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BEES OF THE FUTURE

ORIGINALLY, AS IN America, there were no honeybees in Australia. European settlers brought their beehives to Australia with them by ship in 1832. Thanks to isolation and strict quarantine regulations, the descendants of these bees were still free from *Varroa* in August 2012. Despite this, beekeepers, governmental authorities, and bee experts are preparing for the time when this may no longer be the case. The country is in a state of siege and reports that individual swarms of wild Asian or European bees, potentially afflicted by *Varroa,* could reach the continent by ship or air are a source of concern throughout the continent.

In 2011 alone, twenty-five such colonies of bees were discovered by the Australian quarantine inspectors and fortunately intercepted in time. Even if just one colony infested by *Varroa* finds its way into the country, it would be enough to establish the destructive mite in Australia. The general fear is that Melbourne is the most likely gateway for *Varroa*, as its large harbor and airport and its proximity to already afflicted New Zealand make it especially vulnerable.

In 2007, we saw how quickly an uninvited guest could enter Australasia. At that time, a swarm of Asian bees, the main host of *Varroa*, managed to swarm on land, without being noticed, from the mast of a yacht. Fortunately, these invaders were not only later established to be free from *Varroa*, but were also discovered early and destroyed. Nevertheless, the public authorities had to declare that the Asian bees had become established in Australia at the end of 2011. The expectation is that the mites will arrive and will spread *Varroa* throughout the continent.

Professor Boris Baer, director of the Centre for Integrative Bee Research (CIBER) at the University of Western Australia in Perth, sees the delay in the mite reaching Australia as a unique chance. “We are working on reacting calmly and having a running start when the time comes. If all goes well, we will have alternatives to the usual barrage of chemicals,” he said. Defense through chemical substances is only a temporary solution; parasites are adaptable and develop resistance to pesticides and antibiotics so that newer substances have to be continuously tried and tested before being applied. Additionally, as the parasites cannot be treated with these substances without affecting the host, conventional chemical treatment also carries with it the danger that the bees will be weakened and the destructors strengthened.

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This means that alternatives have to be found. At CIBER, three interest groups—beekeepers/breeders, government authorities, and scientists, groups that normally keep well clear of each other—have joined forces. This group has been working together since 2008 and is financed by the Australian government, Western Australian bee breeders, and international research grants, and is all about using synergy "so that the right questions reach the right ears and good answers don't get lost somewhere amongst real or digital files," said Baer. He cites as an example a positive lesson from the recent past. Western Australian beekeepers and breeders have already withstood one plague, American foulbrood, which ravaged the country twenty years ago and which was said to be impossible to overcome without the use of chemicals. This experience should encourage them to approach the *Varroa* problem without relying on chemicals.

Once an Australian state was infected with American foulbrood, its borders with other states were closed to bees and bee products. Despite addressing the problem without using aggressive antibiotics, there were no catastrophic losses. "Local bee breeders are still able to cope reasonably well with foulbrood," says Baer. "Bees are bred, by and large, to manage the disease by themselves." Researchers at CIBER are counting on similar results when *Varroa* or other diseases eventually reach the continent. They have confidence in the powers of resistance of nature and are trying to strengthen them.

CIBER has not only brought together beekeepers, government officials, and scientists, its own research team consists of experts from various disciplines, ranging from biochemistry to classical biology and from molecular biology to physics. Normally, scientists dealing with "how" questions (How can we explain metabolic processes?) are not interested in "why" questions (Why do metabolic processes happen in such and such a way?). But here they approach the answers to a key question together. Professor Baer explains: "What is the molecular fingerprint of a bee with strong resistance? What is it that makes it different to a vulnerable bee? And even better, how can we share this with the honeybees that we have bred? Unique opportunities are emerging to fully understand biological processes."

One PhD student at CIBER discovered that the ejaculate of drones protects against certain infections as it contains special molecules that kill the unicellular fungus *Nosema apis*. Interestingly, the bees themselves have developed this form of resistance, a natural defense, as it were. The next step will be to identify the active agents that the bees have developed against these intestinal parasites and maybe use them as medication. Additionally, it would be interesting to test the ejaculate of drones from different colonies for *Nosema* resistance and later to breed them with bee strains that are particularly resistant.

The research team also suspects that the sperm from drones from hives that are *Varroa*-tolerant could be used to establish a strain that, in time, would also be *Varroa*-tolerant. In this respect they are also considering carrying out an experiment that could be controlled because it would be conducted on an isolated island off the Western Australian coast which at the moment is reserved for military forces. Under continuous scientific observation, native queens would be artificially inseminated by imported sperm from drones from *Varroa*-tolerant colonies and would raise new colonies there.

Who knows? Maybe the "new colonies" from this experiment could be mixed with *Varroa*-infected European honeybees in, say, Papua New Guinea in controlled field trials. If a strain of the island test bees developed into a *Varroa*-resistant strain and were then repatriated to Perth, they could function as a genetically programmed local weapon in the battle against the *Varroa destructor*.

Results of preliminary trials from 2011, in which a hundred Australian queens were exported to the USA to raise new colonies in *Varroa*-infected areas, have not discouraged the CIBER team. The US beekeepers, for the first time in their careers, discovered more mites than bees in their hives. The experiment failed, or to quote the wry comment of Professor Baer: "There's room for improvement."

For a number of years it has been recognized that parasites can be transmitted by bee sperm. If they were introduced to a new colony by artificial insemination, however, nothing would be gained from increased mite resistance; it would be replacing one evil with another.

Professor Baer sees another starting point in Australia's feral bees. Feral bees shouldn't be confused with the diverse types of bee that are generally termed "wild bees." Ferals are wild honeybee colonies that trace their ancestry to the bees that the European settlers brought to Australia in 1832. They escaped from human custody and survived in the wild where they developed a particularly good immune system unaided by outside help.

The widespread feral bees in Australia managed to regain an astonishing amount of what animals in the wild have to know. Wild bees have to find ways to tackle local diseases. As they are not kept in boxes or given extra rations in winter, only those colonies that pass on their genes despite infestations, winter temperatures, and drought are strong enough to produce young queens and drones.

The CIBER team is planning to bring back some of this capacity to resistance to the cultured Western Australian bees. The scientific breeding objectives are clearly defined by Baer:

> We have to go back, and in this case it is not a step back. We have continued to distance our honeybees from what a bee is and should be. Bees are no longer able to cope with the challenges of parasites, pesticides, and climatic changes as their immune systems have been ruined through breeding where the only interest is in X amount of kilos of honey per colony. And if *Varroa* doesn't get them then the next plague or the one after that will. We have to go back to go forward.

Evolution is the teacher, the pacemaker, and the signpost. Life remains on the planet after 4 billion years mainly because it has reinvented itself countless times. The question of how this was possible keeps both practical and theoretical evolutionary biologists busy.

Darwin created the foundations of the theory of evolution with his book *On the Origin of Species*. His theoretical concept stated that animals that are better adapted to their environment than their competitors pass on their genes because they reproduce more successfully and produce better adapted offspring. Under given conditions, species that are less well adapted are less capable of passing on their genes. They either become extinct or find a new niche better suited to their special abilities. So, for instance, plants that are crowded out by faster-growing species adapt to colder climates where their competitors are not able to compete. Natural selection, survival of the fittest, adaptability—today Darwin's keywords have become common knowledge. Thanks to numerous research projects, the empirical proof of their accuracy has been supported, even if sometimes they are quoted out of context and cited in terms that are not politically correct. An abridged understanding of evolution and development of the species has prevailed for a long time, at least in the popular imagination. A living creature continues to develop to secure its own survival, and thus the survival of its species. Cheetahs improve their sprinting speeds to be able to hunt down the particularly fast antelopes. Antelopes have to become faster to escape from the cheetahs. And all of this because in life there is an integrated master plan that demands that you have to improve to survive.

Nature demands from its creatures that their genetic information, their blueprint, be passed on to the next generation. Nature is pretty flexible about how exactly this should take place. The fine-tuning of certain individual qualities is not the only development principle. Individuals can also have their genetic information passed on instead of passing it on themselves. Although such behavior is widespread in the animal world, even Darwin recognized that the behavior of individuals that seemingly altruistically help others to reproduce was difficult to explain with his theory of evolution. With the bees, the workers do not, as a rule, lay the eggs, but they do help the queen to raise the offspring.

How can such behavior arise when genes are egoistic units that are only supposed to reproduce themselves? It took until 1962 before an evolutionary biologist named Bill Hamilton came up with the answer. He developed a mathematical model, the concept of inclusive fitness. According to Hamilton, an individual profits from the services of the helper if the individual that receives the services is related and thus shares the genes of the helper. In other words, an individual also propagates genes through relatives such as nephews or nieces. This concept explains altruistic behavior and negates the conflict with Darwin's theory.

The scientific community finally understood Hamilton's brilliant premise some twelve years after its publication, and further developed his ideas to form a branch of science that is known today as sociobiology. The term "kin

selection" from this discipline states that individuals from a certain species abandon their own reproduction and help related individuals to pass on shared genes to the next generation.

The principle is most pronounced in insect societies. Worker bees perform their grueling workload in the service of the community. Perhaps a slightly less exhausting schedule would enable them to live for a little longer than the usual five weeks that lie between the birth and death of a simple honeybee. But only egocentrics pose such questions. An individual bee has achieved its purpose when it has ensured the passing on of its genes as effectively as possible. The best way of achieving this in a colony is by supporting the queen, which shares at least 50 percent of the same genes and which can pass on the genetic building blocks not only one time but millions of times.

To imagine a colony of bees in its entirety as an organism is not so easy, but fundamentally a bee community acts as a single living entity. It consists of an asexual body (a multitude of workers performing various body functions), an organ responsible for conception and birth (the queen), and another organ that takes on fertilization (the drones). Biologists term such a combination of teamwork a "superorganism."

Superorganisms like ant, termite, or honeybee colonies act differently from individuals; their future depends on more than the ability for survival of individuals. For social insects, benefits are intended for the greater good. The strength of the species lies in the community. Had evolution, hundreds of millions of years ago (insect communities have existed for at least this long), only catered for the advantages of a single primeval insect, maybe even an ancestor of *Apis mellifera*, there wouldn't have been social communities.

There are examples of kinship among mammals as well as the socially organized insects. Young, pre-adult vixens assist their mothers in rearing younger offspring and so support the continuity of 50 percent of their genes—that is, the proportion that they share with the cubs. This is a good decision as long as the genes cannot be passed on directly via the birth of their own offspring. When a marmot is on lookout duties for predators it risks being caught by an eagle. Its altruism, however, protects its own genes, which are also found in the closely related clan in the vicinity. Greatly simplified, the kinship principle is *family first*. If you cannot pass on your genes effectively, support those that can.

In addition to the honeybees that live in colonies, the ones we are familiar with, there are other "homeless" bees. We currently know of twenty thousand types of bees divided into nine families, and there are probably more. They are spread throughout the world wherever there is blossom, everywhere except in Antarctica. In Germany, the term "wild bees" has become accepted, and at the moment around six hundred different types are just about surviving—"just" being the operative word that we have become used to when talking about diversity, and it characterizes the state of affairs of wild bees. According to the estimates of Bund für Umwelt und Naturschutz (BUND; Friends of the Earth, Germany), 80 percent of wild bees in Bavaria are endangered or even threatened with extinction.

Although there are no specific studies, we can assume that wild bees, just like tended bees, die from the effects of sprays used in agriculture. The main cause of their deaths, however, has to be the loss of habitat. Wild bee biotopes are disappearing; structurally rich forest margins, hedgerows, extensively farmed pasturelands—lightly fertilized or not at all—remote meadow orchards, small sandy areas and clay ridges and their associated plant life, field margins, and waterside areas have all become increasingly rare.

As a rule, wild bees depend on the diversity inherent to a natural landscape, and modern farming with its standardization and depletion of flora is killing them. The most threatened of the endangered species are bees that are dependent on a single kind of blossom. Or looking at it a from different angle, a small number of flowers are dependent on being fertilized by certain bee or insect species. The experts speak of this mutual dependence as a close symbiotic relationship. For example, a species of mining bees, *Andrena hattorfiana*, can only survive if the right mixture of *Knautia* (such as *Veronica*), *Scabiosa* (such as *Centaurea*), and the thistle-like *Dipsacus* are in the vicinity, and these are groups of flowers that have become scarce in our highly cultivated landscapes.

The fact that we seldom recognize or even notice wild bees as bees isn't only because they have become scarce and because their appearance, to the untrained eye, is similar to that of our honeybee. Most of them don't swarm and their combs are not found in hollow tree trunks—for the layman, two classic signs of bees. The majority of wild bees are solitary, loner bees.

The life cycle of these solitary bees is very different to that of the superorganism honeybees. While honeybees are specialists, the solitary wild bees could be labeled as generalists. Every fertilized female takes care of building the nest and raises its offspring alone. There is no parallel division of labor as with the honeybees. As a loner, a wild bee builds the brood cells, lays eggs, and forages for pollen and nectar, which is fed to the larvae as a more or less runny mixture. Finally, the solitary bee mother seals the brood cells in which the larvae go through their metamorphosis. Solitary bees can rear two generations in a year, and in especially warm years with an Indian summer, sometimes three. Much of what the honeybees have to do to organize their social life is not applicable to the wild bees. They don't have to stockpile and there is no need for the waggle dance to pass on information. Solitary wild bees don't have to take up a series of jobs in their lifetimes, which at times honeybees have to do exclusively. Everything that has to be done has to be done one thing at a time by the mother bee. Drones, the male offspring of wild bees, are, as with honeybees, little more than flying sexual organs; they leave the nest well fed, mate with female bees of their species, and then die.

Most wild bees have very short stings that cannot penetrate human skin. They have no need for the defense capacities that honeybees have as there is not much for wild bees to defend; as far as propagation goes, it is better to fly away and rear offspring elsewhere when attacked than to risk life. Solitary bees can also be high-performance pollinators: *Anthophora* can visit up to 8,800 blossoms a day, more than double the capacity of a single honeybee.

Entomologists have discovered that, in the realm of wild bees, there are degrees of solitariness and sociability, with some bees being more social than others. There are quasi-social bee types—the mothers performing their maternal duties next to each other, nursery to nursery as it were—and semi-social bee types—mothers that share responsibility for the brood, to some degree at least. Biologists recognize stages of evolution in the development of solitary bees—from primitive eusocials (for instance, colony-building bumblebees) to the eusocial honeybees.

The bumblebee occupies one such intermediate stage on the way to being a superorganism. Their colonies produce reproductive animals in fall. The drones and the non-mated queens from various colonies fly off and mate. The drones die in the process and the young, now fertilized, queens gorge on pollen and nectar and overwinter alone, often in deserted mouse nests from the end of August until mid-April. In spring they crawl out of their winter quarters and search first for early blossoms and then for a nest site where they begin to build the first wax cells, adding a bit of pollen and nectar and then laying their eggs. The queen rears the first workers until they are able to fly and take care of their mother, which can then concentrate on laying more eggs.

People use bumblebees commercially in greenhouses, very often for the pollination of tomatoes. These, like the blossoms of all the nightshade family, rely on buzz pollination. The insects vibrate their flight muscles rapidly to shake loose the pollen from the anthers. As species of the nightshade family do not produce nectar, the pollen is the only incentive for bumblebees or bees to visit the blossom, and it serves as nutrition for larvae because it contains particularly high proportions of protein and nitrogen. Honeybees do not get to the pollen by buzzing but by undoing the anthers to access the pollen.

Cuckoo bumblebees are an interesting subspecies that specialize in making others rear their brood. Just like a cuckoo profiting from the absence of a reed warbler or a wagtail to deposit its eggs in a host nest, cuckoo bumblebees lay their eggs in host brood cells, ingeniously choosing cells that have already been stocked for future larvae. The same law applies for these bumblebees as for all freeloaders: If they are too successful, they endanger the continued existence of their host. Their survival as a species is only secure if they make use of their form of outsourced parental care in moderation. Their relationship has become well balanced over an evolutionary period of time. The same applied originally to the relationship between the parasitic *Varroa* mite and the host bee. It became unbalanced only when another species of bee came into play so that not only the Asiatic *cerana* bees were afflicted but also the European honeybees. As we know, the encounter between *Varroa destructor* and *Apis meliferra* can be traced back to human interference. It is quite possible that at some stage they would have encountered each other anyway, but at a less dramatic rate.

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The same goes for other factors that are making life difficult for honeybees and wild bees. Even creatures with short gaps between generations like insects struggle to adapt to the speed with which landscapes are being transformed by humans. And unlike birds and mammals, they have few food and brood reserves. At best they benefit from the protection of the more valuable habitats of species such as birds, amphibians, reptiles, and mammals that have captured the imagination of the public. Vertebrates are simply better suited as mascots of nature conservation.

But there are increasing signs in the media that conservationists also want to provide protective measures for six-legged creatures. The Internet is awash with numerous tips on which plants and nesting aids can be used to attract wild bees to parks and gardens. The tips, instructions, and offers range from complete bee hotels (ready-made in DIY stores) to simple pieces of wood with variously sized holes drilled in them and everything in between—nesting tiles, nesting boards, clay plates with or without perforations, reed boxes, tree disks, bundles of thin bamboo canes. And every now and then suggestions are made that require little effort, but might be about doing something that some gardeners don't find too easy: Gardens shouldn't be too organized and it helps to leave a few seminatural corners for guests like birds, hedgehogs (in Europe) or porcupines (in North America), butterflies, beetles, and wild bees to live, feed, and make their nests in.

In such places you can occasionally witness something special, such as the daily toil of the leafcutter bee described in detail by Karl von Frisch, the pioneer of bee research:

> The leafcutter bee makes a hole in rotten wood, then flies off to a green leaf of a rose or elderberry or a raspberry bush or something similar and then cuts with her sharp mandibles a slightly elongated circular piece out of the leaf, rolls it together and flies back to her burrowed tunnel, then she makes a thimble-like form out of the little piece of the leaf for a cradle. In the leafy thimble she places some food and then lays her egg on top, then she seals the opening with another circular piece of leaf.[1]

We don't know how many generations of insects it took for a simple field, forest, and meadow bee to become such an accomplished builder, but we do know that it could not have happened suddenly; it must have taken an unimaginably high number of intermediate stages. And each one of these stages must have had a purpose, otherwise evolution would not have allowed them to be genetically stable. We don't know the exact route to perfection; we only know that nature can allow a great deal of time. Since, however, humans have transformed the environmental conditions quicker than creatures can adapt, the time for development and adaptation seems to be running dramatically short. This is particularly true of creatures with long gaps between the generations, large animals like tigers, rhinos, gorillas, and birds. And maybe honeybees, too.

Pessimists could deduce from all this that our own future is not looking so good either, but we can view it a little less fatalistically. It doesn't seem improbable that the global honeybee population can survive the invasion of the *Varroa* if we support them. Hope doesn't lie in further chemical miracle cures but rather in approaches like the CIBER group's approach of isolating, producing, and applying measures against *Varroa* by using the natural immune response of bees.

As far as the sinister CCD is concerned, the lack of precise understanding makes it difficult to develop comparable concrete strategies. How are you supposed to combat an invisible enemy? Experts believe that this phenomenon is the result of a combination of different factors, one of which is collateral damage from chemical pesticides that produce a side effect of overriding the bees' orientation systems.

But whether the bees are being attacked by insecticides or mites, the bee colonies are more severely affected, as their immune response has already been weakened by unbalanced breeding efforts and by industrial approaches to beekeeping. We want as much honey and as many almonds, strawberries, etc., as possible as soon as possible—all for as little money as possible and with as few bee stings as possible. We have adapted our favored bees in the course of their domestication to these requirements, maybe a little too diligently. Maybe the example of the honeybee is once more showing us that the Earth cannot be subdued with impunity, particularly if this power is being exercised without limits and without respite.

Maybe it isn't too late to give some thoughts to how we could again adapt. One thing remains true: Nature can survive without humans but humans cannot survive without nature.