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Global apiculture: a new outlook

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Apiculture has always benefited from the fact that the social organization of the honeybee interests scientists. In the tropics, especially, the management of bees will be capable of much improvement when their behavioural patterns are more extensively studied and better understood. This in turn will lead to a higher economic return from apiculture. At present there is still a geographical imbalance, with the majority of research workers in temperate zones and the greatest unsolved problems in the tropics. It seems likely, however, that the next decade or two will see an increased diversification of research effort, resulting in our knowledge of bees in the tropics beginning to approach that of those in temperate zones.

Bees are kept for honey production in at least 145 countries of the world, at technological levels that vary enormously. At one extreme, simple receptacles that serve as hives are put out to attract swarms of bees, and the bees are killed after they have stored honey which can be harvested. At the other extreme are enterprises operating over a large geographical area, with 20 000 hives or more; one man with appropriate mechanical moving equipment manages at least 1000 hives, which he trucks from one source of nectar and pollen to another. Most of the world's beekeepers work at levels between these extremes. All of them obtain a harvest of honey from resources that would otherwise go to waste, and some harvest beeswax, pollen, propolis, royal jelly, or bee venom as well. The honey may add to the diet of a poorly nourished family, or it may be bartered, sold as a cash crop, or exported on to the world market. World production has increased in recent years and is now about 900 000 tonnes per annum, of which 200 000 tonnes reach the world market.

The versatility of apiculture, and the fact that it can be carried out wherever flowering plants grow, lead to the need to consider it in a global context.

The bees used for honey production

Until 1950 or later, apiculture was commonly regarded as being centred in Europe and North America, with outposts in Australia and New Zealand. *Apis mellifera*, the honeybee used in these countries, was assumed to be the 'normal' honeybee, although it was known that some different bees in India and other parts of Asia also produced honey.

In fact the honeybees (*Apis*) are a tropical genus which probably originated in south-east Asia. They are highly social, and live in permanent colonies headed by a single queen. Two of the four species, *Apis dorsata* and *Apis florea*, are not found outside the tropics of Asia; they are more primitive than the other two, and build a single-comb nest—in the open, not in a cavity. Honey has been, and still is, collected from such wild colonies in trees and rocks: a colony of the large *Apis dorsata* bees may yield 10–20 kg. *Apis florea* is quite tiny and the honey harvest from it only a few decagrams; perhaps because the yield is low, *Apis florea* honey is especially prized. In the tropics, stingless bees (Meliponinae) are also kept in hives and used for honey production, usually on a small scale.

The other two species, *Apis cerana* and *Apis mellifera*, share many characteristics. They build their nest in a dark cavity, and it contains usually 6–10 parallel vertical combs (figure 1); brood is reared in the centre part where temperature regulation can best be achieved, and honey is stored in the outer parts. *Apis cerana*, the smaller bee, is native throughout tropical south-east Asia, and also in the lower reaches of the Himalayas and—east of this massif—as far north as China, Korea, Japan, and the Far Eastern (Primor'ye) Province of USSR.

Apis mellifera is a larger and more vigorous bee than *Apis cerana*, and builds larger colonies. In different forms it is native throughout Africa and the Middle East (tropics/subtropics) and most of Europe (temperate zone). European bees have a good overwintering ability, and this enabled them to colonize most of this continent where flowering plants are plentiful enough. At northern latitudes both *Apis mellifera* and *Apis cerana* colonies are able to survive the winter by clustering in a ball on the combs, in a thermally efficient way, so that a sufficient number of the individual bees escape being chilled, and remain alive until the spring, when brood rearing becomes possible again.

The New World—the Americas, Australasia, and Pacific area—have no native honeybees, but when *Apis mellifera* bees were introduced by man they were able to colonize all temperate and subtropical areas. A tropical African form of *Apis mellifera* was taken to Brazil in 1956, in an effort to introduce bees better adapted to tropical American conditions where European *Apis mellifera* did poorly. A number of swarms headed by African queens escaped, and the resulting hybrids with European *A. mellifera* already present multiplied and spread at an alarming rate [1]; they are now found as far north as Panama. These bees (like their African ancestors) are much more

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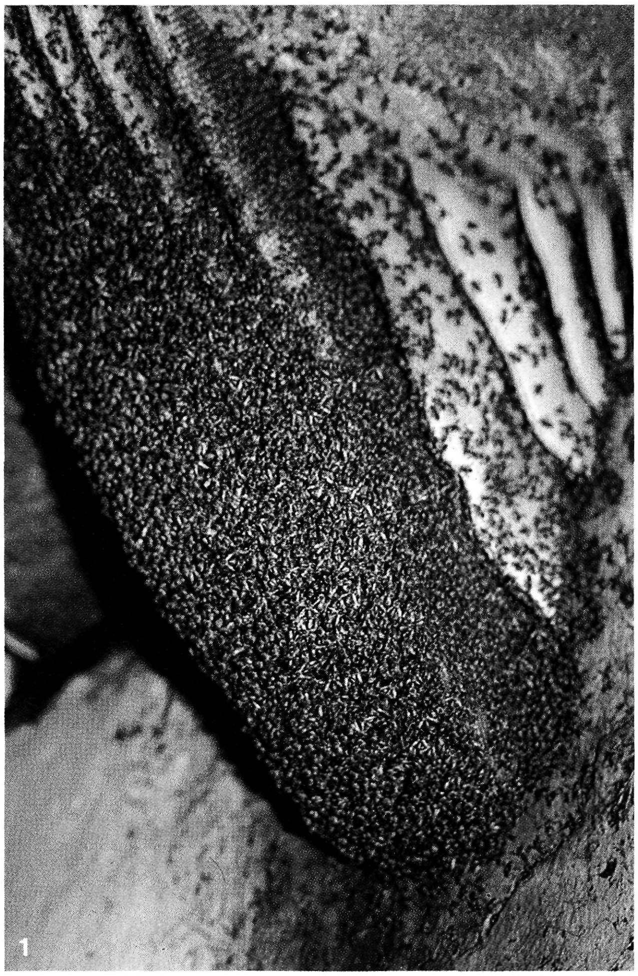

Figure 1 Part of a nest of *Apis mellifera* built inside a dwelling house. These are tropical African bees in Ethiopia.

'aggressive' than temperate-zone bees, and are sometimes referred to in the popular press as 'killer bees'.

The profitability of beekeeping

Most of the world's honey production is obtained with European *Apis mellifera*, and these bees have also been successfully introduced into several subtropical Old World regions where *Apis cerana* is native; they are not adapted to the full tropics.

One measure of profitability of beekeeping in a region is the amount of honey harvested annually per colony. This is the difference between the amount produced by a colony and the amount used by the colony to maintain its population throughout the year. Many factors affect this honey harvest, including hive management practices and availability of honey sources within flight range. But there are broad regional differences, and the potential honey yield per hive is likely to be highest in two types of region. The first is in the subtropics, where temperatures are high enough for plants to flower, and for bees to fly and forage, all through the year; here the short dearth period is often caused by drought (figure 2). The second is in regions at relatively high latitudes that have a continental climate and good bee forage. Here, plant growth is compressed into a relatively short period, and is very vigorous; nectar secretion is plentiful during the very long days, when bees can forage during the many hours of daylight. By the use of package bees (see below) these conditions can give honey yields of 300 kg/hive in parts of Canada, and help to make Canada's national average (57 kg/hive) the highest in the world.

At intermediate latitudes, in the temperate zones, yields are often lower. They are also lower in the full tropics, for a different reason. Tropical dearth seasons are relatively short, and colonies therefore do not need to store as much honey as those faced with a winter period. Also, plants may well be coming in flower not too far away from the dearth area, and the temperature is high enough for the bees to fly. Colonies therefore leave their nests (empty of food) in the dearth area and migrate to a new resource-rich area. As a result of this behaviour pattern, the same colony may store honey in two areas, although the beekeeper's harvest in either of them may be small. All tropical *Apis* show some migratory behaviour, but in a temperate-zone winter such an escape from food shortage is of course not possible.

Some representative national averages of annual honey yields in the early 1970s [2] are:

Region	Country	Yields kg/hive
High latitudes	Canada	57
	Sweden	26
Other temperate zone	Switzerland	6
	UK	17
	USA	25
Subtropics	Argentina	30
	Australia	37
	Mexico	30
Full tropics	Brazil	17

The main honey-exporting countries are nearly all in or around the subtropics; the top three in 1981 [3] were China 54 111, Mexico 42 616, Argentina 28 729 tonnes exported. The next on the list was Canada (8220).

As stated earlier, many contributory factors affect honey yields, and these have been discussed elsewhere [2, 4].

Bee management

The collection of honey from wild nests, often called honey hunting, is still carried out in parts of tropical Asia and Africa. Even here a modicum of bee management may be practised, as when part of the comb containing brood (and with luck the queen) is deliberately left in situ by the honey hunter, so that the colony can regenerate itself in the same site.

In primitive beekeeping the beekeeper sets out receptacles that serve as hives; these may be hollow logs (figure 3), clay pots, or boxes and baskets of various types, according to local materials and traditions [5]. At its most elementary, the only management is to put out the hives for swarms to enter, and later on to kill the bees and take the honey. A more advanced stage is to use smoke to drive the

Figure 2 Apiary in Mexico in the dry season. Many dry areas can produce much honey.

Figure 3 Log hive in Kenya. Hives are usually sited in trees, for safety.

Figure 4 Peasant beekeeper in Middle Egypt; she has just cut out a comb from one of a stack of mud hives.

Figure 5 Beekeepers in Western Australia working a three-tier multiple-queen 'hive', using a *mini-gantry to lift the super.*

bees away from the end of the hive which contains the honey to the other and to cut out the honey combs, leaving the bees and brood nest behind.

Management of swarms is important in primitive beekeeping; they are looked out for, captured, and used to populate empty hives. Peasants in Egypt today use long horizontal cylinders of dried mud as hives (figure 4) and they populate a new hive by introducing an 'artifical swarm', consisting of several combs with bees and brood from a similar hive; the bees are then likely to rear their own queen from worker larvae. (The very earliest evidence of beekeeping in antiquity is provided by pictures of roughly cylindrical mud hives in tombs and a sun-temple in Egypt, dating from 2500 BC to 600 BC.) [5]

In the past 300 years beekeepers have learned to incorporate certain fundamental management techniques, namely:

1. Requeening a colony by inserting a new queen temporarily in a cage, where she will be safe until the workers have learned to accept her scent.
2. Superimposing a separate honey chamber above the part of the hive where the brood is reared, and using a queen excluder (a grid that lets workers through but not the larger queen), so that the honey can be harvested free from brood and pollen.
3. Feeding bees to tide them over a dearth period; this was recommended practice as early as Roman times.

A considerable breakthrough came when bar hives of various kinds were invented: parallel bars of wood were inserted across the top of a hive at the same distance apart as naturally built combs. The bees built their combs down from these bars, but they still attached them to the hive walls at the sides. It was then learned that bees would 'respect' a bee-space—as between two opposite comb surfaces, for instance—and not built comb across it. The final advance was made by the Rev. L. L. Langstroth in Philadelphia, USA, in 1851; he extended the top-bar down at its two ends to make a frame [6]. The ends of the frame were kept a bee-space distance from the inner hive walls; the bees did not build comb across the gap, and the frame could be readily removed without breaking the comb. Langstroth was one who could express his ideas on paper, and his book *Langstroth on the hive and the honeybee: a beekeeper's manual* (1853) spread the gospel of the new 'rational' beekeeping throughout the world. Modern beekeeping is based on the use of such hives; wooden frames are fitted with sheets of beeswax (or plastic) foundation embossed with the pattern of the bees' hexagonal cells, on which the bees build out combs. Honey is extracted from the framed combs by spinning them in a centrifuge, the 'caps' of the cells having been previously sliced off.

Langstroth's development made it possible to manipulate a colony of bees in temperate-zone conditions so that it produced honey greatly in excess of its requirements, so that the beekeeper could take his harvest and still leave enough to support the colony through the winter. This manipulation is basically:

1. The colony winters with enough stores (checked by the beekeeper), in a hive of a suitable size.
2. In spring, honey chambers (supers) are added one by one as the colony expands, so that—ideally—the colony continues to grow but is never crowded enough to swarm; if necessary more brood space is provided.
3. The colony, not having swarmed, has a very large force of foraging bees for the main honey flow, and accumulates considerably more honey than it needs for the next winter.

In nature the colony would have reproduced by swarming at stage 2, leaving two colonies by the end of the season, each with some honey, but the beekeeper would get hardly any unless he killed a colony to do so. Success for the beekeeper (honey production) is an alternative to success for the colony (reproduction by swarming).

Multiple-queen colonies

In the active season a normal honeybee colony consists of say 50 000 adult workers, 30 000 immature workers, a few hundred drones, and a single queen that is the female parent of all the rest. The idea of 'breaking' this natural unit has attracted attention during the past 50 years, in the interests of higher productivity.

Usually a colony rears new queens only if the queen heading the colony is defective in some way, and produces insufficient pheromone(s) to inhibit the workers from queen rearing. But polygyny is not unusual in some races of honeybees, and the mother and one or more of her daughters may co-exist in different parts of the same brood nest, for a time. In practical beekeeping, a multiple-queen colony usually means one in which two or more queens are maintained in separate brood nests in the same hive, separated from each other by two layers of queen excluder.

The benefit of two-queen units is that their large populations enable them to store more honey than their separate component parts, each with one queen. Working them is a skilled operation not suited to all areas, or to all beekeepers, or to very large enterprises.

In Western Australia multiple-queen hives that extend horizontally instead of vertically have been in commercial use. The unit consists of a row of six 8-frame Langstroth brood boxes, separated by dividers, their flight entrances facing alternately to either side of the row. The single super (honey-storage chamber) holds 50 frames and extends across all six brood boxes, each of which has its own queen excluder. Alternatively, a three-decker outfit has been used, with a row of six separate honey supers below the 50-frame super (figure 5). All lifting is mechanical, by gantry or by a mobile mini-gantry. I have not heard of such units in use in any other country.

Package-bee apiculture

Many methods in modern large-scale beekeeping were developed in the USA and Canada, through a range of latitude from 25°N in Florida to 55°N in Alberta. In the southern states of America where spring comes early, the mass production of queens was extended in a practical and imaginative way to the production of 'packages' of 2 lb (1 kg) of newly reared worker bees with a young mated queen. The bees are shaken into the package boxes, which have two opposite sides of wire mesh to provide ventilation. The queen is inserted in a small cage, and sugar syrup is supplied in a safe feeder.

Around half a million packages are produced each year, and shipped to northern areas where spring comes late, usually by truck (600 per vehicle) or plane. An ancillary development is the use of package bees for a single summer in regions farther north than bees could be overwintered, but where, as we have seen, large honey crops may be harvested. As soon as the honey flow ends, the bees are killed and all the honey is harvested.

Package bee production has been developed in some other countries, but only the USSR encompasses a latitude span similar to that of the USA and Canada. A load of packages of bees in transit needs closely controlled conditions of temperature and humidity, and if these are not maintained the bees can easily be killed. Other hazards include delays at frontier posts between countries and, in aircraft, insecticide spraying. Partly for these reasons, no equivalent industry has been developed between, for instance, Mediterranean countries and northern Europe.

Queen rearing, bee breeding, and instrumental insemination

Large-scale rearing of queens for sale has been a specialized industry for many decades. Honeybees mate in flight, and from 1954 onwards evidence accumulated that queens do not mate with a single drone, but with a number of them (commonly 6–10), during a single flight. Only a few seconds are required for each mating, and matings can follow in quick succession. Drones are not attracted to a queen until she has reached a critical distance above the ground, which can vary from about 5m to 40m, for reasons still not fully understood. The workers' flight space is below that of the reproductives.

Drones are likely to fly more than 5 km from their colonies, and queens nearly as far. In tests with genetically marked bees (cordovan, in which black coloration is replaced by brown) 3 of 12 queens mated with drones from 16 km away. So, however carefully a queen is selected, the genetic make-up of her worker offspring cannot be assured so long as there are any adventitious colonies containing drones within say 15 km of her own colony. The area of a circle of 15 km radius is about 700 km^2 (70 000 ha). Sites used for controlled mating stations in different countries are: desert oases (excellent); small islands (often windy, but satisfactory if 15 km off shore); deep valleys with high mountains on either side to provide isolation (but very few such bee-free valleys are available).

The difficulties in ensuring 'pure' mating were appreciated long before details of the mating process itself were understood. An inviting approach to the problem was instrumental insemination of the queen. This was achieved in 1927, and the procedure is now a routine one [7, 8]. The queen (anaesthetized with carbon dioxide) is immobilized in a tube from which the tip of her abdomen protrudes, in the field of a binocular microscope. A specially designed syringe is mounted appropriately, and is charged with semen from several drones, which is then injected into the queen's vagina, beyond the valvefold which is held out of the way by a hook.

In the Old World, still with some populations of relatively pure ancestry in isolated areas, there is a wealth of genetic material for bee breeding. In the New World, where much attention has been paid to bee breeding, this situation does not exist, since all honeybees were introduced. It is, perhaps, a pity that the American initiatives in bee breeding could not benefit more from the richness of Old World material. Restrictions in importing foreign stocks have become progressively more severe, in view of the danger of importing pathogens along with the bees.

Global problems with bee diseases

Bees are very easily transported by air from one part of the world to another and—unless the utmost precautions are taken—diseases and parasites may be transported with the bees into areas previously free from them.

The smallest effective unit for transport, which weighs only a few grams, is a mated queen with about 20 'attendant' workers and a small supply of sugar candy for food. This queen is used to replace the queen of a colony of local bees, and within a few weeks or months all the bees in the colony will be the progeny of the new queen. Future generations of queens and drones can be reared from this progeny.

Diseases and parasites of *Apis mellifera*, introduced from temperate zones into Asia, were transmitted to the native *Apis cerana*. A recent transmission in the opposite direction has raised a much greater outcry: the mite *Varroa jacobsoni*, parasitic on *Apis cerana*, has infested *Apis mellifera* colonies. It has been inadvertantly taken, with bees, to many countries in Europe, and has arrived in North Africa with bees from eastern Europe, and in South America possibly with bees from Japan.

In order to provide a base-line for monitoring the incidence and spread of bee diseases and parasites, preliminary world maps have been prepared at the International Bee Research Association (IBRA) [10, 11]. These maps, which indicate only the presence or absence of a disease or parasite in each country, are now encouraging specialists to prepare more informative maps of individual countries such as India [12]. As might be expected, the countries for which least information is available lie in the tropical belt.

A few decades ago it was believed that most if not all the common infections of both adult and immature honeybees had been identified: they were specific bacteria and microsporidia, a fungus and an internal mite, and a virus causing sacbrood. Some or all of these pathogens were believed to lead to severe losses of bees, or to the death of whole colonies. But in the past thirty years Dr L. Bailey at Rothamsted Experimental Station in the UK has identified and characterized 18 viruses in honeybees, of which 10 occur in Britain. Many are probably very common, although sufficient data are not available to indicate their world distributions. This has led to the concept that most pathogens of honeybees are endemic, that they sometimes cause severe diseases and are always damaging, but that their incidence and the diseases they cause usually pass unnoticed or are accepted as 'normal'. Consequently their eradication should not be regarded as the only solution: their control by avoiding management methods and other circumstances that aggravate them is assuming greater importance.

The movement of honeybees around the world has wider undesirable implications than the spread of the mite *Varroa jacobsoni*. The introduction of alien genetic stock into an area already populated with honeybees of any species can have far-reaching effects (as in South America).

World honey sources

Another subject which requires, and is now receiving, global attention is the identification of the plants that are the most important sources of honey. Honey sources of many temperate-zone countries are relatively well documented, as a result of decades of study by beekeepers and scientists. But we have seen that the bulk of the honey coming on to the world market is produced in the subtropics, which have a flora that is both richer and less well documented. The tropical flora is richer still, and its honey-producing potential even less known.

IBRA is at present preparing a *Directory of the most important world honey sources*, funded by the International Development Research Council in Canada. Plants for inclusion are selected according to merit, from the many thousands on record as being visited by bees. Details of each plant, and of its nectar and pollen and the honey originating from it, are being stored on disc and will be printed as an appropriate entry in the *Directory*.

Bees used for crop pollination

The provision of honeybee colonies for crop pollination is an accepted part of apicultural work (figure 6). The scale may vary from 20 hives taken in spring to a cherry orchard in Kent, England, to the 20 000 used annually in a single establishment growing alfalfa for seed in California, USA [15]. Colonies need special preparation before they are used for pollination. Pollen foragers are usually more effective pollinators than nectar collectors, so the colonies are put in pollen deficit—for instance by reducing existing pollen stores and by inserting extra brood to rear, for which more pollen is required.

In some circumstances a device known as a pollen dispenser or pollen insert is fitted across each hive entrance, by means of which the outgoing foragers are dusted with a metered amount of the pollen selected by the grower, from a variety that will cross-pollinate flowers of the crop (usually apple or pear trees) under treatment.

Different races of honeybees can show different preferences for different crops. For instance long-tongued bees are most effective with flowers whose nectar is hidden in a long corolla. As an alternative long-tongued bumble bees (*Bombus*) have proved useful with tetrapoid red clover (*Trifolium pratense*) in parts of Europe, and they can be reared in suitable domiciles. Line-breeding of honeybees has been undertaken in the USA to produce honeybees that forage preferentially in alfalfa [16], but this work does not seem to have been followed up recently, and a more promising development may be the use of bees outside the genus *Apis*. In Western USA and Canada millions of the leafcutter bee *Megachile rotundata* are reared annually in 4-mm straws, or grooves or holes in wooden or plastic boards; they are taken into alfalfa fields in spring, a shelter containing 10 000 nesting females sufficing for each 2 hectares. In the same region, where the soil is alkaline, *Nomia melanderi* may be reared for the same purpose; this is a highly gregarious solitary bee that nests in the ground, and is amenable to propagation by setting up 'bee beds' near the alfalfa fields.

Figure 6 Hives taken to an apple orchard for pollination. Yakima Valley, Washington State, USA.

The present significance of the tropics for apiculture

The variety of honeybees and of plant honey resources in the tropics have been mentioned briefly. What remains to be said is that the tropical/subtropical belt round the world is of special economic importance in that it is the region whose apicultural potential is still largely unrealized. Natural resources of nectar, honeydew, and pollen are likely to be wasted as far as man is concerned unless bees are organized to harvest and store them, and a much larger proportion is so far utilized in the temperate zones, where there has been greater development, than in the tropics.

Beekeeping needs almost no land and, at its most elementary, hives can be home-made from materials obtainable locally. It is always labour-intensive. At an appropriate level, therefore, it can be a widely profitable occupation in Third World countries. A number of development programmes have been carried out, and some of these have been very successful although there are many factors that can reduce their long-term effectiveness. Guidelines for conducting programmes, with a directory of those already undertaken, have now been published [17].

In the global context considered here, the co-ordination of development programmes is one example of action needed both now and in the future, in order to make the most effective use of the world's apicultural resources. Such action can certainly benefit rural peasants in poor countries.

It has been recommended [18] that IBRA should play this co-ordinating role on a permanent basis, and funds are being sought so that it can be done. In summary, examples of enterprises to which this concept of global strategy should be applied include:

1. Identification and analysis of constraints to apiculture in developing countries, and recommendations for removing them.
2. Provision of a monitoring and co-ordinating service for agencies funding apicultural development programmes.
3. Monitoring bee diseases and parasites.
4. Assessment of important plant sources of honey.
5. Monitoring the position of bees and pollination in relation to pest management.
6. Action to promote both general and specialized training in appropriate branches of apiculture.
7. Action to ensure adequate transfer of knowledge and technology to specialists and beekeepers who need it.

The International Conferences on Apiculture in Tropical Climates (1, London, 1976 [19]; 2, New Delhi, 1980; 3, Nairobi, 1984) provide a periodical forum for discussion of these subjects.

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