemophilous, but the last four genera were entomophilous; structures relating to insects were found even in the two anemophilous genera.

There was no fierce biting, pushing or fighting observed among collectors on flowers in this study. It contrasts with the report of Koeniger & Vorwohl (1979) who found interactions between and among *A. dorsata*, *A. cerana*, *A. florea* and *Trigona iridipennis* foraging on artificial sucrose sources in Sri Lanka. However, Roubik (1989: page 106) suggested that such behaviour may result from the artificial stable nectar source inducing nest defence or robbing behaviour which is not normal for foraging bees. Oldroyd *et al.* (1992) reported no fierce competition among *A. dorsata*, *A. cerana*, *A. florea*, *A. andreniformis* and *Trigona* sp. on the nocturnally-dehiscent king palm (*Archontophoenix alexandrea*) in Thailand.

For sympatric insects, their long evolution must give them the means to live together, especially very closely related species with similar demands. Their competition is reduced by either foraging on different sources of food, or on the same source but at different times. Stone *et al.* (1996) provided evidence for the partitioning of pollinators by different *Acacia* species in Africa. Oldroyd *et al.* (1992) found the partitioning of time on food source by sympatric honey bee species in Thailand. This study shows that the species of insects visiting *Melaleuca* and *Nypa* flowers are

different. More than 20 species are found on the *Melaleuca*, and less than ten species on the *Nypa*. It suggests that there is a partitioning of pollinators/collectors between the two plants, although most species on *Nypa* were also found on *Melaleuca*. In addition, the observations of four visitors on *Nypa* flowers in Table 5 show that different groups of insects visit flowers at different times of the day. The peaks of the visitations by the four groups are completely separate. Especially, the distributions of the two honey bee species, *A. dorsata* and *A. florea* on the two plants *Melaleuca* and *Nypa* in Figure 3 show the partitioning of the food source. Both *Melaleuca* and *Nypa* flowers attract *A. dorsata* and *A. florea*, the two closely-related species that have the same food of pollen and nectar. However, the partitioning has been done with the priority to the species of larger body size and presumably more demand. *Apis dorsata* forages on *Nypa* flowers early in the morning, and then shifts to *Melaleuca* flowers at mid-morning. In different ways, *A. florea* visits *Melaleuca* flowers early in the morning, when the nectar is not the best but still good; and then shifts to *Nypa* after mid-morning, when most competitors have gone. These results suggest that the different insects, especially *A. dorsata* and *A. florea* have temporal partitioning of the food source. The partitioning by body mass of *A. dorsata* and *A. florea* in this study agrees with the observations of Oldroyd *et al.* (1992). Moreover, there is also partitioning of time in a honey bee species to visit different food sources. Figure 3 shows that in each bee species, the time to visit *Nypa* and the time to visit *Melaleuca* are different. Therefore, this study of pollination ecology suggests the following partitioning in the *Melaleuca* forest:

1. Different plants have different visitors;
2. Different visitors visit the same plant at different times;
3. In a visitor species, time is partitioned to visit different plants.

Some interesting questions are suggested by the findings of this study. In the areas where *A. florea* does not have to share *Melaleuca* nectar and *Nypa* pollen with *A. dorsata*, will *A. florea* visit the flowers at the best times of the flower rewards? In the areas where *A. florea* and the Asian hive honey bee, *Apis cerana* co-exist, is the partitioning the same as *A. florea* and *A. dorsata*? And in the areas where the imported European honey bee, *A. mellifera* is introduced, is there partitioning of the food source or competition among the honey bee species?



Plate 1: Flowers of *Melaleuca cajuputi*. From ten to fifty small flowers group into an easily accessible inflorescence and their pistils elevate.

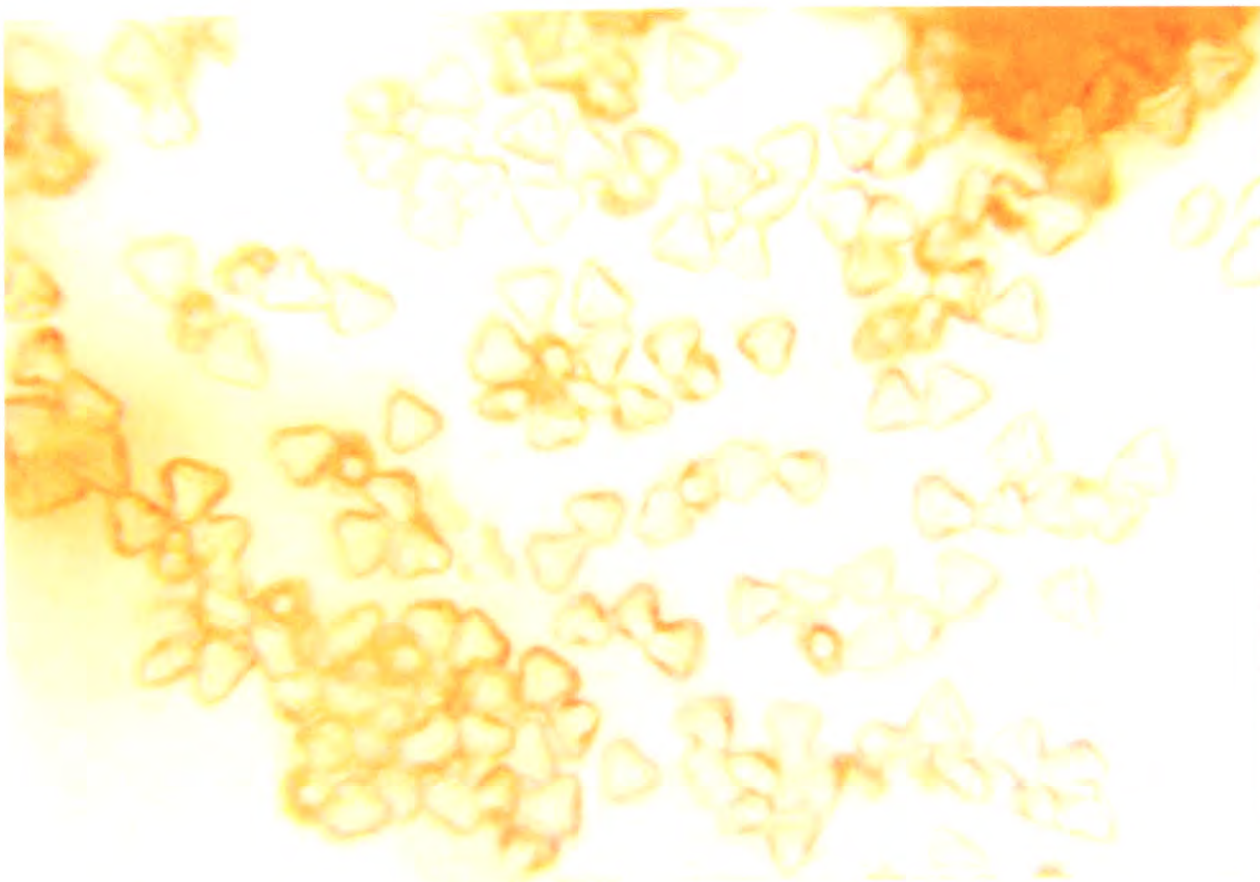


Plate 2: Pollen grains of *Melaleuca cajuputi* flowers. They are white in colour and look triangular in outline. The size of the grain is $17.5 \pm 1.1 \mu\text{m}$ ($n = 30$).



Plate 3: *Apis dorsata* visits *Nypa fruticans* flowers before the sun rises. The inflorescences are so big and strong that the insects can land on the inflorescence and collect pollen easily.

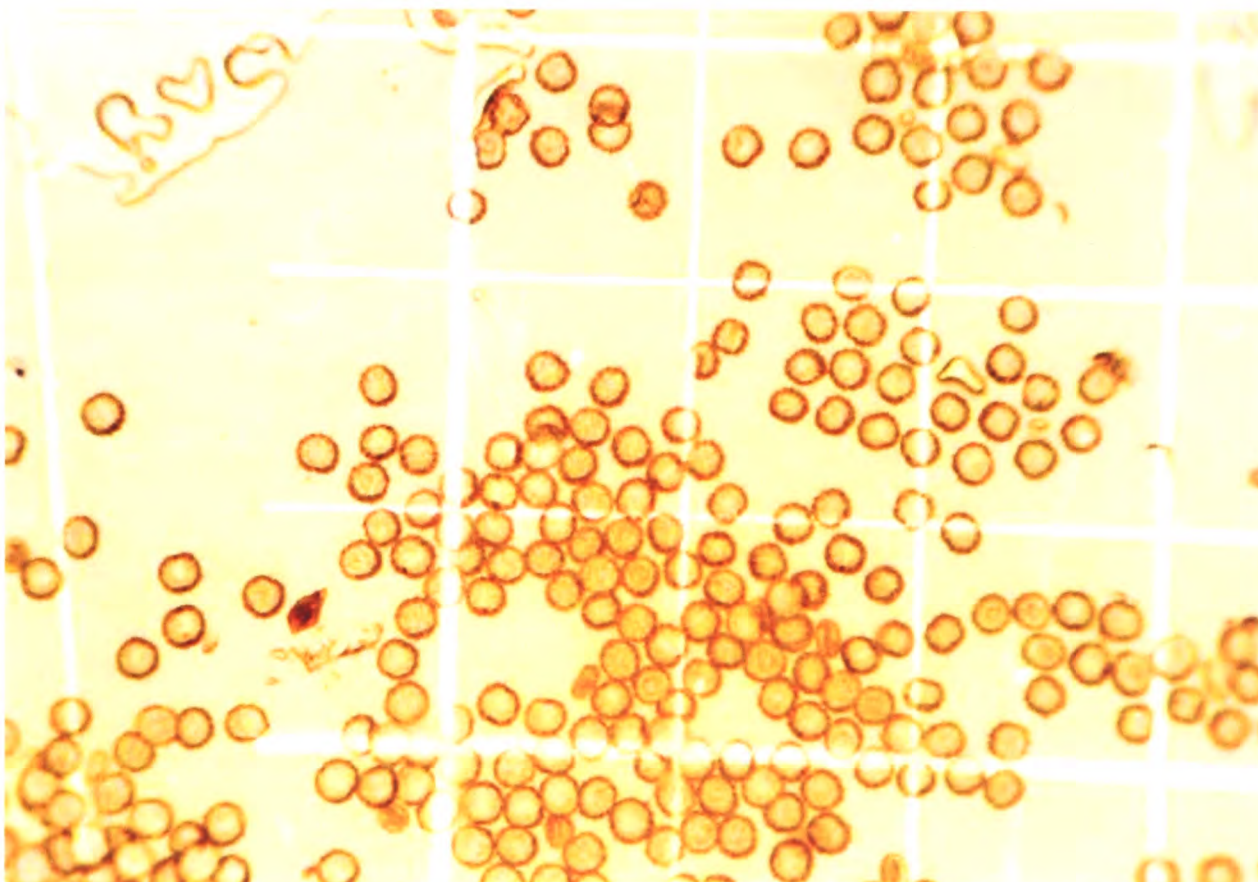


Plate 4: Pollen grains of *Nypa fruticans* on a haemocytometer. They are orange in colour and look round in outline. The size of the grain is $44.7 \pm 2.4 \mu\text{m}$ ($n = 30$). Notice that the square of the haemocytometer is 0.25 mm x 0.25 mm.

CHAPTER 5

PARTITIONING OF POLLEN SOURCE OF *NYPA FRUTICANS* FLOWERS AMONG HONEY BEE SPECIES

Introduction

Nypa fruticans palms usually flower from December to June. They do not provide nectar but they are a very good source of pollen. Flowers start opening before dawn and flowering finishes by sunset. Pollen grains are rather large and very attractive to insects; and the inflorescences of *Nypa fruticans* are so big and strong that insects can land on them and collect pollen easily. Many insects are observed collecting pollen on the opening inflorescences at all times of the day.

In the previous chapter, the distributions of the two honey bee species, *A. dorsata* and *A. florea* on *Nypa fruticans* and *Melaleuca leucadendron* suggested the partitioning of the food source. Both *Nypa* and *Melaleuca* flowers attract *A. dorsata* and *A. florea*, the two closely-related species, that forage for the same food of pollen and nectar. However, partitioning is evident: from early in the morning *A. dorsata* forages on *Nypa* flowers, of which the best pollen reward is from 07.00 h to 09.00 h. It then shifts to *Melaleuca* flowers at mid-morning, when the sugar value in a *Melaleuca* flower is the highest. In contrast, *A. florea* visits *Melaleuca* flowers early in the morning, when the nectar is not the best but still good; and then shifts to *Nypa* after mid-morning. These results suggest that *A. dorsata* and *A. florea* have temporally partitioned the same food sources.

Some questions arise from the findings of this study. Why did *A. florea* not visit *Melaleuca* and *Nypa* flowers when the flowers provided the best rewards? Is it

because *A. dorsata* dominates during these optimal periods and *A. florea* loses out? In the areas where *A. florea* does not share *Melaleuca* nectar and *Nypa* pollen with *A. dorsata*, will *A. florea* visit the flowers at the times of the best flower rewards? In areas where *A. florea* and the Asian hive honey bee, *A. cerana* co-exist, is there a partitioning like that between *A. florea* and *A. dorsata*? And in the areas where the European honey bee, *A. mellifera* is introduced, is there a partitioning of the food source or a competition among honey bee species? Therefore, the objectives of this chapter are to study the visitations to *Nypa fruticans* flowers by the following honey bee species:

1. *Apis florea* while its sympatric honey bee, *A. dorsata* is excluded experimentally from flowers;
2. *Apis florea* in the place where it is the only honey bee;
3. The two sympatric honey bee species, *A. florea* and *A. cerana*;
4. The two sympatric species (*A. florea* and *A. cerana*) and the imported *Apis mellifera*;
5. The two sympatric species (*A. florea* and *A. dorsata*) and the two introduced species (*A. cerana* and *A. mellifera*).

Materials and Methods

The study was carried out from December 2003 to March 2004 in *Melaleuca* forests of Ca Mau province, Vietnam where *A. florea* and/or *A. dorsata* are the native honey bees; and in an agricultural area of Ben Tre province, Vietnam where *A. florea* and *A. cerana* are the sympatric species (Figure 1).

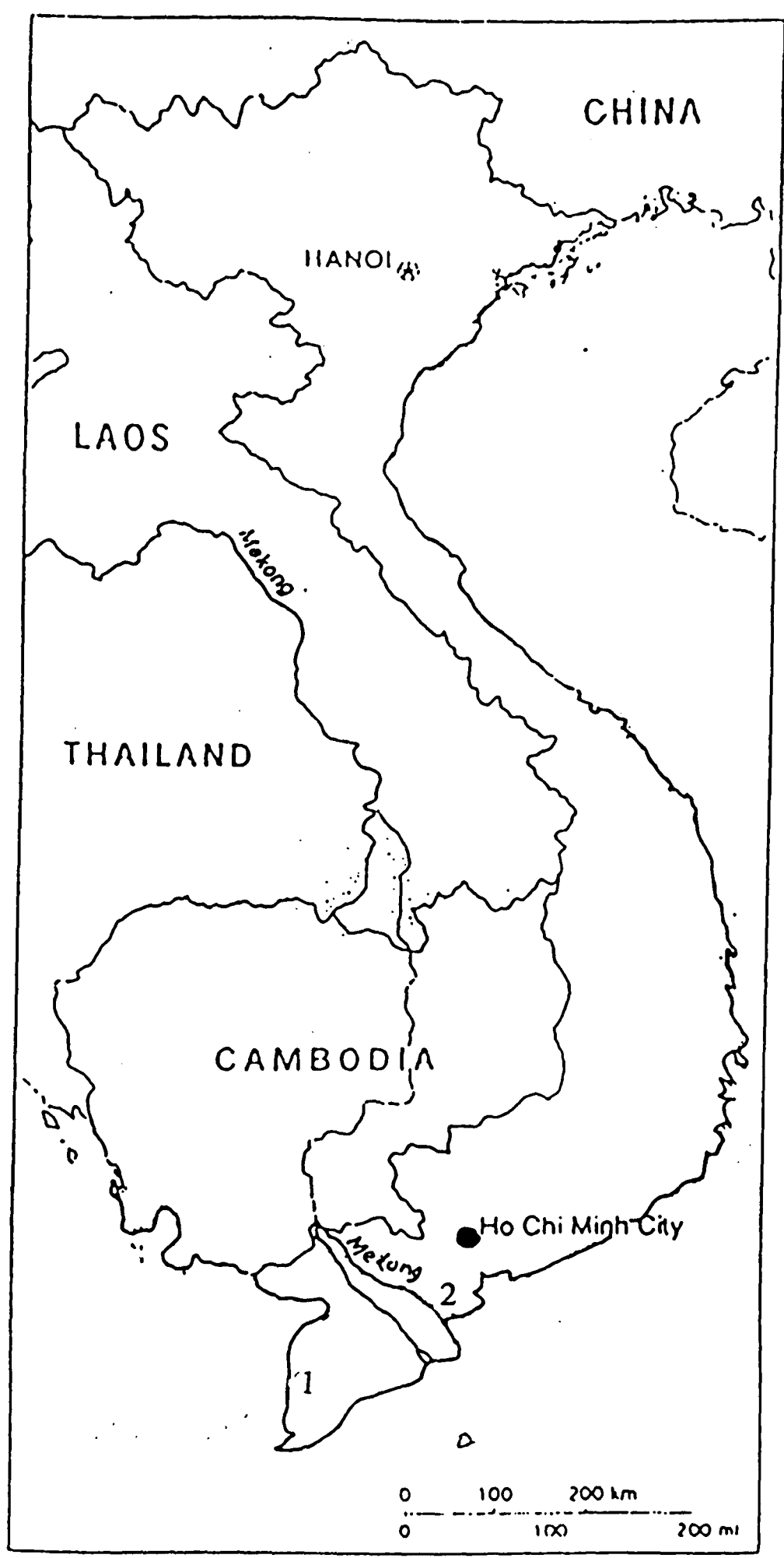


Figure 1: Map of Vietnam showing the study sites.

1 Ca Mau Province

2 Ben Tre Province

In the experiment, *Apis dorsata* was excluded from 19 groups of inflorescences of *Nypa* flowers using nylon netting with holes of 4 mm square (see Plate 1). In a *Melaleuca* area where *A. florea* was the only honey bee, the bee visitations were counted on 17 groups of inflorescences of *Nypa*. In the agricultural area of Ben Tre province where *A. florea* and *A. cerana* are sympatric, their visitations were counted on 35 groups of inflorescences; and then, two weeks after a professional apiary of more than 100 *A. mellifera* colonies was transported into the area, the visitations of the three honey bees were observed on 12 groups of inflorescences. Finally, for the study of visitations to flowers of the four honey bee species, an *A. cerana* colony and an *A. mellifera* colony were introduced into a *Melaleuca* forest where *A. florea* and *A. dorsata* are sympatric; then the observation was carried out on 17 groups of inflorescences. The bee visitation was quantified by counting number of bees on the group of selected inflorescences once every hour from 05.00 h to 18.00 h.

Statistics and graphics:

Kolmogorov-Smirnov tests (Sokal & Rohlf 1995) were applied to analyse the distributions of visitors on flowers during time of the day. All tests are two tailed. Graphics were drawn using Microsoft Excel 2002 SP-1.

Results

When *A. dorsata* was excluded from *Nypa* flowers, *A. florea* visited the flowers about an hour earlier than it did when the two species partitioned the source. The distributions of *A. florea* visitations on flowers in the two cases are very highly significantly different ($D = 0.4499$, $P < 0.001$). Similarly, in the place where *A. florea*



Plate 1: Inflorescences of *Nypa* flowers were covered using nylon netting with holes of 4 mm square to exclude *A. dorsata*.

was the only honey bee, it visited the flowers about two hours earlier and the two distributions of visitations are also very highly significant ($D = 0.4507$, $P < 0.001$). Figure 2 demonstrates the distributions of *A. florea* on *Nypa* flowers in the three cases.

The distributions of both *A. florea* and *A. cerana* on *Nypa* flowers during time of the day are shown in Figure 3. Like *A. florea*, *A. cerana* did not start pollen collection very early; no bees were found on *Nypa* flowers at 05.00 h. The distributions of the two species are different significantly ($D = 0.7430$, $P < 0.001$), which shows a temporal partitioning of *Nypa* flower source between the two sympatric species.

After an apiary of *A. mellifera* was transported into the area occupied by *A. florea* and *A. cerana*, there was a change in visitations of *A. florea* to *Nypa*. Most of them visited the flowers earlier (06.00 h in the morning) than normal and then the numbers gradually decreased during the rest of the day; however, its distribution is still different from those of *A. cerana* ($D = 0.3878$, $P < 0.001$) and *A. mellifera* ($D = 0.2069$, $P < 0.001$). The Asian hive honey bee, *A. cerana* still kept its visitation to *Nypa* flowers early in the morning. The European honey bee, *A. mellifera* had the same distribution of visitors on *Nypa* flowers as the Asian honey bee, *A. cerana* and their distributions are not significantly different ($D = 0.2244$, $P > 0.05$). Figure 4 also demonstrates that the European honey bee, *A. mellifera* had started to collect pollen very early in the morning (05.00 h) before the sun rose.

Figure 5 demonstrates the visitation patterns of the four honey bee species to *Nypa* flowers when *A. cerana* and *A. mellifera* were introduced into the area where *A. florea*

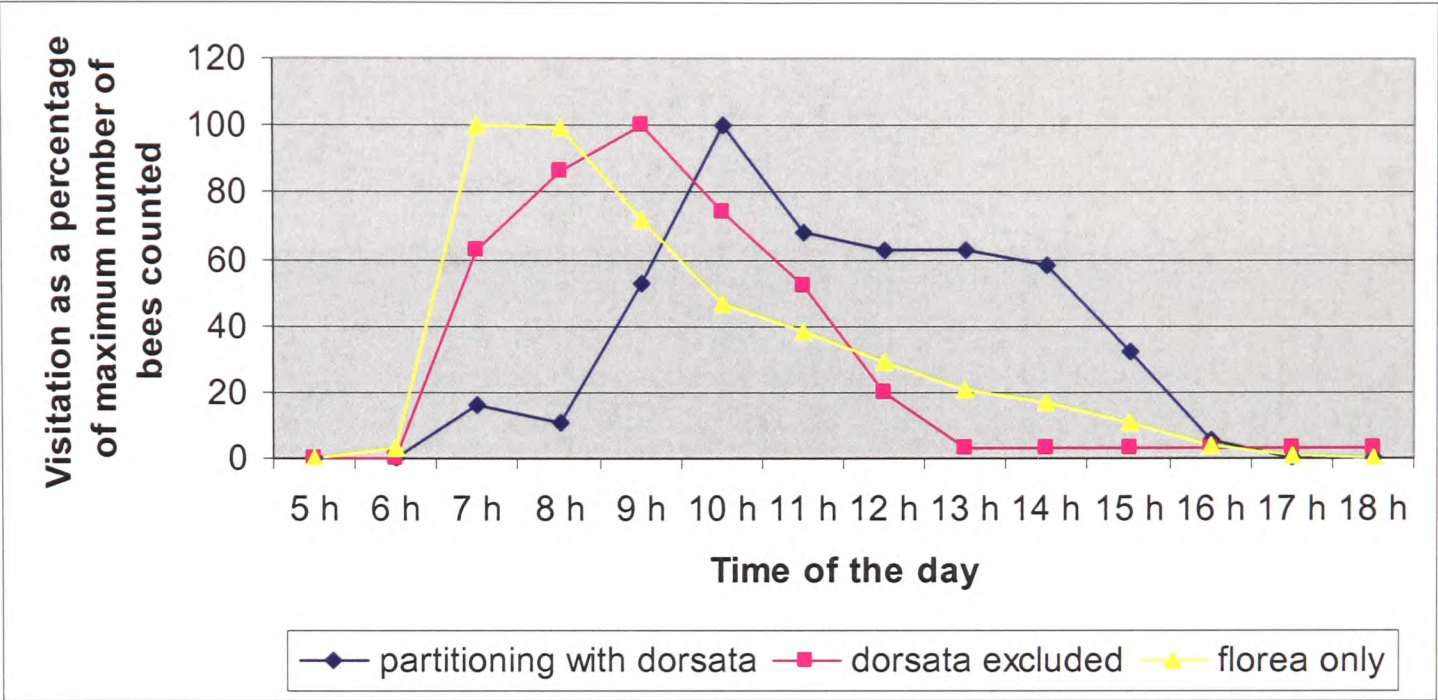


Figure 2: Distributions of *A. florea* on *Nypa* flowers in three cases (number of bees on the selected inflorescences was counted once every hour):

1. Partitioning with *A. dorsata* (data from the previous chapter: in total, 89 *floreas* bees were counted on 29 groups of inflorescences);
2. *Apis dorsata* excluded using netting with holes of 4 mm square (in total, 346 *floreas* bees were counted on 19 groups of inflorescences);
3. *Apis florea*, the only honey bee in the area (in total, 2217 *floreas* bees were counted on 17 groups of inflorescences).

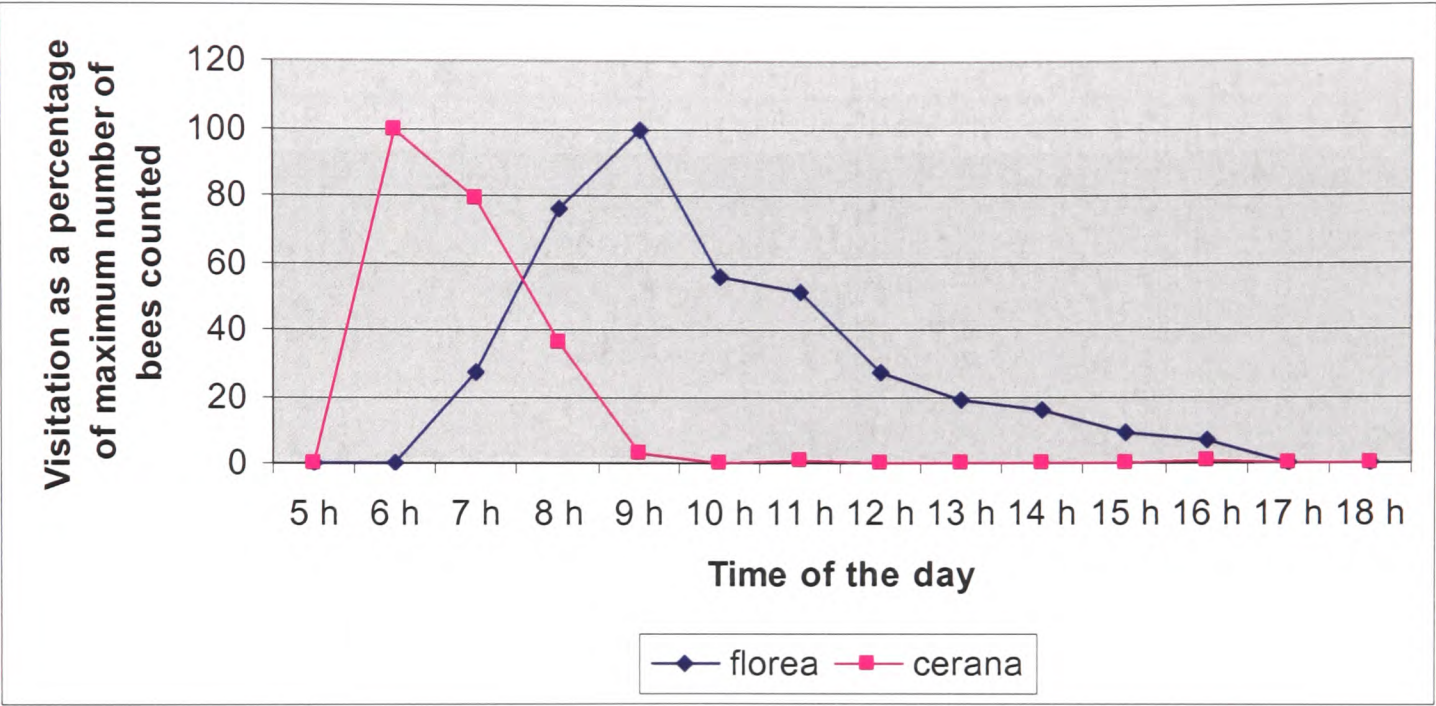


Figure 3: Distributions of *A. florea* and *A. cerana* on *Nypa* flowers.

Number of bees on the selected inflorescences was counted once every hour. In total, 1094 *florea* and 237 *cerana* bees were counted on 35 groups of inflorescences.

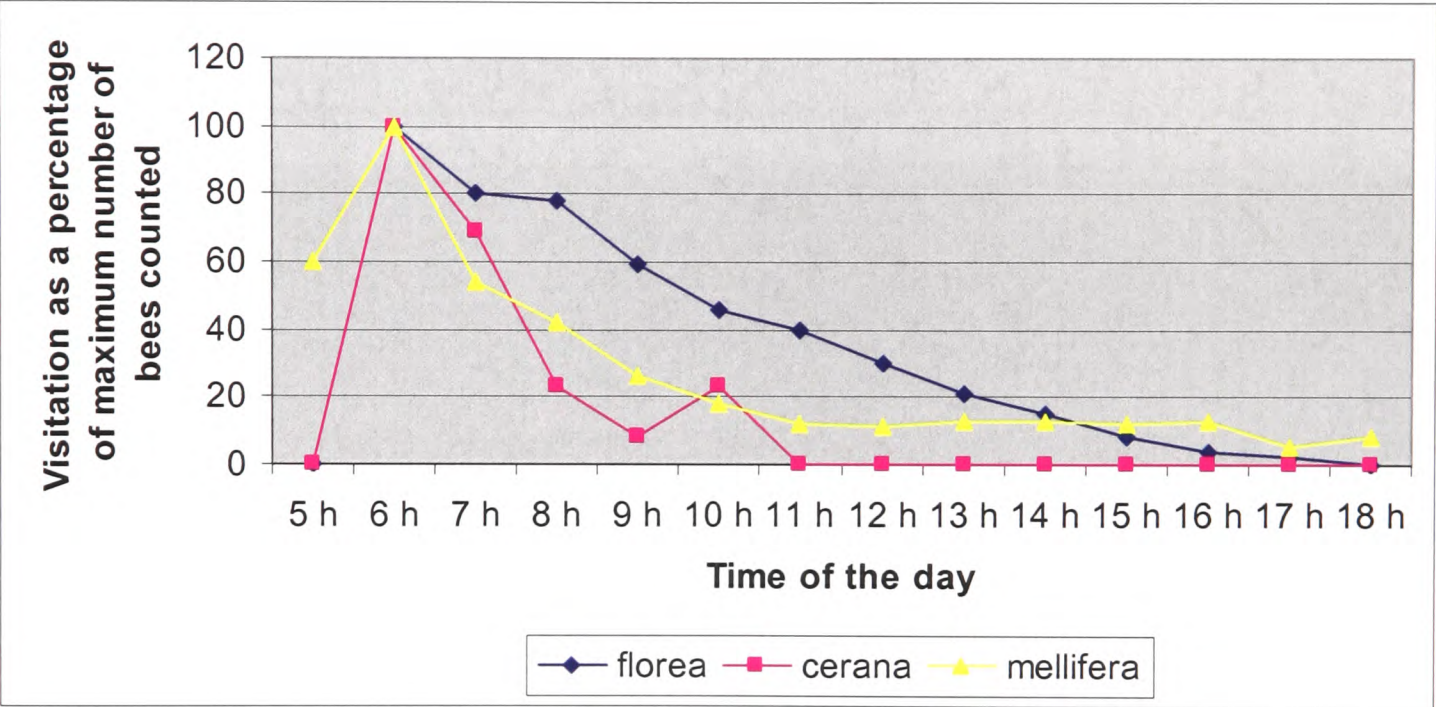


Figure 4: Distributions of *A. florea*, *A. cerana* and *A. mellifera* on *Nypa* flowers.

Number of bees on the selected inflorescences was counted once every hour. In total 2217 *florea*, 29 *cerana* and 1105 *mellifera* bees were counted on 12 groups of inflorescences.

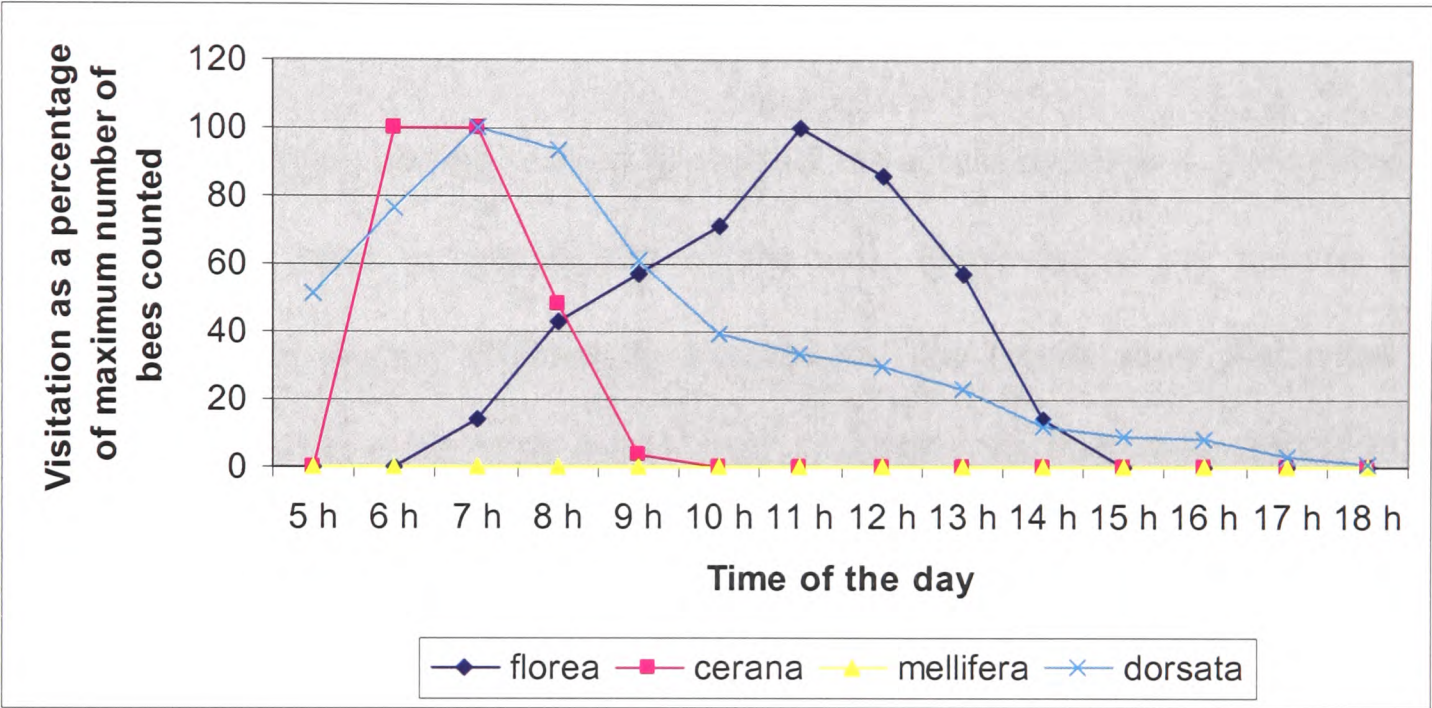


Figure 5: Distributions of *A. florea*, *A. cerana* and *A. dorsata* on *Nypa* flowers.

Number of bees on the selected inflorescences was counted once every hour. In total 31 *floreana*, 58 *cerana*, 856 *dorsata* and no *mellifera* bees were counted on 17 inflorescences.

and *A. dorsata* were sympatric. The visitation of *A. florea* was completely separate from those of *A. cerana* ($D = 0.8537$, $P < 0.001$) and *A. dorsata* ($D = 0.4655$, $P < 0.001$). Although the numbers of *A. cerana* and *A. dorsata* on *Nypa* flowers peaked at the same time (by 07.00 h), the distributions of the two species during the day are still very highly significantly different ($D = 0.3881$, $P < 0.001$). In the two weeks of my observations, no *Apis mellifera* were found on the seventeen observed *Nypa* inflorescences.

Discussion

In the field, the nylon netting seemed to obstruct the access of some *A. florea* bees to the flowers and once in, getting out of the nets. However, in my opinion this phenomenon only slightly affected the experiment. The results show that when *A. florea* did not partition the *Nypa* source with *A. dorsata*, its visitations shifted 1 - 2 hours earlier (before this netting experiment, an explorative study had shown that the temporal partitioning of the flower by the two honey bees was similar to the result in the previous chapter). In the natural condition of pollen collection by many visitors inclusive *A. dorsata*, *Nypa* flowers released most pollen at 09.00 h (see Chapter 4). In this study, *A. dorsata* was absent or excluded, so the peak of pollen release might be earlier. *Apis florea* perhaps visited the pollen source when the flowers provided most pollen. It is also possible that *A. florea* foraged on *Nypa* flowers before the peak of pollen release in order to spend mid-morning on collection of nectar from *Melaleuca* flowers. In nature, honey bee species tend to visit flowers when they offer the best reward or the bee species partitions its foraging time in order to visit different kinds of flowers to gain the most benefit.

Like in the *Melaleuca* forest where *A. florea* and *A. dorsata* are sympatric, there is a temporal partitioning of the flower source between honey bee species in areas where *A. florea* and *A. cerana* are sympatric. *Apis cerana* collected pollen of *Nypa* flowers in the first half of the morning only, then shifted to other nectar sources, such as coconut, longan and water plum flowers.

When *A. mellifera* was transported into the area of *A. florea* and *A. cerana*, there was clear evidence of competition. *Apis mellifera* chased the local honey bees away from *Nypa* flowers and that behaviour was more aggressive to *A. cerana* than to *A. florea*. In comparison with *A. florea*, *A. cerana* is more closely-related to *A. mellifera* and has more similar demands. In addition, all of the three species foraged on *Nypa* flowers early in the morning. *Apis mellifera* had a similar frequency distribution on the flowers to *A. cerana*. *Apis florea* changed its original distribution to spend more time on *Nypa* flowers because *A. mellifera* foraged on the flowers all the day. It is usually considered that the European honey bee, *A. mellifera* is more productive than the Asian honey bee, *A. cerana* perhaps because the former is the earlier worker and stronger competitor as indicated in this study.

When the *cerana* and *mellifera* colonies were introduced into the *Melaleuca* forest, there was also a competition between the local giant honey bee, *Apis dorsata* and the introduced *Apis cerana*. The former chased the latter away from the *Nypa* source but the behaviour between the two species was not as aggressive as that between *A. mellifera* and *A. cerana* in the previous observation in Ben Tre province. The distribution pattern of visitations by *A. cerana* on *Nypa* flowers is still highly different statistically from that of *A. dorsata*.

Nypa pollen was very attractive to *A. mellifera* but why did the European honey bee never visit *Nypa* flowers in the *Melaleuca* forest where *A. dorsata* was present? The low number of *A. mellifera* foragers from a colony did not seem to be the reason, because the number of *A. cerana* was also low but 58 *cerana* foragers were found on *Nypa* flowers. Competition between the Asian giant honey bee, *A. dorsata* and the European honey bee, *A. mellifera* on the *Nypa* source is perhaps the reason. If so, could the competition be so fierce that *A. mellifera* did not get access to the flowers? Does *A. mellifera* usually concede in the competition with *A. dorsata*? Or did it do so in this experiment just because the number of *A. mellifera* colony was too small in comparison with the uncountable number of *A. dorsata* colonies in the area?

Apis cerana is not native in the submerged *Melaleuca* forests, so this honey bee and *A. dorsata* are not sympatric. However, their habitats overlap in many places in Vietnam and other Asian countries. As shown in the previous chapter, Oldroyd *et al.* (1992) proposed that there is a temporal partitioning of *Archontophoenix alexandrea* flowers among *A. dorsata*, *A. cerana*, *A. florea*, *A. andreniformis* and *Trigona* sp.; however, the number of *dorsata* foragers in their study was too small for statistical analysis. *Apis mellifera* has been imported into Asia from Europe; there is no co-evolution between this European honey bee and any Asian honey bee species. The distributions of *mellifera* and *cerana* on *Nypa* flowers were very similar statistically; and the former chased the latter away from the flowers. In addition, no simultaneous presence of *A. mellifera* and *A. dorsata* on *Nypa* flowers suggests a competition between the two species.

CHAPTER 6
APICULTURE OF *APIS DORSATA*:
SOCIO-ECONOMIC FACTORS OF RAFTER BEEKEEPING

Introduction

The domestication of the Asian giant honey bee, *Apis dorsata* is difficult but many efforts have been made to manage this honey bee species and some techniques have proved successful. Crane (1999) gives a detailed history from honey hunting to the active management of honey bee species around the world, including *A. dorsata*. Mahindre (2000) illustrates management of *A. dorsata* colonies using attraction planks in India.

In *Melaleuca* forests of Vietnam, farmers have used rafters to lure *Apis dorsata* swarms to nest. Fougères (1902, cited in Crane *et al.* 1993) and Dau (1991) reported that this traditional beekeeping technique was practiced in the early 19th century. According to Dau (1991), surveys in Southern Vietnam between 1805 and 1836 showed that honey hunting or rafting was the most important occupation of sixty eight villages in the submerged *Melaleuca* forests. Beeswax was used to pay tax and for making candles, and honey and wax were sold to commercial ships from Hainan, China. The forest was devastated first by wars between 1945 and 1975, and then by forest clearing for wood and agriculture. As a consequence, rafter beekeeping dramatically decreased in the area. Fortunately, the technique is still used today in the state forestry and fishery farm of Song Trem, Thoi Binh district, some farms in nearby districts of Ca Mau province and in the nearby province of Kien Giang. Chinh *et al.* (1995a, 1995b) and Tan & Chinh (1995) give detailed descriptions and illustrations which have been used in training courses for rafter beekeeping in Vietnam.

Rafter technique:

In general, the rafter is the trunk of a tree, about 2 m in length and 15 cm in diameter supported by two vertical poles. One vertical pole is about 2 m high and the other 1 m high. The rafter therefore slopes at an angle of about 15 - 35 degrees to the horizontal like the rafter of a house (Figure 1a). It appears like the branch of a tree and *A. dorsata* builds its nest beneath it. Normally, *Melaleuca cajuputi* trees are used to make rafters because they are always available. Other trees; such as *Areca catechu* L. (Arecaceae) and *Annona glabra* L. (Annonaceae), are also used but they form a very small percentage of the total.

A beekeeper splits lengthways a tree trunk of length 1.8 - 2.0 m and diameter 10 - 17 cm into two parts to make two rafters (Figure 1b). A triangular hole is made at one end of the rafter. When the rafter is erected the hole is slotted over the top of the higher vertical pole (Figure 1c). A channel can be made along the flat side of the rafter to drain off rainwater so that it does not seep into the bee comb. The bark is removed (if not it takes the bees time to do the job) and some beekeepers smear the curved side with a thin layer of beeswax.

The beekeeper chooses a quiet open space in the *Melaleuca* forest or makes one by cutting down some high trees. The direction of the rafter is decided before the vertical pole is positioned (Figure 1d). The rafter is supported by the higher pole with the hole in the rafter slotting over the end of the high pole (Figure 1c). The lower pole supports

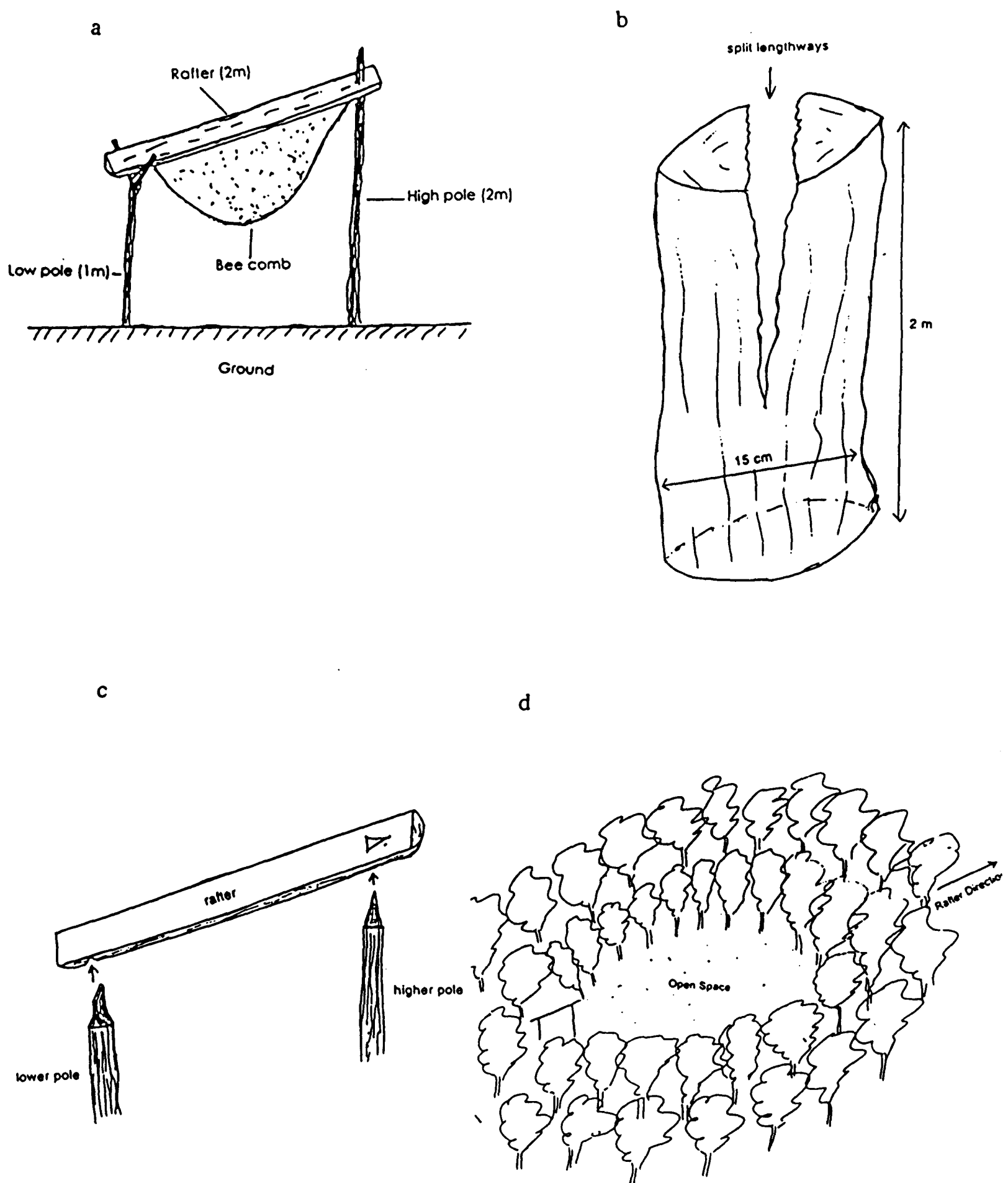


Figure 1: Rafter making and erecting.

- a) The rafter is the tree trunk sloping $6 - 41^{\circ}$ to the horizontal.
 - b) A tree trunk is split lengthways to make two rafters.
 - c) The rafter is supported by the two poles.
 - d) A rafter is erected at the edge of an open space in the forest.
- The higher point of the rafter is directed to the open space.

the rafter with its V-shaped top (Figure 1a) or as shown in Figure 1c. The curved side of the rafter must face downwards. Grasses and small trees beneath the rafter are cleared. Finally it is shaded using small branches and leaves. The rafter is now an ideal nest site for an *A. dorsata* swarm to build a comb.

By observing *Melaleuca* in flower or the water collecting activity of the bees, the beekeeper knows when the honey is ripe for harvest. On average, the first harvest can take place 20 - 30 days after the rafter has been occupied. The second harvest can be carried out about 30 days later. It is possible to harvest a third time from these colonies. The bees were chased away using smoke from a torch made of dry reed and *Melaleuca* leaves. As torches used to be one of the causes of forest fires, commercial smokers designed for use with *A. mellifera* were introduced in 1993. Honey is stored in the highest part of the comb and it is cut off without destroying the brood. However, beekeepers usually cut a part of the brood from a big colony because they believe that if they do not the next harvest will be smaller. This does not seem logical – the more bees the more honey produced. It is possible that when the brood is cut, queen cells are removed which prevents swarming. This does not seem logical either – swarming produces more colonies, so more honey is harvested. In the past, open containers were used during harvest in the forest, so honey was mixed with dirty leaves and water; it was then squeezed by hand and stored in non-airtight containers. Therefore, the quality was low and the honey was spoiled after a few months of storage. Since 1993, containers with covers for harvest as well as air-tight containers for storage have been used. The honey comb is cut into small pieces, squeezed and filtered. Consequently, the quality is much improved and can be stored longer.

Beeswax is harvested from the honey combs, very little wax from old brood combs and the honey and beeswax are sold in local markets.

There are two seasons in the year in southern Vietnam: the dry season from December to April and the rainy season from May to November. The dominant plant species in the *Melaleuca* forests is *Melaleuca cajuputi* (Myrtaceae), which is suited to acidic soil in coastal areas (Brinkman & Xuan 1991). Its flowers are a very good source of nectar and pollen. The tree blooms from December to September with two peaks from February to April and from June to August. The bees start to arrive in the area in December, peak in February or March and stay until May. The first honey season is mainly between February and April. In May the major part of the colonies fly away, but again start to return in June and peak in July. The second honey season is in July and August. After that the colonies depart in September. At other times of the year some *A. dorsata* colonies can be found in the *Melaleuca* forests, but these colonies store little honey.

The need for a socio-economic study:

Many papers on the traditional rafter technique have been written by local researchers (Nam 1959; Dau 1991; Chinh *et al.* 1995a, 1995b; Tan & Chinh 1995; Tan *et al.* 1997, 1999) and internationally (Crane *et al.* 1993; Mardan 1993; Mulder 1995). However, these studies have only surveyed socio-economic aspects in a preliminary manner or mostly examined the techniques and ecology of the system, and very few have dealt with socio-economic aspects. Moreover, between 1985 and 1995, the state forestry farm of Song Trem allocated forest land to individuals (forest holders) from local and other crowded areas in Ca Mau province, and since then, conflicts have

arisen in the community between the beekeepers and the new forest holders. This study analyses the role of rafter beekeeping and its economic efficiency as well as the misunderstandings and conflicts that have arisen between the beekeepers and the forest holders. In addition, the need for preservation of traditional rafter beekeeping in the *Melaleuca* forest is discussed.

Materials and Methods

The study was carried out in the state forestry and fishery farm of Song Trem, Thoi Binh district, Ca Mau province, Vietnam from March 2001 to September 2002. For the study of social factors, separate interviews were carried out with 15 randomly selected forest holders and 15 rafter beekeepers using questionnaire. Key officials of the Song Trem state farm as well as the provincial Department of Agriculture and Rural Development were also interviewed for information on management and social condition.

For the study of economic efficiency, 30 beekeepers were chosen at random. Each was interviewed separately using questionnaire to collect data for the past three years; i.e. from the rainy season 1999 to the dry season 2002. Methods of collecting and processing the data followed those from earlier economic studies on *A. mellifera* and *A. cerana* beekeeping in Vietnam (Binh & Tan 1992, 1994; Tan & Binh 1994). Field works and observations were conducted with the beekeepers to estimate the time needed for activities such as rafter making and erecting, honey collecting, etc. All of the costs relating to rafter beekeeping activities were considered to be the total production costs. All values beekeepers obtained from the activities were the total production values. Profit was the subtraction of the total production values and the

total production costs. Income was the addition of the profit and labour cost because the labour was from the beekeeper himself or his family. Production cost per litre of honey was calculated according to the formula:

Production cost per litre of honey = (total production costs) / (X + Y)

where X = total amount of honey harvest

where Y = value of beeswax equivalent to Y kg honey using the exchange ratio at the time of survey.

Statistics and graphics:

Most data was given in MEAN $\pm$ SD (n). Because the data on rafter numbers, honey yield and honey harvest are not normally distributed, the nonparametric tests such as Friedman and Mann-Whitney were applied. ANOVA, Student's t test and Pearson's correlation were used for the analyses of the occupation rates because their distributions are normal. All tests are two tailed. Most statistical analyses were performed and graphics were drawn using MINITAB package version 12.21.

Results

The state forestry and fishery farm of Song Trem

The farm of Song Trem was founded in 1982, and covers an area of 10,079 ha, of which 6,500 ha is covered with *Melaleuca* forest and 970 ha is reserved for agriculture. The remainder is occupied by houses and canals, or is wasteland. The farm stretches 25 km along the right-hand side of the river Trem. To reach the forest

from the river, large canals have been dug one kilometre apart, and inside the forest smaller canals have also been dug every kilometre to join the large canals. The canals form a transport system in the forest for boats, and divide the forest into plots of about a square kilometre each (Figure 2). The farm has seventy staff members who care for the forest, and protect it from fires and illegal tree cutting. Currently, most of the farmland is allocated by contract to forest holders. There are 1166 households of 5876 people living on the state farm. Data from the local authority and our survey show that up to 70% of households are very poor, with an income of only 7,500 Viet Nam Dong (VND) per person per day (1 USD = 15,000 VND).

The role of rafter beekeepers in managing and protecting the Melaleuca forest

A few officials of the provincial forestry department have told me that honey collection in the *Melaleuca* forest was one cause of forest fires. Nevertheless they, as well as all other key personnel interviewed in the study, recognise that the well-organised groups of beekeepers play an important role in managing and protecting the *Melaleuca* forest.

Under the French colonisation (by 1860's to 1945), beekeepers were allowed to make rafters, and they paid tax. Rafter beekeeping continued during the wars between 1954 and 1975, and beekeepers were important in protecting forests from fires. After 1975, more people started beekeeping, and beekeepers' groups were better organised. When the state forestry farm was founded in 1982, beekeepers were given the responsibility for replanting trees, and security, because they knew the forest very well. Each group of beekeepers was allocated a plot of forest, on which it carried out rafter beekeeping

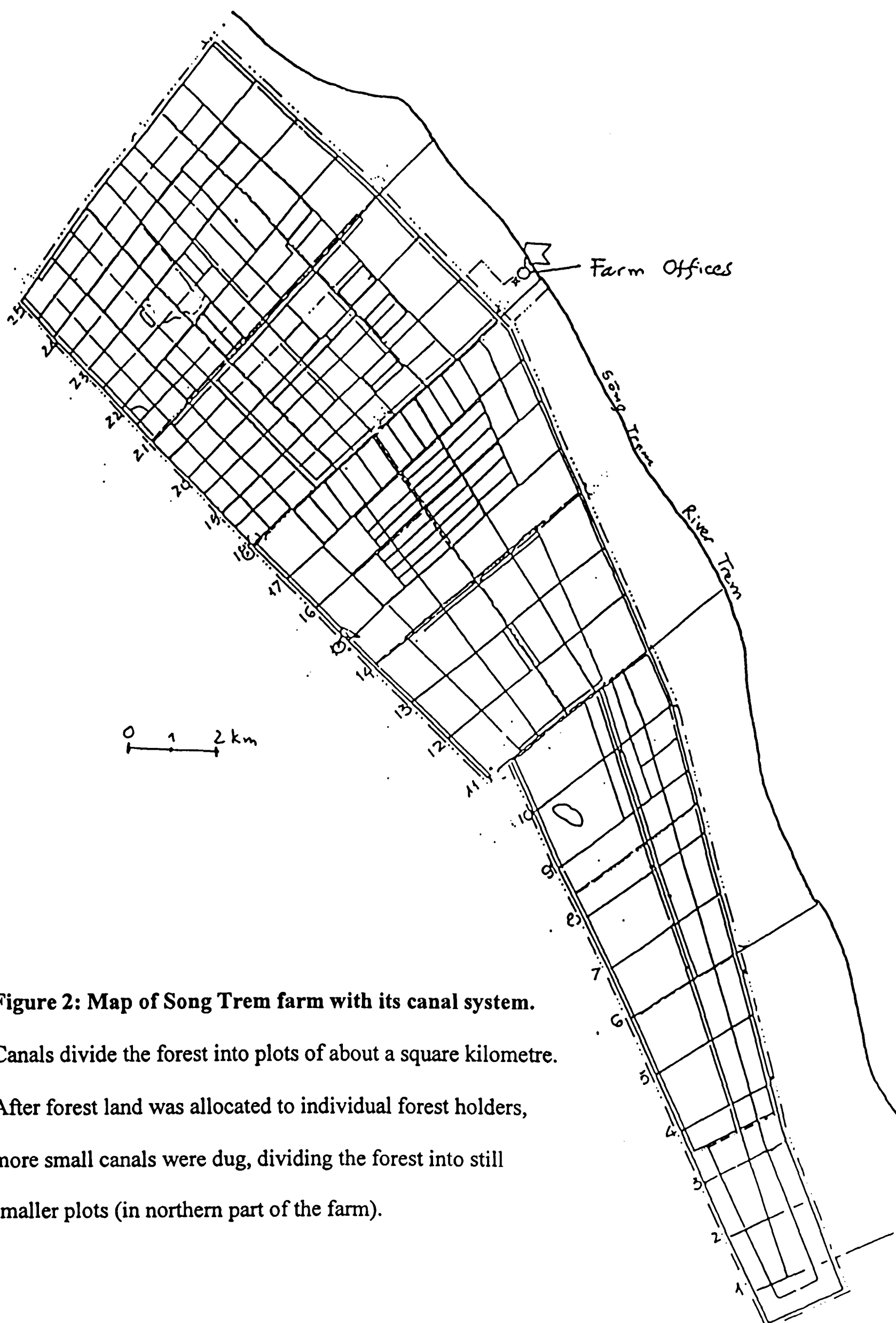


Figure 2: Map of Song Trem farm with its canal system.

Canals divide the forest into plots of about a square kilometre.

After forest land was allocated to individual forest holders, more small canals were dug, dividing the forest into still smaller plots (in northern part of the farm).

and which the group patrolled and protected. A group leader is elected to co-ordinate the group's activities. Groups meet once a month to discuss forest protection issues, exchange knowledge and determine the best time to harvest honey. In any one month, honey harvesting is allowed only for about 4 - 6 days. The timing of the harvest is strictly regulated in the dry season, to prevent fires. Small groups of 2 - 3 people collect honey early in the morning and leave the forest before noon. Beekeepers are very careful when using smoke; and recently smokers have been used and fires are now rare. During harvesting, the area outside the forest is patrolled until late evening, to discover and control any fires. When interviewed in our study, all fifteen beekeepers said that they were serious in protecting the forests from fire and tree cutting: if no trees exist no bees arrive, and their incomes are threatened.

A negative aspect of rafter beekeeping, often pointed out by its critics, is that trees (usually 3 - 4) need to be cut down to make the rafter, supporting poles and shaded clearing. All the forest holders interviewed considered this tree cutting to be illegal and harmful to their livelihoods. However, this tree cutting has a minimal impact on the forest: a beekeeper makes at most ten rafters per hectare on which there are from 5 - 10,000 trees. Therefore, the number of trees cut down by beekeepers represents only a very small percentage (less than 0.7%) of the forest and the rafters can be used for three years.

Recent changes in forest management policy and the emergence of community conflicts

The state forestry farm started allocating forest land to individuals by contract in 1986. Some individuals were local, but most came from other areas in the province. Each household was allocated a forest plot of 5 ha, 100 m along the canal and 500 m deep into the forest. The households are allowed to use about 0.35 ha along the canal to build a cottage and to grow fruit trees and vegetables. The next 1.5 ha is used for growing rice and farming fish. The remainder of the plot (3.15 ha) must be preserved. In 1995, 4900 ha of forest was allocated in accordance with this policy. After receiving land, many forest holders dug further small canals to isolate their land from that of others so the forest was divided into still smaller plots (Figure 2). Contracts were signed between the forestry farm and the forest holders. Some new holders allowed beekeepers to erect rafters on their land, but others did not. The latter affected the lives of beekeepers, and fifteen beekeepers said that they lost 20 - 50% of their income; this has resulted in conflicts between the two groups. Some beekeepers have become more reliant on rice growing, while others have taken jobs locally or moved to cities.

The points of view of the new forest holders and the beekeepers

In our interviews, the fifteen forest holders held different points of view. One group (47%) recognised that raftering was beneficial to both beekeepers and themselves. The remaining 53% did not want beekeepers to work in their plots for several reasons: the fewer people that enter the forest the better; honey harvesting causes fires; beekeepers cut trees for raftering and even steal trees and fish. Some forest holders want to do the rafter beekeeping themselves. Finally, some even said that bees were

harmful to crops and forest. In general, because they had signed the contracts with the state forestry farm, they felt that they had the right to evict beekeepers from their land.

All the fifteen beekeepers interviewed had a different point of view: rafter beekeeping is their traditional occupation and the forest is their livelihood; 66% said that the forests still existed because of them; all said that they are professional beekeepers, and never caused forest fires; 40% accused the forest holders, honey hunters and honey stealers of causing fires, because they did not know the proper technique of honey collection.

However, when asked about cooperation in rafting between a beekeeper and a forest holder, more than 90% of people in the two groups agreed to make contracts about sharing honey and beeswax.

General economic information on rafter beekeeping

Table 1 shows general economic information concerning a beekeeper's family. Rice was the main agricultural crop. While farmers in other areas of the Mekong delta could grow 2 - 3 crops a year and yield 4 - 5,000 kg of paddy rice per hectare per crop, people in the study area could only manage one crop a year and about 3,000 kg of paddy rice per hectare per crop due to constraints of soil and irrigation in the *Melaleuca* forest. Paddy rice was sold at 2,000 VND/kg in 2000 - 2001 and 2,300 VND/kg in 2002. The beekeepers and their family members could be employed and got paid for tree cutting and shrimp raising. Daily salary levels for such work were about 30 - 35,000 VND/labour. However, the income from beekeeping represents an

Table 1: General information of a beekeeper family (1 USD = 15,000 VND).

Information	Mean	SD	n	Range
Land area per beekeeper family (ha)	0.65	0.53	30	0 - 2.4
No. of people/family	5.8	2.3	30	1 - 12
Total values of production activities of family per year (thousand VND):				
Cultivation	4,100	3,300	30	0 - 14,900
Employment	4,470	4,150	30	0 - 12,000
Rafter beekeeping	6,870	4,750	30	1,400 - 23,000
Total	15,440	8,100	30	6,200 - 37,900

average of 44.5% (ranging from 11 - 100%) of the total income of a beekeeper's family.

Table 2 shows the results of my survey on the rafter numbers and the occupation rates of thirty beekeepers during six seasons over three years. The number of rafters varied greatly among beekeepers (Friedman test for number of rafter, treatment by beekeeper, blocked by season and year, $S = 153.82$, $DF = 29$, $P < 0.001$) and decreased very slightly from the rainy season 1999 to the dry season 2002 (Friedman test for number of rafter, treatment by season and year, blocked by beekeeper, $S = 11.19$, $DF = 5$, $P = 0.048$). The occupation rates were very highly significant among the thirty beekeepers (two-way ANOVA, $F_{29, 145} = 7.69$, $P < 0.001$) and among the six seasons (two-way ANOVA, $F_{5, 145} = 37.95$, $P < 0.001$). Surprisingly, the occupation rate did not relate to the raftering experience of the beekeepers as shown in Figure 3.

Because the numbers of rafters and the occupation rates are different among beekeepers, their annual honey harvests vary, ranging from 62 to 1060 litres. On average, a beekeeper could harvest 322 litres of honey per year. In addition, he could harvest 9.7 kg of beeswax (equivalent to 19 litres of honey) and 6.3 kg beeswax (equivalent to 10 litres of honey) per rainy season and dry season, respectively. Table 3 shows some comparisons between the rainy and the dry seasons.

Production costs

Total production costs of rafter beekeeping comprised labour costs and material costs (Table 4). Labour costs included rafter making, erecting, visiting and repairing; honey

Table 2: Number of rafters and occupation rate (%) of 30 beekeepers during six seasons (three years).

Beekeeper	Season and year												Mean												
	Rainy 99				Dry 00				Rainy 00					Dry 01				Rainy 01				Dry 02			
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%		No.	%	No.	%	No.	%	No.	%	No.	%		
1	200	50	150	33	150	47	100	50	100	70	100	30	133.3	46.7											
2	60	83	60	33	60	83	60	33	60	67	60	12	60.0	51.9											
3	80	50	80	38	80	75	80	38	80	62	80	62	80.0	54.1											
4	80	50	80	38	80	50	80	38	80	50	80	38	80.0	43.8											
5	20	50	30	33	30	60	40	42	40	50	50	30	35.0	44.3											
6	200	25	200	20	200	30	200	10	200	20	80	12	180.0	19.6											
7	150	53	150	40	150	80	150	33	150	67	150	47	150.0	53.3											
8	150	67	150	27	150	67	150	20	150	80	150	30	150.0	48.3											
9	70	57	70	14	70	71	70	21	70	28	70	21	70.0	35.7											
10	120	100	120	58	120	83	120	62	120	100	120	33	120.0	72.9											
11	110	54	110	36	110	54	110	18	110	54	110	38	110.0	42.7											
12	150	60	150	27	150	67	150	20	150	47	150	20	150.0	40.0											
13	100	60	100	50	100	70	100	20	100	60	100	15	100.0	45.8											

14	70	71	70	71	70	71	70	71	70	71	60	83	68.3	73.4
15	120	67	120	17	120	67	120	22	120	56	95	84	115.8	52.1
16	200	50	100	60	100	60	200	25	200	25	50	40	141.7	43.3
17	180	83	150	67	150	87	150	67	150	80	50	74	138.3	76.2
18	50	80	60	50	60	83	80	62	80	75	40	50	61.7	66.8
19	100	50	100	30	100	45	100	30	100	45	100	20	100.0	36.7
20	130	46	130	23	130	46	130	23	130	62	150	40	133.3	40.0
21	80	62	80	28	80	38	80	25	80	44	80	31	80.0	37.9
22	90	50	90	33	90	67	90	44	90	56	90	17	90.0	44.4
23	70	86	70	43	70	71	70	57	70	86	70	43	70.0	64.3
24	150	47	150	17	150	43	150	40	150	53	150	33	150.0	38.9
25	200	50	200	45	200	75	200	25	200	60	200	40	200.0	49.2
26	200	75	200	40	200	60	200	40	200	75	200	25	200.0	52.5
27	200	15	200	12	200	18	200	20	200	25	200	15	200.0	17.5
28	200	60	200	30	200	75	200	25	200	50	200	15	200.0	42.5
29	120	83	120	42	120	75	120	50	120	83	100	30	116.7	60.6
30	150	67	150	20	150	53	150	47	150	67	150	33	150.0	47.8
Mean	126.7	60.1	121.3	35.8	121.3	62.4	124	36.0	124	58.9	109.5	35.4	121.1	48.1

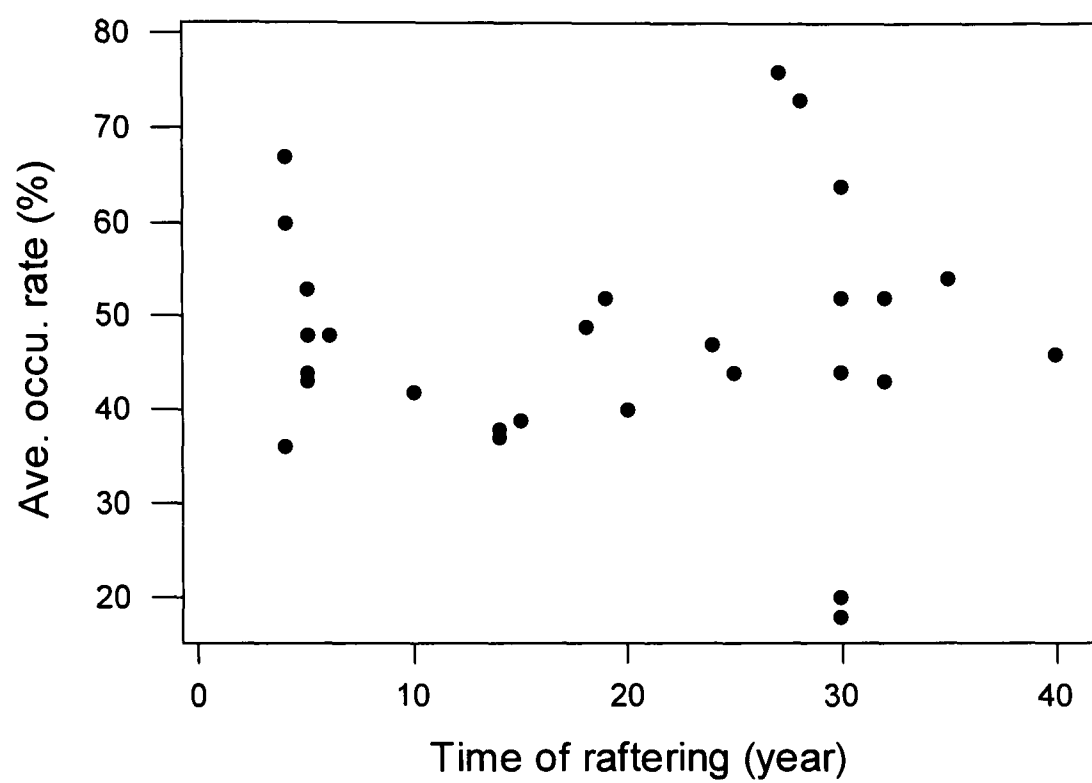


Figure 3: Relationship between the occupation rate and the rafting experience of the beekeepers ($r = 0.039$, $P = 0.839$, $DF = 28$).

Table 3: Comparison of some criteria between the rainy and the dry seasons. Data is given as MEAN $\pm$ SD (n).

	Rainy	Dry	Significance
No. rafters/beekeeper	124.0 $\pm$ 50.0 (90)	118.3 $\pm$ 48.8 (90)	Mann-Whitney test, W = 8417.5, P = 0.4320
Occupation rate (%)	60.5 $\pm$ 17.9 (90)	35.8 $\pm$ 16.9 (90)	t test, t = 9.53, P < 0.001
Honey yield (litres/colony/season)	2.62 $\pm$ 1.39 (90)	3.26 $\pm$ 2.06 (90)	Mann-Whitney test, W = 7409.0, P = 0.0351
Honey harvest (litres/beekeeper/season)	194.6 $\pm$ 136.1 (90)	126.7 $\pm$ 109.3 (90)	Mann-Whitney test, W = 9432.0, P < 0.001

Table 4: Economic efficiency of rafter beekeeping.

Indicator	Value in thousand VND	
Total production costs:		
Labour	1,785	(78%)
Materials	502	(22%)
Total	2,287	(100%)
Total production values:		
Honey	6,304	(92%)
Beeswax	560	(8%)
Total	6,864	(100%)
Profit	4,577	
Income	6,362	
Production cost of honey	6.5 per litre or 5.0 per kg	
Total production values		
Total production costs	3.0	
Profit		
Total production costs	2.0	
Income		
Total production costs	2.8	

collecting, squeezing and filtering; beeswax melting and casting, as well as the beekeepers' meetings. Material costs consisted of wood to make rafters, transport, honey containers and rafting tools, such as axes and knives.

In general, it took about 2.5 hours for a beekeeper to make and erect a rafter. Visiting and repairing rafters was done three times a season and it took about two days (16 hrs) to do the job for 100 rafters. Collection of honey from 100 colonies was finished in 12 days (96 hrs). Honey squeezing and filtering of 100 litres of honey takes one day (8 hrs). Beeswax melting and casting takes about 4 hours per 10 kg. Meetings of beekeepers were monthly and of 4 hours duration each. The price of a *Melaleuca* tree to make two rafters was about 15,000 VND and a rafter could last for three years. A boat for transport was about 600,000 VND and it was used for four years. Depreciation of honey containers, axes and knives was about 50,000 VND per year.

In details, the annual cost of labour for a beekeeper comprises the following:

- Rafter making and erecting: $2.5 \text{ hrs/rafter} \times 121 \text{ rafters} / 3 = 101 \text{ hrs}$
(divided by 3 because a rafter lasts for 3 year)
- Rafter visiting and repairing:
 $0.16 \text{ hr/rafter} \times 121 \text{ rafters} \times 3 \text{ times/season} \times 2 \text{ seasons} = 116 \text{ hrs}$
- Honey collecting: $0.96 \text{ hr/colony} \times 58 \text{ colonies/season} \times 2 \text{ seasons} = 112 \text{ hrs}$
(58 colonies are from 121 erected rafters multiplied by 48% occupation rate)
- Honey squeezing and filtering: $8 \text{ hrs/100 litre} \times 322 \text{ litres} = 26 \text{ hrs}$
- Beeswax melting and casting: $4 \text{ hrs/10 kg} \times 16 \text{ kg} = 6 \text{ hrs}$
- Meetings: $4 \text{ hrs/time} \times 12 \text{ times} = 48 \text{ hrs}$

Total: 409 working hours or 51 labour days.

Raftering is considered to be hard work and the payment in the area for hard work was 35,000 VND per day.

And the annual costs of materials for a beekeeper are estimated to be as follows:

- Rafter: 7,500 VND/rafter x 121 rafters / 3 = 302,000 VND
- Boat: 600,000 VND / 4 = 150,000 VND
- Containers and tools per year: 50,000 VND

Production values

Table 4 shows that the production values of rafter beekeeping were mainly from honey (occupying 92%), and beeswax accounts a very small percentage (8%). More than 90% of honey was sold wholesale to business people who transported it to consumers in the district town or the big cities of Ca Mau, Can Tho and Ho Chi Minh City. During 1999 and 2002, the price of honey was about 18,000 VND per litre in the rainy season and 22,000 VND/litre of honey in the dry season. The retail price was rather high, varying from 25 to 35,000 VND per litre, but not reliable. Beeswax was sold at 35,000 VND per kg.

Economic efficiency

Results of the study show that on average a rafter beekeeper invested 502,000 VND for materials and about 409 hrs (51 days) a year to erect 121 rafters in the forest. In return, he harvested 322 litres of honey and 16 kg of beeswax, which is equivalent to

29 litres of honey. Some criteria of the economic efficiency of rafter beekeeping are shown in Table 4.

Discussion

Like in many other farms in the *Melaleuca* forests, a system of canals has been dug in the farm of Song Trem. Canal digging in the submerged *Melaleuca* forests is still very controversial. The positive aspects are convenient transport, clear division of land properties and easy accessibility of water source to stop fires if happening. However, the negative one is that the forest becomes dry very quickly and easy to catch fire in the dry seasons. Therefore, in some parts of the forestry farms, dykes have been built along the canals to keep water in the forest. This seemed to work well in the first years: the forest was kept from fires. However, the *Melaleuca* ecosystem was changed: it became submerged all the year round instead of half of it. Consequently, *Melaleuca* trees did not develop and acidic soil was not reclaimed as before. Other wild plants and animals in the forest were affected, too.

The policy of land allocation to the poor people of the state forestry farm has also been a controversial topic recently. Many people were provided land to live on and to cultivate, keeping them from starvation; however, 1.5 hectares of poor land could not help them get out of poverty. In addition, thousands of people in a remote area with little infrastructures may not be good for their lives. The conflicts between the beekeepers and the forest holders have arisen recently but for the conservation of the forests, they need to be resolved through mutual understanding. The roles of the state forestry departments and beekeeping research organisations will be important in this process.

The results of economic study show that the research area is one of the poorest in Vietnam. Little land property, few, unstable jobs, and low paid labour make the local people very poor. Beekeepers are also the poor in the area. On average, the total values of agricultural activities (cultivation, employment and beekeeping) of a beekeeper family were 15,440,000 VND/year. Because the production costs of rice growing (seeds, fertilisers, pesticides and labour) have not been calculated, the annual income of the family must be lower than that amount. The role of rafter beekeeping varies from one family to another. The range from 35 to 200 rafters per beekeeper depends on his time available and experience. On average, a beekeeper could earn 6,870,000 VND per year from honey and beeswax, accounting for 44.5% (ranging 11-100%) total income of the family. The figure 100% shows that there was at least a family in the area without land and they lived completely on the rafter technique. Rafting is also a very good job: the most skilful and hard working beekeeper studied could get 23,000,000 VND a year from honey and beeswax; so an income as high as 21,400,000 VND a year could be obtained from beekeeping.

Thirty beekeepers that were chosen randomly in this study had experiences in rafting from four to forty years. The occupation rates are very different among the beekeepers and surprisingly do not relate to their experience. The rate of 17.5% was from a beekeeper (number 27 in Table 2) with thirty years' experience but he had little time to visit and repair the rafters. That of 76.2% was found in a 27 year-experienced and skilful beekeeper (number 17 in Table 2). Especially, Table 2 shows that beekeeper 10 always kept the number of 120 bee-preferred rafters during the three years and he could have 100% rafters occupied with bees in two seasons.

Therefore, the personal abilities (skill, experience and effort, etc.) of a beekeeper are more important than experience only.

In the dry season many bee colonies have swarmed, which results in an increase in the colony numbers at the end of the season. The rainy bee season starts just about a month after that; therefore, the occupation rate is higher in the rainy season than that in the dry season. Honey of the dry season is normally sold at higher prices than that of the rainy season because of its lower water content. I estimate that the water content of honey is about 23% for the dry season and 27% for the rainy season. Honey from the rainy season ferments quickly and is often spoiled after six months.

A comparison of the economic efficiency of *Apis dorsata* rafter beekeeping with those of *A. mellifera* (Binh & Tan 1992; Tan & Binh 1994) and *A. cerana* (Binh & Tan 1994; Tan & Binh 1994) is shown in Table 5. Although the study of *A. mellifera* beekeeping was carried out in 1992, that of *A. cerana* in 1994, and there have been lots of changes, especially in the former since then, some findings can be obtained from the comparison. *Apis mellifera* beekeeping is professional and commercial, so its production costs are much more diverse with the expensive equipment, bee feed, bee transport, hired labour and capital interest. In *A. cerana* and *A. dorsata*, less capital investment is needed but the labour needed is more intensive. Obviously, there are no bee feeds and bee transportations in *A. dorsata* rafter beekeeping. *Apis mellifera* beekeepers usually have to invest their big capital for many months to get their products, so the capital interest is high. In contrast, the capital interest is considered to be zero in *A. cerana* and *A. dorsata* beekeeping because the investment of materials is very low and the beekeepers can obtain income very soon after their investment.

Table 5: Comparison of the economic efficiencies of the three beekeeping systems (*A. mellifera*, *A. cerana* and *A. dorsata*) in southern Vietnam. Data of *A. mellifera* and *A. cerana* beekeeping was from Tan & Binh (1994).

Indicator	Amount in USD		
	<i>A. mellifera</i>	<i>A. cerana</i>	<i>A. dorsata</i>
1. Total production costs:			
Equipment	168 (12%)	45 (22%)	33 (22%)
Bee feed	498 (37%)	23 (11%)	0
Transportation	100 (7%)	18 (9%)	0
Labour	378 (27%)	120 (58%)	119 (78%)
Capital interest	236 (17%)	0	0
Total	1,380 (100%)	206 (100%)	152 (100%)
2. Total production values:			
Honey	1,368 (89%)	566 (93%)	420 (92%)
Pollen	60 (4%)	0	0
Royal jelly	28 (2%)	0	0
Wax	31 (2%)	14 (2%)	37 (8%)
Bee combs	48 (3%)	32 (5%)	0
Total	1,535 (100%)	612 (100%)	457 (100%)
3. Profit	155	406	305
4. Income	533	526	424
5. Production cost per unit			
Per kg of honey	0.37	0.20	0.33
Per bee comb	1.44	0.27	

Indicator	Amount in USD		
	<i>A. mellifera</i>	<i>A. cerana</i>	<i>A. dorsata</i>
6. $\frac{\text{Total production values}}{\text{Total production costs}}$	1.1	3.0	3.0
7. $\frac{\text{Profit}}{\text{Total production costs}}$	0.1	2.0	2.0
8. $\frac{\text{Income}}{\text{Total production costs}}$	0.4	2.6	2.8
9. Annual honey yield:	38 kg per colony of 10 combs	18 kg per colony of 5 combs	8 kg per rafter

Consequently, the production values of the three systems are less diverse, in order from *A. mellifera* (with honey, pollen, royal jelly, beeswax, bee comb) to *A. dorsata* (honey and beeswax only). Tan & Binh (1994) reported that *A. cerana* beekeeping was, in general, much more economic than *A. mellifera* although each system had its own advantages and disadvantages due to the ecology, investments, techniques and even the personal preferences of beekeepers. In this study *A. dorsata* beekeeping is as highly economic as *A. cerana* with the similar ratios of total production values to total production costs (3.0) and profit to total production costs (2.0). However, because *A. dorsata* beekeeping needs less money invested per beekeeper than *A. cerana* beekeeping (152 USD compared with 206 USD), it brought less production values (457 USD compared with 612 USD) and less profit (305 USD compared with 406 USD). Because the honey yield of *A. cerana* beekeeping was so high, the production cost per kilogram of honey was very low. A special factor in *A. dorsata* beekeeping is that its labour cost occupied up to 78%; so the income of rafter beekeeper was rather good and the ratio of income to total production costs (2.8) was the highest of the three beekeeping systems. Labour-intensive jobs are at present appropriate in the countryside of Vietnam where human resource is abundant. Rafting provides good employment, but is physically demanding and seems not to be chosen by women.

This study shows that *Apis dorsata* beekeeping is a branch of agro-forestry production with lots of benefit. Its economic efficiency is much higher than that of *A. mellifera* and is similar to that of *A. cerana*. Moreover, beekeeping also depends very much on the ecology, investment and knowledge of the beekeepers. With the account of such factors, rafting with *A. dorsata* is the most appropriate beekeeping for the local people in the *Melaleuca* forests.



Plate 1: A rafter ready for bees to occupy.



Plate 2: A rafter is occupied with an *A. dorsata* colony.

CHAPTER 7

GENERAL CONCLUSIONS AND RECOMMENDATIONS

General conclusions

Academic outcomes of the thesis

New data on the biology of *A. dorsata* are presented in the thesis. The findings; such as, the data and ratios of the sizes of drone and worker cells; the weights of the queen, drone and worker; and the egg production of *A. dorsata* queens may be useful for the future comparative study of the genus.

Data on the morphology of worker bees are representative for the race of *A. dorsata* in the *Melaleuca* forests of southern Vietnam and could be useful for further studies on *A. dorsata* subspecies. The development times of worker, drone and the queen bees of *A. dorsata* presented in this thesis are the second to have been recorded in over 30 years (Qayyum & Ahmad 1967).

Information on the nesting behaviour of *A. dorsata* is reported and compared with that of the European honey bee, *A. mellifera*. Because nest site selection assures the development and reproduction of the colony, five common characteristics can be inferred from this behaviour of the two species.

One, a temperate *A. mellifera* swarm selects a cavity which is large enough to accommodate the colony at full development and which is also appropriately small for bees to regulate the nest temperature. Similarly, *A. dorsata* in the tropics selects the

support bigger and longer than the minimum limits to bear its colony at full development including honey storage; however, no “maximum limits” are selected for *A. dorsata*.

Two, while *A. mellifera* in temperate Europe and North America prefers the cavity facing the South for sunshine all the year, the compass direction is not an issue for *A. dorsata* in the tropics. However, with the nest sites open to strong winds, the wind direction is important for *A. dorsata* in selection of nest site.

Three, the open space in front of the nest site is important for both *A. mellifera* and *A. dorsata* possibly in order that the bees avoid predators on nearby tree branches or simply because the nest site at the big open space can be discovered more easily by scout bees.

Four, the preference of nest sites with remnants of beeswax is found in both species. I do not think that this reflects taking advantage of the old beeswax to build their combs, but rather I think that it is an innate predisposition with another, unknown function.

And five, some properties of the nest site; such as, the aggregation, the height from ground level, the material and the nature (man-made or natural) did not seem to be important in nest site selection of the two species.

Nectar and pollen rewards of *Melaleuca cajuputi* and *Nypa fruticans* flowers are firstly presented in this thesis. Six insect species visiting the two plants' flowers were identified to species, and ten others identified to the level of genus. The relationships within and among the plants and the insects of the *Melaleuca* forest are demonstrated. Under the *Melaleuca* canopy, plants are abundant and necessary to insects; in return, the insects presumably play important roles in pollination of the plants. The two

plants have different communities of flower visitors. A visitor species usually visits flowers of a plant at peak when its flowers release their maximum rewards, or the visitor itself partitions the time to visit different plants to gain the most benefits. However, in the area where many insect species are sympatric, there is temporal partitioning of flower sources, perhaps with the priority to the species of larger body size and greater demand. Such partitioning was not observed between an alien honey bee species and a native one.

This thesis also gives a description of rafter beekeeping technique, its role in forest protection and its economic efficiency in comparison with those of *A. mellifera* and *A. cerana* beekeeping.

Practical outcomes of the thesis

In this thesis, the queen cells of *A. dorsata* were successfully reared and the size of the colonies prior to swarming was determined. These data are essential to practical beekeeping: beekeepers can rear queen cells to divide the colonies or prevent the colonies from swarming or build more rafters to attract the new swarms when the mother colonies are going to swarm.

The findings in nest site selection of *A. dorsata* are undoubtedly very useful for practical rafter beekeeping. From now on, beekeepers can be advised to use their rafters with the minimum size of 13 cm in diameter and 162 cm in length, which should be built at the slope of about 30° to the horizontal. To make this slope, they are advised to build the rafter such that the length of the higher pole is longer than the

lower pole by half the length of the rafter. The very large open spaces (larger than 25 m in diameter) which result from forest fires or from tree felling for wood and agriculture, or which are just outside the forest should be chosen first to erect rafters to get the highest occupation rate. A smaller open space in the forest can also be chosen to build a rafter, and if its diameter is bigger than three metres, it is not necessary to fell any trees to make the open space bigger. It makes sense to prevent some trees from being cut down needlessly by a few beekeepers.

The socio-economic study shows that rafter beekeeping is a sustainable and environmentally friendly technique. It is important in forest protection as well as the lives of local people. If rafter beekeeping did not exist, *A. dorsata* swarms might not arrive or they would arrive and build nests on some slanting trees. These wild colonies would be attractive to many people and there would be a high danger of forest fires. Moreover, if rafter beekeeping was not allowed to be practiced, the income of thousands of families would be seriously affected. Consequently, they would become more dependent on other forest products, such as trees and other wild animals; and the forest would be damaged. Conflicts between the beekeepers and the new forest holders was studied and analysed. Then a preliminary plan of bee product sharing was suggested to the two groups.

Information on the economic efficiency of *A. dorsata* beekeeping and a comparison with those of *A. mellifera* and *A. cerana* beekeeping is useful to policy makers working in agricultural and rural development. For example, this thesis suggests that the European honey bee, *A. mellifera*, should be introduced to a limited extent to the commercial beekeepers with large investments; the Asian honey bee, *A. cerana* is

suitable and should be popular with farmers in almost all the countryside of Vietnam; and then the giant honey bee, *A. dorsata* and its traditional rafter technique are the most appropriate for farmers in the *Melaleuca* forests.

The need for the preservation of traditional rafter beekeeping and the Melaleuca forest

Ecologically, the rafter beekeeping benefits the *Melaleuca* forests because trees need bees for pollination. Technically and environmentally, it is a sustainable technique. Scientifically, it can facilitate many biological and behavioural studies on *A. dorsata*. Socially, it creates jobs for people, thus reducing poverty in rural areas. Culturally and traditionally, people working for survival in the submerged *Melaleuca* forests developed the technique. It has also been suggested that foreign interests in *A. dorsata* apiculture may be important in the development of eco-tourism in Asia (Mardan 1994 & Thapa 2001).

With the global awareness in environmental protection and the perception of sustainable development, a human community needs to live harmoniously with nature and with other human communities. For the conservation of the submerged *Melaleuca* forests in southern Vietnam, the Asian giant honey bee, *A. dorsata* and its traditional beekeeping technique should be preserved. As shown in this thesis, the three factors: bees, trees and humans are important and closely correlated.

Recommendations for further studies

In comparative biology among honey bee species, the existence of mating signs on the queens after mating and the mechanism of sperm transfer from drones to the queen are very important features for a honey bee species. Although no mating signs have been seen (Tan *et al.* 1999), the question of whether a mating sign exists in *A. dorsata* is still reserved until a larger number of virgin queens are observed. Moreover, a study on the mechanism of sperm transfer has never been implemented in *A. dorsata*. Therefore, such studies are strongly recommended for the future. As Ruttner (1988) suggests that the number of observations in a morphological study of honey bees should be the number of colonies, not of individual bees, the measurements of morphology on *A. dorsata* bees in the area should be carried out in more colonies in the future. Because there may be a source of potential error with the method of study on the development time of the bee in this thesis, the time duration from the nest site occupation to the laying of the queen is recommended for future investigation.

The hypotheses on the reoccupation of the nest sites by bees should be tested in the future. They are: whether the bees locate the position of their home nest sites genetically and behaviourally, or whether the bees can detect chemically their own substances left on the nest sites when they return, or whether the remnants of beeswax are the signals for the good nest sites.

In this study the European honey bee, *A. mellifera* never visited *Nypa* flowers on which many giant honey bees, *A. dorsata* were foraging. It seems that competition between the local giant honey bee and the imported bee takes place. However; the mechanisms need to be elucidated.

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APPENDICES

Appendix 1: Plants visited by *A. dorsata* in Song Trem forestry farm.

Five skilful local rafter beekeepers were interviewed independently on the presence of the plants reported earlier by Hung & Tan (1999), and their food source of pollen (P) or nectar (N). A positive result was recorded only from the confirmation of at least two beekeepers.

No.	Latin name	Local name	Food source	Flowering month
	Acanthaceae			
1	<i>Hygrophylla salicifolia</i>	Thốt nốt	N	12-2
	Aizoaceae			
2	<i>Glinus oppositifolius</i>	Rau đặng đất	N	2-3
	Amaranthaceae			
3	<i>Althsernanthera repens</i>	Rau diêu	N	3-5
	Araceae			
4	<i>Colocasia esculenta</i>	Môn nước	P	8-9
	Asteraceae			
5	<i>Grangeria maderaspatana</i>	Rau cóc	P N	1-3
6	<i>Gynura procumbens</i>	Kim thất	P	
7	<i>Pluchea indica</i>	Lức cây	P N	7-8
8	<i>Sphyroranthus affricanus</i>	Cỏ chun vệt	P	
9	<i>Thespia divaricata</i>	Cỏ lúc	N	
10	<i>Wedelia biflora</i>	Rau mui	N	
	Convolvulaceae			
11	<i>Ipomaea aquatica</i>	Rau muống đồng	P N	5-6
	Cucurbiaceae			
12	<i>Gymnopetalum cochinchinense</i>	Dây cứt quạ	P N	6-9

No.	Latin name	Local name	Food source	Flowering month
	Cyperaceae			
13	<i>Cyperus elatus</i>	U du	P N	7-8
14	<i>Eleocharis dulcis</i>	Năn bộp	P	8-9
15	<i>E. ochrostachys</i>	Năn kim	P	8-9
16	<i>E. spiralis</i>	Năn xoắn	P	8-9
17	<i>Scleria oblate</i>	Cỏ mây cắt	P	6-7
	Euphorbiaceae			
18	<i>Antidesma ghaesembilla</i>	Chòi mòi	P N	5-9
	Fabaceae			
19	<i>Vigna luteola</i>	Đậu ma	N	7-11
	Gentianaceae			
20	<i>Nyphoides indicum</i>	Súng ma	P N	7-8
	Loranthaceae			
21	<i>Dendrophloe pentandra</i>	Dây chùm gởi	P	6-7
	Malvaceae			
22	<i>Urena</i> sp.	Ké đầu ngựa	P N	3-4
	Melastomaceae			
23	<i>Melastoma affine</i>	Mua	P N	5-6
	Myrtaceae			
24	<i>Eugenia jambolanta</i>	Trâm ôi	N	6-7
25	<i>Melaleuca cajuputi</i>	Tràm	P N	12-9
	Nymphaeaceae			
26	<i>Nymphaea lotus</i>	Súng trắng	P N	7-10
27	<i>N. nouchali</i>	Súng lam	P N	7-10
	Oenotheraceae			
28	<i>Jussiaea repens</i>	Rau dừa nước	N	2-3

No.	Latin name	Local name	Food source	Flowering month
	Palmae			
29	<i>Nypa fruticans</i>	Dừa nước	P	12-6
	Passifloraceae			
30	<i>Passiflora foetida</i>	Nhãn lồng	P N	3-6
	Phylidraceae			
31	<i>Phylidrum lanuginosum</i>	Đũa bép	P N	11-2
	Poaceae			
32	<i>Imperata cylindrical</i>	Cỏ tranh	P	4-5
33	<i>Leersia hexandra</i>	Cỏ bắc	P N	7-8
34	<i>Phragmites karka</i>	Sậy	P	7-9
35	<i>Saccharum spontaneum</i>	Đế	P N	9-11
	Ponterediaceae			
36	<i>Eichlornia crassipes</i>	Lục bình	P N	8-9
	Rubiaceae			
37	<i>Hedyotis paniculata Dene</i>	Cỏ lười đồng	N	
	Rutaceae			
38	<i>Evodia leptia</i>	Bí bái	P N	2-3
	Scrophulariaceae			
39	<i>Bacopa monierii</i>	Rau đắng biển	P	
	Solanaceae			
40	<i>Solanum nigrum</i>	Nụ áo	N	4-6
	Verbenaceae			
41	<i>Premma intergrifolia</i>	Lá cách	P	
	Vitaceae			
42	<i>Cayratia trifolia</i>	Dây giác	N	6-7

In addition, there were fifty two plant species which were confirmed to be present in the area but have not been determined whether they provide food to *A. dorsata*. They are

Acanthaceae: *Acanthus ebracteatus* and *A. ilicifolius* (local name: Ô rô); Annonaceae: *Annona glabra* (Bình bát); Araliaceae: *Scheffora octophylla* (Chum chim); Asclepiadaceae: *Dischidia rafflesiawa* (Dây mỏ quạ), *Sarcolobus globosus* (Dây cám); Asteraceae: *Aegatum conizoides* (Cỏ cứt heo), *Blumea glandulosa* (Cải trời), *Eclipta alba* (Cỏ mực), *Enhydra fluctuans* (Rau ngổ), *Spilanthus acmella* (Cỏ the); Azoliaceae: *Azolla pinnata* (Bèo dâu); Blechnaceae: *Blechnum serrulentum* (Dón); Commelinaceae: *Commelina diffusa* (Rau trai); Convolvulaceae: *Cucusta hygrophyllae* (Dây tơ hồng), *Ipomaea pes-caprae* (Rau muống biển); Cucurbiaceae: *Zehneria indica* (Chùm thăng); Cyperaceae: *Cyperus javanicus*, *C. proceus* and *C. malaccensis* (Lác), *C. tagetiformis* (Lác chiếu), *Scleria poaeformis* (Cỏ đưng); Dioscoreaceae: *Dioscorea esculenta* (Dây khoai từ) and *D. trinervia* (Dây khoai rặng); Euphorbiaceae: *Glochidion littorale* (Múi); Fabaceae: *Derris trifolia* (Cóc kèn); Guttiferae: *Calophyllumi nophyllum* (Mù u); Lemnaceae: *Lemna minor* (Bèo tấm); Marsileaceae: *Marsilea quadrifolia* (Rau bọ); Moraceae: *Ficus microcarpa* (Gừa), *Ficus pisocarpa* (Sộp); Myrsinaceae: *Ardisia humilis* (Com ngội); Oenotheraceae: *Jussiaea eracta* and *J. linifolia* (Rau muống); Parkeriaceae: *Ceratopteris thalictroides* (Ráng gạc nai); Peperaceae: *Peperomia pellucida* (Càng cua); Poaceae: *Cynodon dactylum* (Cỏ chi), *Echinochloa colonum* (Cỏ nước mặn), *E. crusgalli* (Cỏ lông vục), *Ischaenum indicum* (Cỏ mồm), *Hemarthria longiflora* (Cỏ bắp), and *Panicum repens* (Cỏ ống); Pteridiaceae: *Stenocholena palustris* (Choại); Rubiaceae: *Gymnochtodes proboscidea* (Nhàu), *Paederia consimilis* (Dây thúi đệt), *Psychotria serpens* (Dây kiềm); Salviniaceae: *Salvinia cucullata* and *S. natans* (Bèo tai chuột); Scrophulariaceae: *Limnophila aromatica* (Rau om); Solanaceae: *Physalis*

angulata (Thù lù); Typhaceae: *Typha augustifolia* (Bồn bồn); Verbenaceae: *Gmelina elliptica* (Tu hú).

Appendix 2: Statistical analyses in chapter 2.

Analysis 1: Comparison of worker cell size among 110 colonies.

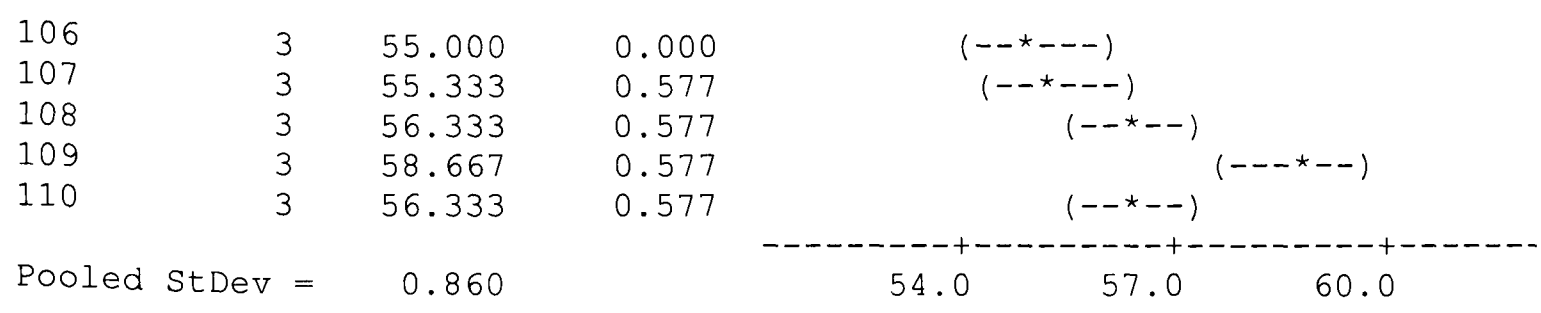
One-way Analysis of Variance

Analysis of Variance for cell diameter

Source	DF	SS	MS	F	P
Colony	109	732.558	6.721	9.09	0.000
Error	220	162.667	0.739		
Total	329	895.224			

				Individual 95% CIs For Mean Based on Pooled StDev			
Level	N	Mean	StDev	-----+-----+-----+-----			
1	3	55.333	1.155	(---*---)			
2	3	54.667	1.155	(---*---)			
3	3	61.000	0.000	(---*---)			
4	3	56.000	2.646	(---*---)			
5	3	54.667	1.528	(---*---)			
6	3	53.000	1.000	(---*---)			
7	3	58.333	0.577	(---*---)			
8	3	52.667	1.155	(---*---)			
9	3	55.667	2.887	(---*---)			
10	3	57.000	1.000	(---*---)			
11	3	54.000	0.000	(---*---)			
12	3	54.000	0.000	(---*---)			
13	3	55.333	0.577	(---*---)			
14	3	55.000	0.000	(---*---)			
15	3	55.000	0.000	(---*---)			
16	3	56.000	0.000	(---*---)			
17	3	56.000	0.000	(---*---)			
18	3	54.667	0.577	(---*---)			
19	3	53.667	0.577	(---*---)			
20	3	56.667	0.577	(---*---)			
21	3	56.000	0.000	(---*---)			
22	3	57.333	0.577	(---*---)			
23	3	55.667	0.577	(---*---)			
24	3	55.000	0.000	(---*---)			
25	3	58.000	1.732	(---*---)			
26	3	54.333	0.577	(---*---)			
27	3	53.667	1.155	(---*---)			
28	3	56.000	0.000	(---*---)			
29	3	55.000	1.000	(---*---)			
30	3	55.333	0.577	(---*---)			
31	3	55.333	0.577	(---*---)			
32	3	58.000	1.000	(---*---)			
33	3	55.667	0.577	(---*---)			
34	3	54.000	1.732	(---*---)			
35	3	56.667	0.577	(---*---)			
36	3	55.000	0.000	(---*---)			
37	3	55.000	0.000	(---*---)			
38	3	56.000	1.000	(---*---)			
39	3	57.000	0.000	(---*---)			
40	3	55.333	0.577	(---*---)			
41	3	55.000	0.000	(---*---)			
42	3	58.000	2.000	(---*---)			
43	3	58.333	0.577	(---*---)			
44	3	53.667	0.577	(---*---)			

45	3	56.333	0.577	(--*--)
46	3	55.333	0.577	(--*--)
47	3	55.000	1.000	(--*--)
48	3	54.000	1.000	(--*--)
49	3	55.333	0.577	(--*--)
50	3	54.667	1.155	(--*--)
51	3	54.333	0.577	(--*--)
52	3	55.000	2.646	(--*--)
53	3	54.000	0.000	(--*--)
54	3	55.000	0.000	(--*--)
55	3	55.667	1.155	(--*--)
56	3	55.333	0.577	(--*--)
57	3	55.667	0.577	(--*--)
58	3	55.000	0.000	(--*--)
59	3	55.333	0.577	(--*--)
60	3	54.333	0.577	(--*--)
61	3	54.333	0.577	(--*--)
62	3	54.667	0.577	(--*--)
63	3	56.000	1.000	(--*--)
64	3	53.333	0.577	(--*--)
65	3	58.000	0.000	(--*--)
66	3	55.000	0.000	(--*--)
67	3	56.000	0.000	(--*--)
68	3	57.333	0.577	(--*--)
69	3	55.667	0.577	(--*--)
70	3	54.667	0.577	(--*--)
71	3	55.000	1.732	(--*--)
72	3	56.000	1.000	(--*--)
73	3	56.000	0.000	(--*--)
74	3	53.000	1.000	(--*--)
75	3	56.667	0.577	(--*--)
76	3	55.333	0.577	(--*--)
77	3	54.333	0.577	(--*--)
78	3	52.333	0.577	(--*--)
79	3	54.667	0.577	(--*--)
80	3	54.667	0.577	(--*--)
81	3	57.000	1.000	(--*--)
82	3	58.333	0.577	(--*--)
83	3	56.333	0.577	(--*--)
84	3	55.667	0.577	(--*--)
85	3	55.667	0.577	(--*--)
86	3	57.333	0.577	(--*--)
87	3	56.333	0.577	(--*--)
88	3	55.667	0.577	(--*--)
89	3	56.000	1.000	(--*--)
90	3	56.333	0.577	(--*--)
91	3	59.333	0.577	(--*--)
92	3	57.000	1.000	(--*--)
93	3	56.667	0.577	(--*--)
94	3	59.000	1.000	(--*--)
95	3	57.000	1.000	(--*--)
96	3	55.667	0.577	(--*--)
97	3	56.000	1.000	(--*--)
98	3	59.333	0.577	(--*--)
99	3	56.333	0.577	(--*--)
100	3	57.667	0.577	(--*--)
101	3	57.000	1.000	(--*--)
102	3	56.333	0.577	(--*--)
103	3	54.333	0.577	(--*--)
104	3	54.333	0.577	(--*--)
105	3	55.000	0.000	(--*--)



Appendix 3: Statistical analyses in chapter 3.

Analysis 1: Discriminant Analysis to analyse the differences between the two groups (coded 0 for unoccupied group and 1 for occupied group).

Group Statistics					
		Mean	Std. Deviation	Valid N (listwise)	
OCCUPATION				Unweighted	Weighted
.00	DIAMETER	12.0978	1.5260	276	276.000
	DIRECTION	88.0616	51.4290	276	276.000
	SLOPE	22.6957	6.9874	276	276.000
	OPEN SPACE	1.0217	.1461	276	276.000
1.00	DIAMETER	12.7273	1.4742	231	231.000
	DIRECTION	84.3680	39.6795	231	231.000
	SLOPE	24.3117	6.0697	231	231.000
	OPEN SPACE	1.1688	.3754	231	231.000
Total	DIAMETER	12.3846	1.5336	507	507.000
	DIRECTION	86.3787	46.4384	507	507.000
	SLOPE	23.4320	6.6279	507	507.000
	OPEN SPACE	1.0888	.2847	507	507.000

Tests of Equality of Group Means					
	Wilks' Lambda	F	df1	df2	Sig.
DIAMETER	.958	22.067	1	505	.000
DIRECTION	.998	.795	1	505	.373
SLOPE	.985	7.573	1	505	.006
OPEN SPACE	.934	35.888	1	505	.000

Analysis 3: Correlation between the Discriminant Score and Variables.

Structure Matrix	
	Function
	1
OPENCATE	.783
DIAMETER	.614
SLOPE	.360
DIRECTIO	-.117
Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions Variables ordered by absolute size of correlation within function.	

Analysis 4: The diameter of nest site affects the bee occupation.

Rafter diameter	9 - 10 cm	11 - 12 cm	13 - 14 cm	15 - 17 cm
Occupied	15	86	96	33
Unoccupied	39	129	92	17

Chi-Square Test

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

Where O = observed values
E = expected values

Expected counts are printed below observed counts

	9 - 10	11 - 12	13 - 14	15 - 17	Total
1	15	86	96	33	230
	24.50	97.53	85.29	22.68	
2	39	129	92	17	277
	29.50	117.47	102.71	27.32	
Total	54	215	188	50	507

Chi-Sq = 3.682 + 1.364 + 1.346 + 4.693 +
3.057 + 1.133 + 1.118 + 3.897 = 20.289
DF = 3, P-Value = 0.000

Tukey - type multi-comparisons for proportions (Zar 1999: 560-561)

Rafter diameter	9 - 10 cm	11 - 12 cm	13 - 14 cm	15 - 17 cm
Occupied	15	86	96	33
Unoccupied	39	129	92	17
n	54	215	188	50
p	0.28	0.40	0.51	0.66
Ranked				
by proportion	1	2	3	4
p'	32.06	39.25	45.60	54.14

B vs A	p'B - p'A	SE	q	q 0.05, ∞, 4	q 0.01, ∞, 4	Conclusion
4 vs. 1	22.06	3.95	5.58	3.633	4.403	P < 0.01
4 vs. 2	14.89	3.16	4.71			P < 0.01
4 vs. 3	8.54	3.20	2.66			P > 0.05
3 vs. 1	13.54	3.12	4.33			P < 0.05
3 vs. 2	6.35	2.02	3.14			P > 0.05
2 vs. 1	7.19	3.07	2.34			P > 0.05

where

$$p' = \frac{1}{2} \left(\arcsin \sqrt{\frac{X}{n+1}} + \arcsin \sqrt{\frac{X+1}{n+1}} \right)$$

$$SE = \sqrt{\left(\frac{410.35}{nA + 0.5} + \frac{410.35}{nB + 0.5} \right)}$$

$$q = \frac{p' B - p' A}{SE}$$

Analysis 5: The slope of nest site affects the bee occupation.

Rafter slope	6 – 13 ⁰	13 - 20 ⁰	20 - 27 ⁰	27 – 34 ⁰	34 - 39 ⁰
Occupied	12	38	92	76	10
Unoccupied	24	64	118	51	20

Chi-Square Test

Expected counts are printed below observed counts

	6 – 13	13 – 20	20 – 27	27 – 34	34 – 39	Total
1	12	38	92	76	10	228
	16.25	46.05	94.81	57.34	13.54	
2	24	64	118	51	20	277
	19.75	55.95	115.19	69.66	16.46	
Total	36	102	210	127	30	505

Chi-Sq = 1.113 + 1.408 + 0.083 + 6.074 + 0.928 +
0.916 + 1.159 + 0.069 + 4.999 + 0.764 = 17.512
DF = 4, P-Value = 0.002

Tukey - type multi-comparisons for proportions (Zar 1999: 560-561)

Rafter slope	6 – 13 ⁰	13 - 20 ⁰	20 - 27 ⁰	27 – 34 ⁰	34 - 39 ⁰
Occupied	12	38	92	76	10
Unoccupied	24	64	118	51	20
n	36	102	210	127	30
p	0.33	0.37	0.44	0.60	0.33
Ranked					
by proportion	1a	2	3	4	1b
p'	35.52	37.68	41.45	50.62	35.58

B vs A	p'B – p'A	SE	q	q 0.05, ∞,5	q 0.01, ∞,5	Conclusion
4 vs. 1a	15.10	3.80	3.97	3.858	4.603	P < 0.05
4 vs. 1b	15.04	4.08	3.68			P > 0.05
4 vs. 2	12.94	2.60	4.93			P < 0.01
4 vs. 3	9.17	2.27	4.03			P < 0.05
3 vs. 1a	5.93	3.63	1.63			P > 0.05
3 vs. 1b	5.87	3.92	1.49			P > 0.05
3 vs. 2	3.77	2.44	1.54			P > 0.05

Do not test for the rest

Analysis 6: Isolation is preferred to aggregation of nest sites.

	Aggregation	Isolation
Observed values:	3	17
Expected values:	7.2	12.8

$$\text{Chi-Square} = (3-7.2)^2 / 7.2 + (17-12.8)^2 / 12.8 = (4.2)^2 / 7.2 + (4.2)^2 / 12.8 = 3.828$$

$$\text{DF} = 1, \text{Chi-Square}_{0.05} = 3.841; P > 0.05$$

Analysis 7: Remnant of beeswax affects the bee occupation.

	With beeswax	Without beeswax
Occupied	8	7
Unoccupied	18	62

Chi-Square Test

Expected counts are printed below observed counts

	With bees	Without	Total
1	8	7	15
	4.11	10.89	
2	18	62	80
	21.89	58.11	
Total	26	69	95

Chi-Sq = 3.695 + 1.392 +
0.693 + 0.261 = 6.041
DF = 1, P-Value = 0.014
1 cells with expected counts less than 5.0

Using Yates’s correction: Chi-Sq = 4.55
P < 0.05
(DF = 1, Chi-Sq (0.05) = 3.84)

Analysis 8: Re-confirmation of the bee occupation regardless of the nest site directions.

Direction	N	E	S	W
Observed values	9	5	4	4
Expected values	5.5	5.5	5.5	5.5

$$\begin{aligned} \text{Chi-Sq} &= (9 - 5.5)^2 / 5.5 + (5 - 5.5)^2 / 5.5 + (4 - 5.5)^2 / 5.5 + (4 - 5.5)^2 / 5.5 \\ &= 0.561 \end{aligned}$$

$$\text{DF} = 3, P > 0.05$$

Appendix 4: Statistical analyses in chapter 4.

Analysis 1: Fluctuation of nectar volume by days, by time of the day and by trees.

Kruskal-Wallis Test

Kruskal-Wallis Test on Nectar volume

Day	N	Median	Ave Rank	Z
1	35	4.40E-01	99.6	4.90
2	35	0.00E+00	65.0	-0.92
3	35	0.00E+00	65.3	-0.88
4	35	0.00E+00	52.1	-3.10
Overall	140		70.5	

H = 26.48 DF = 3 P = 0.000
H = 29.91 DF = 3 P = 0.000 (adjusted for ties)

Kruskal-Wallis Test

Kruskal-Wallis Test on Nectar volume

Time	N	Median	Ave Rank	Z
6	20	2.85E-01	98.0	3.27
8	20	6.20E-01	100.7	3.59
10	20	5.00E-03	72.8	0.28
12	20	0.00E+00	59.7	-1.28
14	20	0.00E+00	51.7	-2.24
16	20	0.00E+00	56.3	-1.69
18	20	0.00E+00	54.3	-1.93
Overall	140		70.5	

H = 31.65 DF = 6 P = 0.000
H = 35.75 DF = 6 P = 0.000 (adjusted for ties)

Kruskal-Wallis Test

Kruskal-Wallis Test on Nectar volume

Tree	N	Median	Ave Rank	Z
1	28	2.50E-02	76.7	0.90
2	28	1.00E-02	70.3	-0.03
3	28	1.50E-02	74.5	0.59
4	28	0.00E+00	55.3	-2.22
5	28	4.50E-02	75.8	0.77
Overall	140		70.5	

H = 5.34 DF = 4 P = 0.254
H = 6.03 DF = 4 P = 0.197 (adjusted for ties)

Analysis 2: Fluctuation of sugar content by days and by time of the day.

One-way Analysis of Variance

Analysis of Variance					
Source	DF	SS	MS	F	P
Factor	2	43.9	21.9	1.57	0.260
Error	9	125.8	14.0		
Total	11	169.7			

Individual 95% CIs For Mean
Based on Pooled StDev

Level	N	Mean	StDev
D1-6h	4	10.500	1.291
D2-6h	3	14.000	6.083
D3-6h	5	14.800	3.421

Pooled StDev = 3.739

One-way Analysis of Variance

Analysis of Variance					
Source	DF	SS	MS	F	P
Factor	6	7260.4	1210.1	60.29	0.000
Error	20	401.4	20.1		
Total	26	7661.9			

Individual 95% CIs For Mean
Based on Pooled StDev

Level	N	Mean	StDev
D1-6h	4	10.500	1.291
D1-8h	5	12.000	3.000
D1-10h	4	28.000	1.633
D1-12h	4	49.750	9.179
D1-14h	3	54.667	4.041
D1-16h	4	43.500	3.697
D1-18h	3	28.000	3.606

Pooled StDev = 4.480

Analysis 3: Pollen release of *Melaleuca* by time and by trees.

Friedman Test

Friedman test for pollen release treated by Time (hours after opening)
blocked by Tree

S = 129.05 DF = 34 P = 0.000
S = 130.39 DF = 34 P = 0.000 (adjusted for ties)

Time (hours)	N	Est Median	Sum of Ranks
0	5	5.69	65.5
2	5	15.00	114.0
4	5	25.49	147.5
6	5	38.20	134.0
8	5	26.97	157.0
10	5	26.69	158.0
12	5	20.46	147.5
24	5	15.74	109.0
26	5	29.77	161.5
28	5	13.57	128.0
30	5	14.83	131.5
32	5	12.43	130.5
34	5	9.71	104.5
36	5	19.57	142.5
48	5	6.69	84.0
50	5	15.63	128.5
52	5	8.03	91.5
54	5	4.91	62.5
56	5	6.94	79.5
58	5	4.80	58.0
60	5	6.83	84.5
72	5	6.03	67.0
74	5	10.69	110.5
76	5	2.34	15.5
78	5	2.00	13.5
80	5	6.03	75.0
82	5	9.74	109.5
84	5	5.37	67.0
96	5	4.14	43.0
98	5	4.09	48.0
100	5	3.69	35.0
102	5	3.00	21.0
104	5	4.06	38.0
106	5	4.00	43.5
108	5	3.89	44.0

Grand median = 11.34

Friedman Test

Friedman test for pollen release treated by Trees blocked by Time

S = 2.42 DF = 4 P = 0.659
S = 2.77 DF = 4 P = 0.598 (adjusted for ties)

		Est	Sum of
Tree	N	Median	Ranks
1	35	8.0000	104.0
2	35	8.2000	113.0
3	35	8.0000	112.0
4	35	8.0000	98.0
5	35	7.8000	98.0
Grand median		= 8.0000	

Analysis 4: Pollen release of *Nypa* by time and by trees.

Friedman Test

Friedman test for Pollen release treated by Time of the day blocked by Tree

S = 61.40 DF = 13 P = 0.000
S = 62.15 DF = 13 P = 0.000 (adjusted for ties)

Time	N	Est Median	Sum of Ranks
5	10	2.312	23.5
6	10	10.241	88.5
7	10	13.670	105.0
8	10	14.027	109.5
9	10	14.634	108.5
10	10	12.241	107.0
11	10	9.991	87.5
12	10	8.098	73.0
13	10	7.884	72.5
14	10	6.277	69.0
15	10	6.384	66.5
16	10	6.634	71.5
17	10	3.312	37.5
18	10	3.170	30.5
Grand median =		8.491	

Friedman Test

Friedman test for Pollen release treated by Tree blocked by Time

S = 6.20 DF = 9 P = 0.719
S = 6.41 DF = 9 P = 0.699 (adjusted for ties)

Tree	N	Est Median	Sum of Ranks
1	14	6.675	72.5
2	14	7.875	81.0
3	14	7.975	84.0
4	14	7.375	74.0
5	14	7.325	79.0
6	14	9.275	94.0
7	14	7.075	76.5
8	14	8.075	82.5
9	14	6.525	63.5
10	14	6.075	63.0
Grand median =		7.425	

Analysis 5: Comparison of insect visitations on the 1st and the 2nd days of flowering on *Melaleuca* flowers (Wilcoxon signed-rank test).

1st day	2nd day	Difference, d	d	Rank of d	Signed Rank
78	70	8	8	2	2
75	28	47	47	12	12
21	12	9	9	3.5	3.5
24	4	20	20	7	7
15	12	3	3	1	1
23	5	18	18	6	6
13	4	9	9	3.5	3.5
32	8	24	24	9	9
13	2	11	11	5	5
66	15	51	51	14	14
130	81	49	49	13	13
69	40	29	29	10	10
53	31	22	22	8	8
41	11	30	30	11	11

$W_+ = 105$ and $W_- = 0$; so $W_s = W_+ = 105 > W_{0.001, 14} = 101$

$P < 0.001$

Analysis 6: Insect visitations to *Melaleuca* flowers by time of the day and by inflorescences (trees).

Kruskal-Wallis Test

Kruskal-Wallis Test on visitations

Time	N	Median	Ave Rank	Z
6	28	0.00E+00	114.2	-3.58
7	28	3.00E+00	247.9	3.42
8	28	5.00E+00	260.6	4.09
9	28	5.00E+00	263.2	4.22
10	28	3.00E+00	222.6	2.10
11	28	2.00E+00	224.9	2.22
12	28	1.00E+00	197.5	0.78
13	28	0.00E+00	168.6	-0.73
14	28	0.00E+00	159.5	-1.20
15	28	0.00E+00	138.0	-2.33
16	28	0.00E+00	140.0	-2.22
17	28	0.00E+00	126.1	-2.95
18	28	0.00E+00	109.5	-3.82
Overall	364		182.5	

H = 96.58 DF = 12 P = 0.000
H = 123.11 DF = 12 P = 0.000 (adjusted for ties)

Kruskal-Wallis Test

Kruskal-Wallis Test on visitations

Tree	N	Median	Ave Rank	Z
1	26	6.50E+00	254.0	3.59
2	26	3.00E+00	239.3	2.86
3	26	0.00E+00	156.8	-1.29
4	26	0.00E+00	158.8	-1.19
5	26	0.00E+00	147.4	-1.76
6	26	0.00E+00	156.3	-1.32
7	26	0.00E+00	131.1	-2.59
8	26	0.00E+00	147.3	-1.77
9	26	0.00E+00	132.9	-2.50
10	26	1.00E+00	199.9	0.87
11	26	3.50E+00	225.2	2.15
12	26	1.00E+00	206.5	1.21
13	26	1.00E+00	205.3	1.15
14	26	1.00E+00	194.3	0.60
Overall	364		182.5	

H = 49.75 DF = 13 P = 0.000
H = 63.42 DF = 13 P = 0.000 (adjusted for ties)

Analysis 7: Kolmogorov-Smirnov two sample test (Sokal & Rohlf 1995: 434-439) to compare the frequency distributions of *A. dorsata* and *A. florea* on *Nypa* flowers.

Time	<i>A. dorsata</i>	<i>A. florea</i>	F ₁	F ₂	F ₁ /n ₁	F ₂ /n ₂	F ₁ /n ₁ – F ₂ /n ₂
5 h	110	0	110	0	0.21401	0.00000	0.214008
6 h	134	0	244	0	0.47471	0.00000	0.474708
7 h	181	3	425	3	0.82685	0.03371	0.793140
8 h	62	2	487	5	0.94747	0.05618	0.891291
9 h	18	10	505	15	0.98249	0.16854	0.813951
10 h	6	19	511	34	0.99416	0.38202	0.612141
11 h	2	13	513	47	0.99805	0.52809	0.469965
12 h	1	12	514	59	1.00000	0.66292	0.337079
13 h	0	12	514	71	1.00000	0.79775	0.202247
14 h	0	11	514	82	1.00000	0.92135	0.078652
15 h	0	6	514	88	1.00000	0.98876	0.011236
16 h	0	1	514	89	1.00000	1.00000	0.000000
17 h	0	0	514	89	1.00000	1.00000	0.000000
18 h	0	0	514	89	1.00000	1.00000	0.000000

Locate the largest unsigned difference D. In this case D = 0.891291

$$D_{\alpha} = K_{\alpha} \sqrt{\frac{n1 + n2}{n1n2}}$$

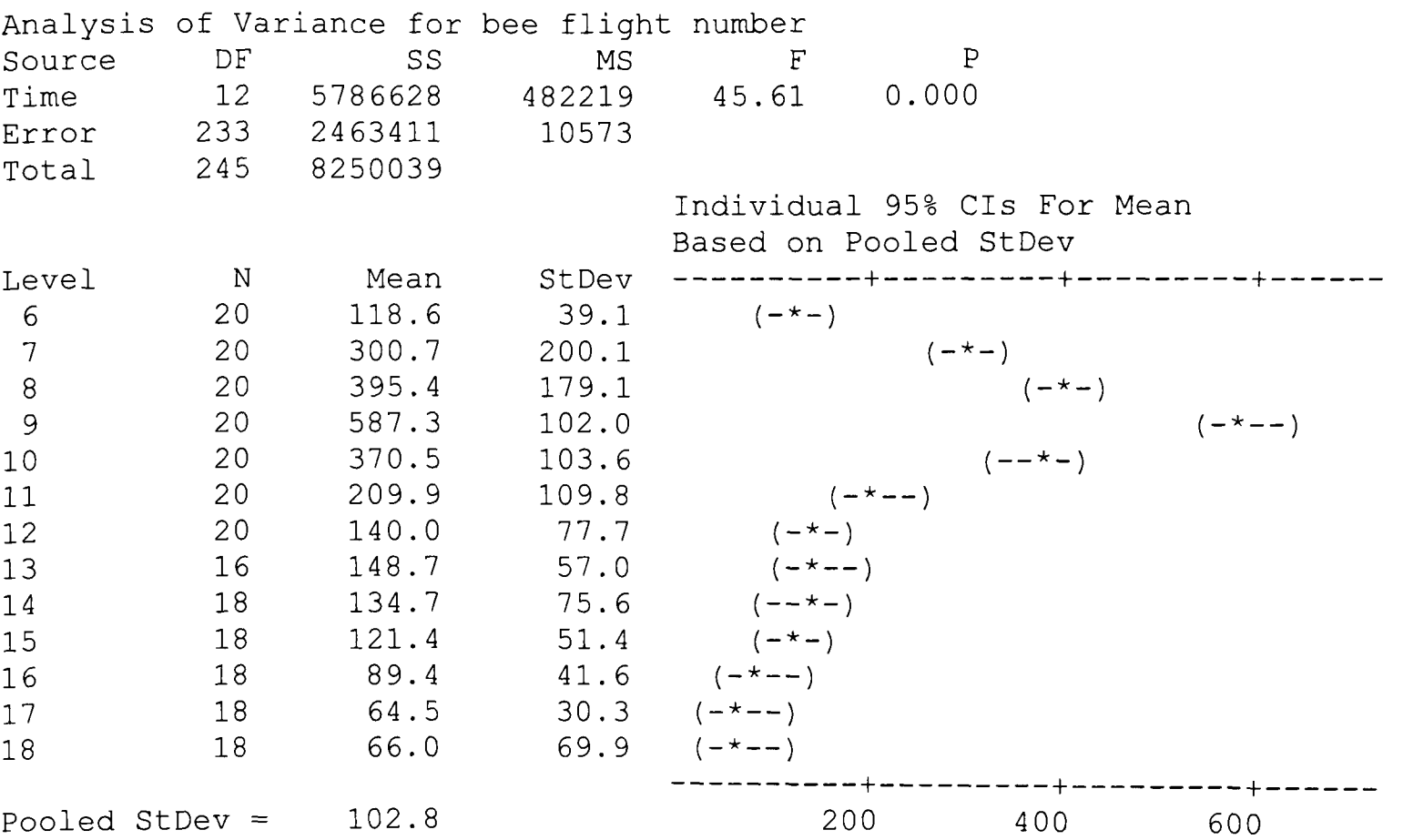
$$\text{where } K_{\alpha} = \sqrt{\frac{\left[-\ln\left(\frac{\alpha}{2}\right)\right]}{2}}$$

Thus K_{0.05} = 1.3581, K_{0.01} = 1.6276, and K_{0.001} = 1.9494

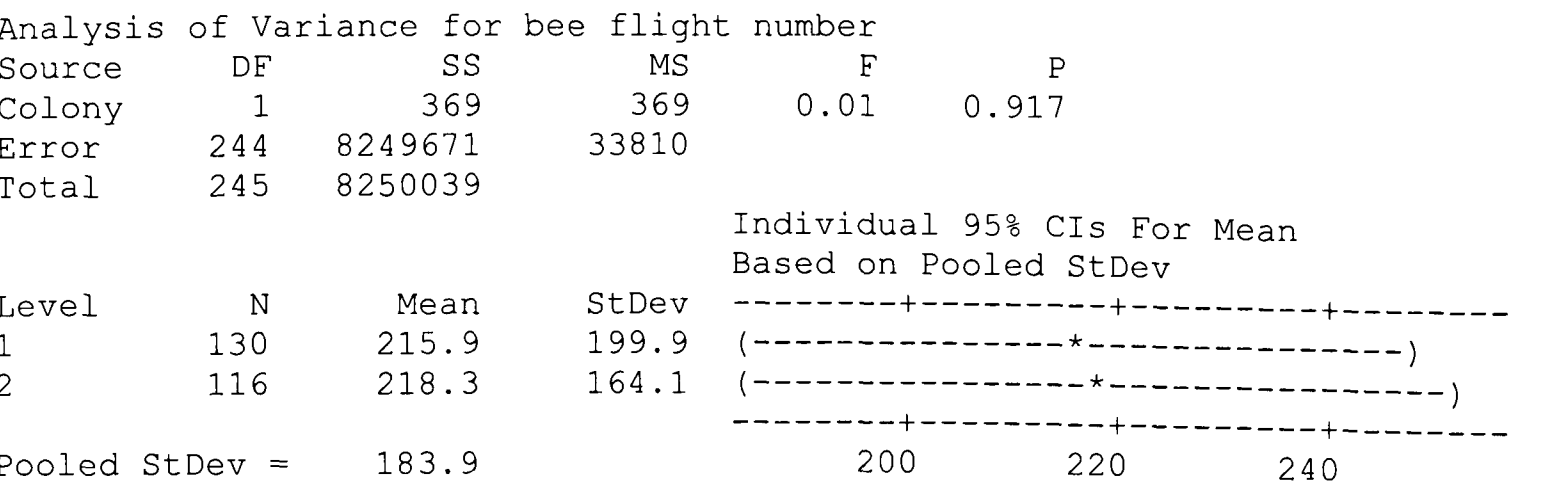
$$\text{In this case } D_{0.001} = 1.9494 \sqrt{\frac{514 + 89}{(514)(89)}} = 0.2237, \text{ so } P < 0.001$$

Analysis 8: Flight activity of *A. dorsata* colonies by time of the day, by colonies and by in-out directions.

One-way Analysis of Variance



One-way Analysis of Variance



One-way Analysis of Variance

Analysis of Variance for bee flight number					
Source	DF	SS	MS	F	P
Direction	1	7387	7387	0.22	0.640
Error	244	8242653	33781		
Total	245	8250039			
Individual 95% CIs For Mean					
Based on Pooled StDev					
Level	N	Mean	StDev	-----+-----+-----+-----	
1	123	222.5	192.7	(-----*-----)	
2	123	211.6	174.5	(-----*-----)	
				-----+-----+-----+-----	
Pooled StDev =		183.8		200	225 250

Appendix 5: Statistical analyses in chapter 5.

Kolmogorov-Smirnov two sample test (Sokal & Rohlf 1995: 434-439) to compare the frequency distributions of *A. cerana* and *A.mellifera* on *Nypa* flowers.

Time	<i>A. cerana</i>	<i>A. mellifera</i>	F ₁	F ₂	F ₁ /n ₁	F ₂ /n ₂	F ₁ /n ₁ – F ₂ /n ₂
5 h	0	171	0	171	0	0.15475	-0.154751
6 h	13	285	13	456	0.44828	0.41267	0.035606
7 h	9	155	22	611	0.75862	0.55294	0.205680
8 h	3	121	25	732	0.86207	0.66244	0.199626
9 h	1	73	26	805	0.89655	0.72851	0.168045
10 h	3	52	29	857	1	0.77557	0.224434
11 h	0	35	29	892	1	0.80724	0.192760
12 h	0	31	29	923	1	0.83529	0.164706
13 h	0	38	29	961	1	0.86968	0.130317
14 h	0	38	29	999	1	0.90407	0.095928
15 h	0	34	29	1033	1	0.93484	0.065158
16 h	0	36	29	1069	1	0.96742	0.032579
17 h	0	13	29	1082	1	0.97919	0.020814
18 h	0	23	29	1105	1	1	0

Locate the largest unsigned difference D. In this case D = 0.224434

$$D_{\alpha} = K_{\alpha} \sqrt{\frac{n1 + n2}{n1n2}}$$

$$\text{where } K_{\alpha} = \sqrt{\frac{\left[-\ln\left(\frac{\alpha}{2}\right)\right]}{2}}$$

Thus K_{0.05} = 1.3581, K_{0.01} = 1.6276, and K_{0.001} = 1.9494

$$\text{In this case } D_{0.05} = 1.3581 \sqrt{\frac{29 + 1105}{(29)(1105)}} = 0.2554, \text{ so } P > 0.05$$

Appendix 6

Questionnaire for the study of economic efficiency of rafter beekeeping

1. Name of beekeeper:

2. Age:

3. Address:

4. Experience of rafter beekeeping (years):

5. Number of people in the family:

6. Area of land owned (ha):

1999

2000

2001

2002

7. Number of rafters erected in

Dry season:

x

Rainy season:

x

8. Number occupied with bees in

Dry season:

x

Rainy season:

x

9. Total honey harvest (litres):

Dry season:

x

Rainy season:

x

10. Price of honey (VN Dong/litre):

Dry season:

x

Rainy season:

x

11. Beeswax harvest (kg):

Dry season:

x

Rainy season:

x

12. Price of beeswax (VN Dong/ kg):

Dry season:

x

Rainy season:

x

13. Other incomes from beekeeping:

Dry season:

x

Rainy season:

x

14. Sources of income other than beekeeping for the family during the last 3 years:

	1999	2000	2001
• Rice farming:			
Yield:			
Price:			
• Fruits:			
• Vegetables:			
• Fish/shrimp:			
• Other agricultural products:			
• Payments from tree cutting:			
How often?			
How paid?			
• Payments from shrimp raising:			
How often?			
How paid?			
• Other employments?			

15. Your ideas:

Questionnaire for the study of conflict between new forest holders and beekeepers

- 1. Name of interviewee:
- 2. Age:
- 3. Address:
- 4. Number of people in the family:
- 5. Total income per year:
- 6. Is it necessary to preserve the *Melaleuca* forest?

Why?

-
-
-
-

- 7. Is right or wrong to cut trees down for making rafters?

Why?

-
-
-

- 8. For forest holder: Do you allow beekeepers to make rafters in your land?

Why?

-
-
-

For beekeepers: Why do you practice rafter beekeeping?

-
-
-

Is it good to have a contract between beekeepers and forest holders?

If yes, how to share the profit?

-
-
-

- 9. Your ideas:

Analysis 1: Numbers of rafters by beekeepers and by year-seasons.

Friedman Test

Friedman test for Total rafters by Beekeepers blocked by Year-season

S = 150.79 DF = 29 P = 0.000
S = 153.82 DF = 29 P = 0.000 (adjusted for ties)

Beekeepe	N	Est Median	Sum of Ranks
1	6	129.58	111.5
2	6	60.00	17.5
3	6	80.00	49.5
4	6	80.00	49.5
5	6	34.67	8.0
6	6	197.67	148.5
7	6	150.00	130.5
8	6	150.00	130.5
9	6	70.00	30.5
10	6	120.00	99.0
11	6	110.00	88.0
12	6	150.00	130.5
13	6	100.00	76.0
14	6	69.83	28.5
15	6	119.50	93.0
16	6	149.50	109.0
17	6	148.50	113.0
18	6	60.92	23.0
19	6	100.00	76.0
20	6	130.17	112.5
21	6	80.00	49.5
22	6	90.00	63.0
23	6	70.00	30.5
24	6	150.00	130.5
25	6	200.00	166.5
26	6	200.00	166.5
27	6	200.00	166.5
28	6	200.00	166.5
29	6	119.67	95.5
30	6	150.00	130.5
Grand median	=	122.33	

Friedman Test

Friedman test for Total rafters by Year-season blocked by Beekeepers

S = 2.41 DF = 5 P = 0.790
S = 11.19 DF = 5 P = 0.048 (adjusted for ties)

Year-sea	N	Est	Sum of
		Median	Ranks
1	30	120.00	109.0
2	30	120.00	105.5
3	30	120.00	105.5
4	30	120.00	109.5
5	30	120.00	109.5
6	30	120.00	91.0
Grand median		=	120.00

Analysis 2: Occupation rates by beekeepers and by year-seasons.

Two-way Analysis of Variance

