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MAN'S UTILIZATION OF NATURAL RESOURCES THROUGH BEES

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One significant result of man's travels to the moon is that many people on the earth are now familiar with photographs of their planet as an isolated sphere in space. This has brought home, as nothing else could, the fact that the earth is a single entity whose resources are strictly limited : there is no longer a rich New World to be sought out, populated, and exploited.

"Only one earth" is the title of a report published in 1972, for the United Nations Conference on the Human Environment. The book carried the sub-title "The care and maintenance of a small planet", and the authors, Barbara WARD and René DUBOS, like others since, stressed the need for conservation and proper utilization of the world's natural resources.

The theme of this Congress is bees in relation to the environment, and my subject this afternoon is the complexity of interactions between three factors : bees, their environment, and man.

Nectar is a component of the environment in which we and our bees live. It is produced by both wild and cultivated plants, wherever in the world they grow. In general it is a natural resource that is not accessible to man, and that is wasted unless bees or some other insects collect it — or, occasionally, tiny birds, mammals or marsupials. The performance of bees is truly astonishing. The fuel consumption of a flying bee is about $1/_2$ mg honey per kilometre, or 3 million km to the litre. In providing one kilogram of surplus honey for market, the colony has had to consume something like a further 8 kg to keep itself going, and the foraging has probably covered a total flight path equal to 6 orbits round the earth — at a fuel consumption of about 25 g of honey for each orbit.

The historical background

Looking back in time, social bees had evolved, and were producing honey, long before man existed. Honeybees have been producing honey in many parts of the Old World for 10 or 20 million years. In the New World there were no honeybees, but in the tropical and subtropical areas stingless bees produced substantial amounts of honey. Then, as now, honey was stored by the social bees and used in the next dearth period. Then, as now, the honey was sometimes taken instead by various animals — although not by man, since he had not yet evolved. Recent descriptions of honey-harvesting by primates such as baboons, gorillas and chimpanzees are of particular interest, especially the use of sticks as tools. MERFIELD and MILLER have reported that each of a group of chimpanzees they watched held a long twig, poked it down the hole where the bees' nest was and withdrew it coated with honey. The behaviour of human beings getting honey in early times is strikingly similar. For instance in the Bible, the First Book of Samuel relates that Jonathan, son of Saul "stretched out the stick that was in his hand, dipped the end of it in the honeycomb, put it to his mouth and was refreshed".

The earliest known direct record of honey hunting by man is a painting in a rock shelter in eastern Spain, made possibly as early as 7000 BC. Harald PAGER from Austria has recently discovered many paintings in rock shelters in Southern Africa that show bees and combs, and also ladders such as that in the Spanish painting. One, in the Matopo Hills of Rhodesia, portrays the honey hunter at work, with a firebrand that is driving the bees from their nest — the prototype of the modern beekeeper's smoker. In an article in the next issue of the journal *Bee World*, Harald PAGER presents evidence from the caves at Altamira in northern Spain, that honey-hunting was a significant human activity as far back as the Ice Ages. This is much earlier than the rock painting in eastern Spain.

So far man — and animals — have intruded into the bees' environment to rob them of their honey. *Beekeeping* was a later development. The earliest written record we know of the use of hives is a section of Hittite laws codified by Hammurabi about 1800 BC, in what is now Asia Minor. The theft of beehives, *and also of empty hives*, was dealt with by imposing fines ; this suggests that containers specifically constructed for housing bees were in use.

We have even earlier pictorial evidence that bees were taken from their natural environment and kept in man-made hives, from Ancient Egypt, where a stone carving in relief, made about 2400 BC, shows the treatment of honey and, on the left, traces of horizontal hives. Hives are shown more clearly in an Egyptian tomb at Thebes, around 600 BC. The shape of these hives shows a strong resemblance to hives made of mud, cow dung and straw that are still used in the High Simien mountains in Ethiopia.

The very primitive nature of this Ethiopian hive serves to illustrate the fact that man has made hives for bees out of whatever materials he had available, for his own benefit and convenience in using the bees to provide him with a honey harvest. Also for his own convenience, man grouped his hives together in an apiary, which could be fenced and protected. Where the population density of wild honeybee colonies was limited by the number of nesting, sites and not by food available, the provision of hives of any sort — of wood, straw, or pottery — would lead to an increase in the number of colonies. Bearing in mind the theme of this Congress, "The bee and the environment", we should note that the natural environment for bees is a scattered population of individual colonies, at a density over the countryside low enough to give each colony enough food within its foraging range. And by "enough food" I mean enough for its own use in its annual breeding cycle, plus enough to store to see the colony through its next dearth period, whether this is determined by cold (as in the temperate zones) or by rainfall (as in the tropics).

Nowadays the bulk of the world's honey crop is harvested from movable frame hives, and the honey extracted by centrifuge from the framed combs. The number of hives in the apiary is commonly a number suitable for transport in a truck or other vehicle. Such measures have been devised by man to enable him to use the bees to win a harvest he cannot get unaided. It would be an exaggeration to call it factory farming, but it benefits the beekeeper rather than the bees. The beekeeper's achievement is to manage his bees so that they store a great deal more honey than they need — otherwise he himself would get no harvest. The use of movable-frame hives enables the beekeepers to remove and handle what he calls "his" honey harvest with a minimum of trouble. Such hives are of little or no benefit to the bees ; they may, indeed, be detrimental, in that transference of frames from one hive to another can transmit disease. The unnatural concentration of colonies in an apiary or bee-house is also conducive to the spread of disease, as is the migration of an apiary from one foraging area to another, where there is contact with bees from other areas. The beekeeper does, however, keep a watch for disease and treats any he finds. Moreover in an unexpected or excessive dearth period the beekeeper feeds his colonies and prevents their death from starvation.

The use of beeswax foundation is said to "save" the bees from making wax themselves. But, again, this is a benefit to the beekeeper, rarely to the bees : in the swarming period they are well able to produce wax and build combs expeditiously, because they are physiologically adapted to these activities at this period of their reproductive cycle. Any of the bees' energy released may be diverted : into making and storing surplus honey that the beekeeper can take.

Man's harvest from bees

We must now return from considering man as part of the bees' environment to bees as part of man's environment. Honey is one material benefit man gets from bees, and some 600 thousand tons of it are harvested in the world each year. Honey is a substance bees *make*, from nectar and honeydew ; in this it is unique among bee products, and I shall come back to it later.

Two substances bees collect and store : pollen and propolis. To each the bees add secretions that make the substances suit their own needs. Three further substances used by man are secretions from glands of the worker bees : beeswax from the wax glands on the underside of the abdomen ; bee venom from the venom glands, also in the abdomen ; and brood food or royal jelly from the hypopharyngeal glands in the head.

Man cannot obtain any of these substances — except to some extent pollen and propolis — without bees. Bees also provide a service which is of far greater economic value to him than all the substances they produce : pollination. Many crop plants cannot produce seed or fruit without pollination, and in a wide range of these plants pollination needs the mediation of insects, of which bees are the most important.

Honey, pollen, propolis, beeswax, bee venom and royal jelly ; these are the bee products so far used by man. They provide the bees themselves with food (honey and pollen), housing (propolis and beeswax), security against enemies (bee venom) and the means of rearing brood, so that the colony continues as a living organism (royal jelly). Man has devised various uses for them. In particular, all six products have been employed in pharmacy. Beeswax was for centuries important as a source of light, for instance in candles ; two of its main uses today are in armaments and in cosmetics, but neither industry is willing to provide detailed information about its techniques. There has been for some time a severe world shortage of beeswax.

I now want to discuss honey in some further detail. Honey has always been a food for man as well as for bees, but its consumption varies greatly in different parts of the world. First, there are European countries with a long tradition of eating honey, where more is consumed than is produced, imports making good the deficit. Even here the *highest* per capita consumption (Netherlands and the German Federal Republic) amounts to only 1 or 2 kg a year and, by and large, people eat about 100 times as much sugar as honey. Second, there are countries with a much higher honey yield per colony, and also a high honey consumption : USA, Canada, Australia, New Zealand ; these are all New World countries peopled from Northern Europe. Here again, people eat up to 100 times as much sugar as honey.

The third group of countries, in South and Central America, can give high honey yields per colony, but the people eat little of the honey ; they sell it for export instead. Sugar is also a commercial crop in many parts, and on average sugar consumption is 500 times the honey consumption. The average sugar consumption in Cuba is 79 kg a head. At the other extreme is Asia, where consumption of both honey and sugar is very much lower, only 4 grams of honey per capita and 7 kg of sugar. Japan, recently, has changed its eating habits and become more like a European country with regard to honey and sugar. This leaves Africa where, traditionally, in the tropical regions, the honey was used for making beer i.e. drunk as alcohol, not eaten as honey. Honey consumption per capita is higher than other continents with tropical regions, but sugar consumption is comparatively low.

Before leaving the question of honey and sugar consumption I should like to clear up one common misconception. It is more or less true that, before sugar was widely nown, "honey was man's only sweetener". But it is not true that man ate the amounts of sweet food that he does now. World sugar production (and consumption) has increased by fifty times since the early 1800s. It is my surmise that the per capita consumption of honey was somewhere about the same before the use of sugar as it is now. The 50-fold increase in sweetness of the diet is a new and, if you like, artificial development, related to the sugar industry, and having little to do with honey.

The secret of honey

Much fanciful literature has been written about the magic of honey. As a scientist, I want to deal with fact, not fancy, but honey gains rather than loses interest as we learn more of the facts about its production in an environmental context.

In most species of insect, when the female lays an egg she herself provides the food for the larva that develops. Some insects place the egg on a source of food already available — the blowfly on carrion, the cabbage butterfly on a cabbage plant, and so on. Other insects collect food and form it into a convenient package, and then lay each egg on the prepared food. With many insects the prepared food is a mixture of nectar/pollen: nectar provides carbohydrates; pollen provides protein, vitamins and other substances which the larva needs to grow and develop. The whole process of provisioning, egg laying and larval growth takes only a few days, so long-term storage of the food is unnecessary. With social insects, instead of this mass provisioning there is progressive feeding: food is stored in the nest, and a specialized group of the insects uses this food for rearing larvae, either feeding it to them directly, or eating it themselves and secreting glandular brood food. Social insects that form only temporary colonies, like bumble bees and wasps in temperate regions of the world, may keep food in the nest for a few weeks or even months. In the tropics they form permanent colonies, but food is available for most of the year, and long-term storage is not necessary.

The most highly developed social insects form permanent colonies, wherever in the world they live. The European honeybee we know so well, *Apis mellifera*, and its Asiatic counterpart *Apis cerana*, build their nests in cavities, with many parallel combs of cells in which they rear brood. These bees have developed the ability to withstand winter — a dearth period of cold — by conserving energy to the utmost; they remain clustered together, minimally active and consuming minimal amounts of food. When the temperature begins to rise and the day to lengthen, the bees are able to start rearing brood again *because they have stores in the nest*. Fresh supplies of spring pollen stimulate brood rearing, which is possible on quite a large scale because the honey the bees stored last summer has overwintered without deteriorating.

Honey is a solution of sugars, and such solutions easily ferment, especially at the temperature in a hive, and when there has been contact with yeasts from the environment. What is it that prevents honey from spoilage through fermentation? The nectar the bees collect is mainly a dilute solution of sugar, most or all of which may be sucrose. In making honey, bees secrete enzymes from glands in the head, including invertase which can "invert" sucrose into glucose and fructose. Largely as a result of this chemical action — I shall not go into the many complications and variations — the sugar in honey is nearly all glucose and fructose. Why do the bees not simply evaporate from the nectar as much water as possible, and store the concentrated sugar solution that remains, irrespective of its composition? Why indeed are they equipped with glands that produce the enzymes necessary for this elaborate chemical processing? The answer to these questions is most likely to be that, in the past, the system gave the bees some evolutionary advantage. Dr. Jonathan WHITE in the United States has given what I think is the right explanation, in a book published this year: by inverting the sucrose in the nectar, they increase the attainable density of the final product, and thus produce a high-energy food, whose resistance to spoilage by microorganisms is also greatly increased by its high sugar concentration. Dr. WHITE refers to experiments carried out by R. E. LOTHROP and F. H. C. KELTY in the 1940s and 1950s respectively, which showed the following. At a temperature of 30°C, the solubility of glucose in a solution of fructose is abruptly increased if the fructose concentration is raised above $1^1/_2$ grams per gram of water. The gram of water would then hold in solution, as well as the fructose, $1^1/_4$ grams of glucose, half as much again as a dilute fructose solution could carry. Further, the sugar *sucrose* does not have the *glucose* characteristic of greatly increased solubility in concentrated fructose solutions. Further again, at higher temperatures glucose does not have it either. So inversion of sucrose into glucose and fructose makes it possible for the bees to produce a more concentrated solution of sugars than could ever be attained with sucrose. Honeys are supersaturated solutions with water contents only about 18%, and their high sugar concentrations are possible only because the bees have changed the sugar composition in this specific way.

The bees get two clear advantages: resistance to spoilage by fermentation, even during year-long storage, and high-energy food to store in as little space as possible. We ourselves are now in fashion if we work for the conservation of energy, and if we use dehydrated foods. The bees have been converting nectar into high-energy food stores, and dehydrating it, literally for millions of years.

I should like to say a word to research workers who are interested in honey chemistry, or in environmental problems concerning bees in general. All four species of honeybees store honey, also stingless bees (Meliponini) and bumble bees *(Bombus)*. There is a rich field for study in the composition and characteristics of the honeys from these bees, and from some other groups of insects including the wasps *Polybia* and *Nectarina* and the honey ants such as *Meliphorus*. The enzymes produced

Dr. Eva CRANE and Prof. G. F. TOWNSEND during one of the Congress sessions by the different groups, and the nectar and other sugar-sources they use, should be studied in conjunction with their honeys. Dr. Michael BURGETT has, for instance, found that a number of these social Hymenoptera secrete the enzyme glucose oxidase, which helps to protect nectar in the hive from microbial spoilage.

Using bees to get honey

A honeybee colony may need something like 100 kg of honey and 50 kg of pollen to keep itself going through the year. The amounts vary greatly, according to the flight activity and the amount of brood reared. If there is sufficient nectar or honeydew within foraging range a colony will continue to store honey in great excess of its likely requirements. This is why the beekeeper can, by suitably managing and manipulating colonies, get a honey harvest for himself that provides an economic return on his capital investment and annual costs. A colony's honey store is, however, not a constant source to be drawn upon at the beekeeper's convenience. At any one time it represents a balance between food consumption (or removal) and food income and reserves from the past. Food consumption depends largely on the amount of brood rearing and nest expansion, which follows an annual cycle determined basically by climate and day length. Food income depends on plant development, and is less simple : most nectar sources flower only for one short period each year, and the cycles of plant and insect development that govern honey dew production are even more complex. So food does not come in regularly, or in one smooth annual cycle. It comes in several short "flows", corresponding to the different plants within foraging range.

The diagram shows the average weekly gain or loss in weight of hives in an apiary during the summer months (for the rest of the year, November to March, there would be no gains in weight ; the colonies would be using up the stores they had). The hives were in Arkansas, U.S.A., and the flow in May from holly *(Ilex opaca)* would largely be used up in annual spring brood rearing. The flow in June-July is from sweet clover *(Melilotus)* and that in September from Spanish needle *(Bidens)*. These flows are not accompanied by the same intensive brood rearing, and these are what provide the bees with their winter honey stores — and the beekeeper with his honey harvest.

So far we have considered bees in their natural environment. What the beekeeper does is to move his hives to flows available at different places ; this movement is refered to as migration. Much of the world's commercial honey is obtained in this way, because the strongest honey-producing flows are usually from dense stands of a single plant species such as eucalypt, acacia, citrus, or ling heather. These provide little or no forage for the bees except once in the year, and the bees must be pastured elsewhere except during the specific flow.

Table 1

HONEY PRODUCTION AND CONSUMPTION IN THE DIFFERENT CONTINENTS

	Europe*	USSR	USA + Canada	Australia + New Zealand	S. and C. America	Asia *	Africa	World total	Old World / New World
Area (million km²)	4.7	22.4	19.6	8.0	20.8	27.9	32,3	136	87 = 64% / 49 = 36%
Total honey harvest (1 000 tonnes)	121	103	125	24	102	73	83	630	379 = 60% / 251 = 40%
Average honey harvest per colony (kg)	9	11	26	35	25	12	6	12.5	9 / 27 (× 3)
Average honey consumption per capita (kg)	0.4	0,5	0.7	0.5	0.1	0.004	0.26	0.17	0.13 / 0.38 (× 3)
Average sugar consumption per capita (kg)	36	45	49	57	42	7	11	20	15 / 46 (× 3)

* excluding USSR

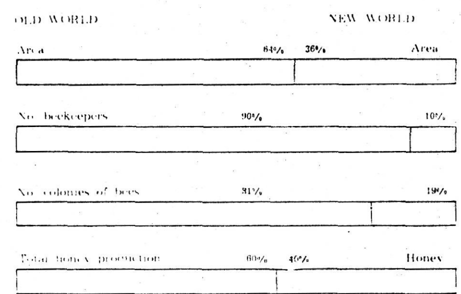

Fig. 2 — Comparison between beekeeping in the old World and [illegible] World

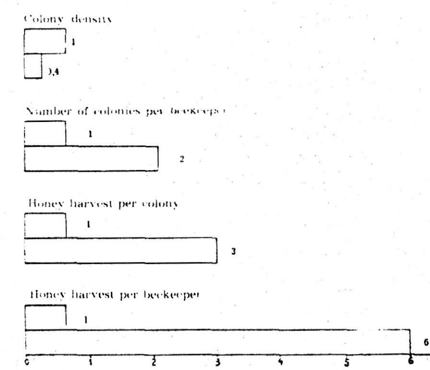

Fig. 3 — Efficiency of honey production in the New World as compared to the Old World

Man can thus give colonies of bees a new environment, and does so to his own advantages. On a larger scale, it is through man's actions that honeybees ever arrived in the New World. They are not native to the Americas, Australia or New Zealand, but were taken there by early settlers. In point of fact they have thriven so well in the New World that this now provides most of the world's export honey.

Figures for individual countries have been listed, then summarized by continent, and finally grouped into New World and Old World, and these two regions compared. Today we have time to look only at a few comparisons between the New and Old Worlds. Only 10% of the world's beekeepers are in the New World, but they have 19% of the world's colonies of bees, and produce 40% of the world's honey.

The difference is shown even more strikingly in another diagram. Here the Old World is taken as standard and the New World compared with it. The honeybee colony density in the New World is less than half that in the Old World, where they are much more thickly concentrated. But in the New World each beekeeper owns twice as many colonies on average, and his honey harvest per colony is 3 times as high. His total honey harvest is thus 6 times as great as in the Old World. This brings us back to bees in relation to their environment — which is in many ways richer in the New World than the Old. This fact, coupled with the great adaptability of the honeybee in exploiting a wide range of plants as food sources, results in lower costs of production, and consequently lower prices, of honey from the New World. Or, if you like, it explains why home-produced honey from many parts of the Old World appears to be expensive. Even the price of honey is basically an environmental problem.

Conclusion

In closing, I want to show you a woodcut made in the late 1600s, because it seems to me to sum up in an attractive way the principles involved in the triangular situation between bees and man, and their mutual environment. The heading is a Latin motto: "So we the bees make honey, but not for ourselves". The cleric on the left is eating a piece of honeycomb as a token of his preaching, perhaps from the book of Proverbs: "Pleasant words are as an honeycomb, sweet to the soul, and health to the bones". The cultivated rose and the wild thistle symbolize the extremes of plant life, all yielding honey to the bee, who is a "chymick bee", being something of an alchemist in mysteriously producing gold-like honey.

On the right, "Everything is to be found in books" refers to the scholar in his study below. He, like the bee, gathers knowledge from all available sources and stores it for use by others.

This Congress should indeed providt a rich harvest of scholarship and technical experience. As for the bees, they make the honey from their environment resources, and we take it from them. Those who love bees may perhaps draw comfort from the fact that bees are creatures of instinct, not reason, and they cannot understand or regret their exploitation by man.