Towards Sustainable Beekeeping

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This document comprises an update of an article which appeared in four parts in *The Beekeepers Quarterly* (Issues 91, 92, 93 & 94, 2008) together with an introduction on various possible ethical stances beekeepers might adopt. This introduction is added because it was pointed out by an aspiring sustainable beekeeper that there should moral principles behind sustainable beekeeping that are more fundamental than those of sustainability or bee-appropriate management. This introduction on ethics is an effort to get closer to the 'why' of the approach described, rather than just the 'what'. Anyone wishing to skip the 'why' may wish to jump directly to the more practical discussion which starts under the heading *Part 1 of Towards Sustainable Beekeeping* below (page 5).

Agricultural and environmental ethics applied to beekeeping

Agricultural and environmental ethics is a relatively new academic discipline. For example, the journal of that name did not start until 1988, and the Food Ethics Council was not founded until ten years later. However, the field is well developed and offers some perspectives applicable to beekeeping.

In my understanding of ethics, an action is only moral in the real sense if it is done out of free choice, i.e. with no kind of compulsion, e.g. instinct, norms, culture or religion etc. Furthermore, it is evident that the person doing the action understands and recognises the justification of the moral principle motivating it, that is, that he/she[1] recognises the ideal and is not being forced to follow it. This being so, we cannot prescribe in advance what beekeepers must do. They have to decide themselves on the right course of action.

Disregarding extreme views, for example that we should not take honey from colonies at all, four possible moral stances or fundamental attitudes vis-à-vis nature in general and bees in particular can be distinguished and supported with moral argumentation[1]: dominator, steward, partner and participant. The series runs from the most anthropocentric to the most biocentric attitude, or from the most utilitarian position to one of respect for the intrinsic value of the living being. Please note well that no single attitude of the four characterised here is more important or defensible ethically than any other. It is a matter of completely free choice where in the spectrum of attitudes an individual beekeeper places himself.

The dominator

The dominator holds that nature is for supporting the existence of the human race. Therefore it is merely a source of raw materials to serve human goals and to be conquered, controlled, subdued, domesticated. The dominator seeks the maximum utility and profit that is legally and economically possible. Nature on its own follows a course of trial and error by the natural selection. But by breeding technology the trial and error process runs more efficiently, from a limited pool of starting material, and at the expense of fewer misfits.

The dominator beekeeper will modify the genetics of his bees by whatever available technique that is also profitable. It may involve artificial insemination and even recombinant DNA technology. If he cannot find the desired genetics locally, he will import them, if necessary from the other side of the world. He will keep his bees in conditions that give him greatest control over them, using frames, embossed foundation, queen excluders, synthetic acaricides, antibiotics, swarm prevention, queen clipping etc. If possible he will try to breed out any tendency to swarm and select for supersedure. Mindful of the labour cost, he will open the hive only as often as he needs for maintaining full control. He will take as much honey as possible and leave sugar in exchange. In search of lucrative pollination contracts he will truck bees thousands of miles. By his supering strategy, including

[1] In the remainer of this document just 'he' will be used, but in all cases 'he' or 'she' is meant.

chequerboarding if he deems it profitable, he will make sure during the main flows that the bees perceive empty space above their heads that urgently must be filled.

The steward

The steward also sees nature from an anthropocentric perspective but, unlike the dominator, he recognises definite limits. He sees himself as entrusted with the use of nature, not with its consumption. The steward at least endorses a duty to care for organisms other than humans, regardless of the extent to which they resemble humans in their capacity for suffering. The problem is then one of ranking the intrinsic values of organisms which the steward recognises. Subjecting an animal to a particular form of husbandry or breeding must not happen arbitrarily. Although human interests prevail over those of animals and plants, the latter's interests are more important than purely economic interests. Accordingly, society accepts that animals can be used for various purposes, but sets limits on that use. However, bees fall outside such control. The steward's duty of care extends to species conservation, protection of ecosystems to the extent that sometimes human interests must yield to avoid putting nature out of joint. The steward does not want to damage its integrity but will gladly domesticate it within limits.

The beekeeper with the steward attitude to nature favours the more traditional methods of breeding, but, like the dominator, would resort to modern techniques if a very good case could be made, for instance risk of entire loss of the species in a particular region due to epidemic. He will keep his bees in the way that most beekeepers do, though perhaps avoiding extremes such as queen clipping or not letting the bees winter on their own honey. He will nevertheless control swarming in the conventional ways, though try to balance his inspection frequency against the possible harm it does to his colonies. He will also inspect comb for disease and treat accordingly, perhaps favouring non-synthetic acaricides and, instead of antibiotics, comb replacement combined with requeening. He is willing to migrate short distances with his colonies to ensure that they are presented with a good supply of nectar and pollen. He will err on the cautious side when deciding how many hives a particular locality can support.

The partner

The partner regards animals as potential allies, thus presupposing that they have their own 'say' when interacting with humans. He conceives nature as an interplay of life forms, in which each invests its own expressiveness and intrinsic value. This need not conflict with a scientific approach but does call for a respect for nature. Mankind distinguishes itself from other life forms in that it is not only embedded biologically in nature but also is free to have a conscious relationship with nature, an ethical attitude to it. The partnership is nevertheless asymmetrical, because it consists of the interaction between life forms at different levels of organic complexity. Organic or ecological husbandry satisfies the requirements of the partner but so does a sustainable husbandry that is not necessarily certified organic. In such husbandries, technological exploitation can occur as long as the animal is not unnaturally forced, i.e. its species-specific functions are not prevented. The exploitation might even be of mutual benefit. Biodiversity including diversity of husbanded species is respected.

Compared with the dominator and the steward, the partner beekeeper is willing to accept lower profits in return for maintaining his bees under somewhat more bee-friendly conditions. When breeding he avoids any form of laboratory based genetic modification, though would nevertheless accept conventional queen breeding in mini-nuclei. His hive may or may not contain frames. If it does, he will make them deep enough to contain the brood nest in one box. If he uses foundation, perhaps only as starter strips, it will be from beeswax produced by colonies that have not been treated with synthetic chemicals. If he does not use a queen excluder, he will manage his hive to minimise the chance of the queen laying in the honey boxes. By keeping inspections to a bare minimum, reducing colony density in the landscape, allowing healthy drone populations and letting the bees winter on their own honey he will optimise colony health. If, despite these measures, his bees succumb to disease, he will opt for requeening and comb replacement rather than using chemicals, or he will cull colonies. To control Varroa he will use formic acid, which is already present in the hive or some other natural acaricide that does not contaminate his wax. To raise new queens and make increase he will as far as possible work with the swarming process, intervening to make splits when the time is ripe.

The participant

The participant sees nature as the totality of interdependent and interwoven life forms. Mankind is an integral part of nature therefore respect is due to other organisms, not only because of their intrinsic value, but also because nature's complexity. The innumerable relationships and balances between organisms have a surplus value that exceeds their usefulness to mankind. This has implications that are more far reaching for the participant than for the partner. The participant is more biocentric in his principled choices for setting limits on man's interventions in nature. Although he must also inevitably intervene in nature for the purpose of food production, in doing so he tries as best he can to make use of the inherent dynamism of natural processes. He bases his science and technology on a holistic approach guided by observable phenomena. But participation is not necessarily incompatible with advanced technology. For example, it could be used to investigate the conditions the animal concerned is aiming for, so that husbandry of it can best accord with its essential nature.

Relative to the partner, the participant beekeeper's interests are even more centred on his bees and on their contribution to the natural surroundings. He works with locally adapted bees, raising and selecting them for maximum health. Although he would like to harvest a modest honey crop, he is willing to forego it if there is any risk that by taking it he would have to feed sugar. He is then content to stop at helping maintain the population of bees in the landscape by providing 'bee-appropriate' homes for them in which only natural comb occurs, supported by spales or top-bars. The bees themselves thus determine their optimal cell size and its distribution in the colony, as well as the population of drones they require at any particular time. He avoids supering altogether as he sees it placing unnecessary stress on a colony to fill the space that would be constantly appearing above it. His queens are free to roam the whole hive. He applies the principle that the bees work from the top downwards so he gives extra space underneath the colony by nadiring. This helps minimise swarms being triggered by lack of space. If the bees are nevertheless intent on swarming, provided that the siting of his apiary is not too urban, he allows them to do so and uses the swarms to start new colonies. He disturbs his colonies as little as possible, maybe even only once a year, and instead observes his bees from outside the hive, learning as much as he can from hive sounds and entrance phenomena. He uses no chemical treatments whatsoever. His Varroa policy is co-adaptation or co-evolution of bee and mite. He harvests his honey by taking one or more boxes of it from the top of his hives provided they are broodless and he leaves plenty of honey for the colony's winter needs. He has no wish to return to the practice in skep beekeeping of asphyxiating colonies to harvest the honey. He will be reluctant to move his colonies at all unless the natural food supply has become threatened by unforeseen conditions. He welcomes an ethical scientific study of bees, including sophisticated analytical techniques, especially if this will tell him how to keep his bees in an even more bee-friendly way or conserve the species and its habitats.

The ethical matrix

It should be obvious from the foregoing that the boundaries between the different fundamental attitudes are fuzzy. Indeed, an individual beekeeper's attitude to nature and his bees spans two categories or moves between categories depending on the action contemplated. Another form of ethical evaluation is the ethical matrix[2]. Four principles of medical ethics, beneficence (do good), non-maleficence (do no harm), autonomy (freedom/choice) and justice (fairness) are adapted for application to food ethics by merging the first two under the general heading 'wellbeing' (health/welfare). Four broad stakeholder categories are identified: the animals husbanded (in our case the bees), the producers, the consumers and the biota (the living environment). In ethics this kind of deliberation it becomes a matter of balancing the various interests by considering how the three principles of wellbeing, autonomy and justice apply to the four interest groups. It can be summarised in the 'ethical matrix' (see Table 1).

Respect for: Stakeholders:	Wellbeing (Health & Welfare)	Autonomy (Freedom/Choice)	Justice (Fairness)
Bees	Bee health & welfare	Behavioural freedom	Intrinsic nature
Beekeepers (producers)	Adequate income & working conditions	Freedom to adopt or not adopt a particular beekeeping technique	Fair treatment in trade and law
Honey consumers	Availability of pure, safe honey Public acceptability of how the honey is produced	Respect for consumer choice (e.g. organic versus non-organic)	Affordability for disadvantaged groups
The biota	Conservation of the biota (for its own sake and for availability of bee forage)	Maintenance of biodiversity, including bee forage biodiversity	Sustainability of biotic populations.

Table 1: The ethical matrix

In populating the cells of the matrix it is assumed that both consumers and producers generally accept the evaluations to be made. The ones given in the Table can of course be modified, removed or supplemented to suit the purposes of the person or persons carrying out the evaluation. The matrix can be used to test any action in the honey production chain to see how it impacts the four interests with respect to the three principles. For example, not everything that the beekeeper does to his colonies has its impact confined to his bees and himself. Using synthetic pyrethroids to kill Varroa results in measurable pyrethroid degradation product concentrations in the honey. Or, overstocking a region with honey bees could impact the biota negatively by out-competing particular species of wild bee and rendering them locally extinct.

Regardless of his attitude to nature, any beekeeper wishing to undertake an ethical assessment of his own methods may at least find the ethical matrix a useful way of structuring it. It is presented here with the same four stakeholders given in the source. However, in beekeeping there are two other, albeit smaller, stakeholder groups to take into consideration: the neighbours and other beekeepers in the vicinity. We have to consider if any of our actions impact their wellbeing, autonomy and the justice due to them.

None of the foregoing specifically addresses laws governing beekeeping. All laws originate at sometime in the past from moral intuitions of men or women. The more glaringly obvious considerations of wellbeing, autonomy and justice are usually the first to end up in law. It has been suggested to me that people with attitudes to nature at the two extremes, namely dominator and participant, might be more inclined to break a apiculture law, only for different reasons. For example, the profit motivation might lead to compromises with food standards. The presence of antibiotic contamination or even added sucrose in honey would be an example. And beekeepers trying to pursue a totally natural comb policy in jurisdictions where fixed comb is not allowed might be tempted not to register with the authorities and even hide their hives.

Part 1 of Towards Sustainable Beekeeping, The Beekeepers Quarterly, 91 February 2008

On being asked to write on this subject, I looked around for comprehensive, explicit and concise definitions of the term 'sustainable beekeeping' but was unable to find any that met those criteria. The nearest I got to it was a booklet entitled *Bees and Rural Livelihoods* from Bees for Development, a UK based organisation that works to assist beekeepers in developing countries[3].

To be sustainable, a human activity should meet the needs of the present without compromising the ability of people elsewhere on the planet, or future generations, to meet their own needs. Meeting needs sustainably is often seen in terms of a 'three-legged stool' comprising social needs, economic needs and environmental needs. Take away one of those 'legs' and the whole thing falls down.

Another useful picture for understanding sustainability is that of the ecological footprint. Put simply, it is the area of land that each person requires to sustain their lifestyle. A fair earth share is about 1.8 global hectares per capita. On average, a person in Britain uses about 5.3 gha per capita. The figure is even higher in some other western countries. It means that if everyone in the world lived like British people do they would need three planet earths to sustain them. The whole thing works only because a majority of people in the developing world survive on far less than one 'fair earth share'. But many of them aspire to a better standard of living and certainly deserve their fair earth share. For fairness to be restored, the only logical way that lies within the power of human beings is for those who live on three planets, so to speak, to reduce their consumption. This option has major implications for beekeeping. *Minimising consumption* is one key criterion of sustainability that we shall frequently refer to in the following discussion.

The ecological footprint can be further divided according to particular material flows. For example, the carbon footprint is part of our ecological footprint that has received particular attention in the context of global climate change. How much carbon a beekeeping operation consumes is a factor to take into consideration when judging its sustainability. We need to consider the embodied energies of the materials we use. A beekeeping enterprise doing just this was presented in the previous issue of *The Beekeepers Quarterly*[4]. It offset its carbon consumption by investing in 'carbon-reducing projects such as renewable energy, energy efficiency and reforestation'. However, some regard carbon offsetting as a form of 'greenwash' in that it merely postpones the real solution, namely reducing consumption to one planet living. Indeed, hard liners in the 'business as usual' camp even argue that the best carbon-reducing project is nuclear energy.

This series of articles attempts to show the practical implications of what sustainable beekeeping involves. As we are concerned with a human activity involving an animal, namely the bee, there is an obvious fourth factor necessary for our activity to be sustainable, which does not seem to fit into the 'legs' already mentioned, namely how we treat the bee. Do we deal with it in a way that is appropriate to the essential nature of the bee; are our beekeeping methods bee-appropriate, bee-friendly?

In addition to the four factors society, economy, environment and bee-appropriateness, there is one general and very important overarching principle to be borne in mind throughout this discussion. *What is sustainable in a practical sense varies from place to place on the planet.* For example, we would not recommend making a hive of wood in a region where timber is scarce or where wood digesters such as termites abound.

As the discussion proceeds, it becomes clear that it is difficult to consider just one of the four aforementioned factors in isolation. They affect each other such that we are forced to balance them one with another. For example, it would seem absurd to most beekeepers if they were required to be so bee-friendly that they could no longer rob a colony of its surplus honey. Even so, a new balance between man and bee will have to be found unless we want to risk losing bees altogether.

Out of the four factors, I will deal with the matter of how we look after the bees themselves first because on it depends the entire success of our beekeeping operation. Some beekeepers, especially the more hard-headed among professional beekeepers, may regard some or all of what I propose as ridiculous. In which case nature will continue to be their teacher. Indeed, we may already be seeing some of the lessons in the form of colony collapse disorder (CCD) and the spread of alien pests such as mites and beetles. But in Britain and many other countries, the great majority of hived colonies are managed by amateurs and part-timers working on a small scale. Provided they look after their bees, they are the ones who could have greatest influence for the future well-being of honeybees and the husbandry that goes with them. We do not need to tell beekeepers about the important environmental service performed by their bees or about the important socioeconomic benefits from them. I hope that the larger group of beekeepers whom I am addressing, those who are not *solely* profit-driven, will find something in this series of articles that will be useful in making their operation more sustainable.

Bee-appropriate beekeeping

When I started beekeeping, I heard my mentor say from time to time when different ways of doing things were under discussion 'I don't expect the bees are bothered one way or the other what we do'. In a sense he was right. The honey bee (*Apis mellifera*) seems to be able to make any sort of cavity into its home and even sustains colonies on comb constructed out in the open. However, with the homes we give them and how we manage them, we can take care not to work against the bee's intentions. We can avoid stressing the colony, especially at times of the year when it is less capable of rectifying our mistakes. Coldness/heat, wetness/drought and shortage of food, or of food of adequate quality, if beyond or nearly beyond the capacity of the bee to cope with, can be expected to predispose to stress and thence disease. We will look at the issue of heat and moisture management in the hive first.

Thermal and hygrological issues – 1. Comb support

A bee colony, a super-organism already likened to a mammal[5], maintains a brood nest temperature of about 35ºC, and even in winter, when there is no brood, the temperature is kept as high as 25ºC, whereas conditions outside may be many degrees below freezing. The active, targeted and finely structured nature of this temperature regulation has been revealed by thermal imaging studies in observation hives at the level of individual bees and comb cells[6]. The colony is a *warmth organism* par excellence. In nature, to retain nest heat, the combs are hermetically sealed to the top of a cavity, such as a hollow tree, and fixed to the walls at the side. This creates cul-de-sacs of warmed air which, because the warm air rises and has nowhere else to go, is retained in the nest. Renewal of the nest air by diffusion and active fanning by the bees occurs only at the bottom of the combs. This natural 'air-conditioning' is under the bee's control. Anything that is done to undermine it is done at the expense of increased activity by the bees. Increased activity necessarily increases the consumption of sugars, the bee's heating fuel which it normally derives from nectar or honeydew. Whilst skeps perfectly mimicked the natural arrangement at the top of a feral colony cavity, modern beekeepers undermine nest heat retention by using frames. These leave air gaps round the sides and the tops of the comb, contrary to the natural situation. Some even winter their bees under a queen excluder with a stack of supers on top. This only works in mild climates provided the sugar supply is adequate to balance the excess heat loss.

Bees abhor empty space. They try to fill in the gaps outside the frames with wax and/or propolis. To retain frame mobility, beekeepers must constantly remove the extraneous deposits. But as fast as they remove them, the bees replace them. This too increases consumption of food. Thus beekeeping using frames, because it increases consumption by the bee and thus by the beekeeping operation, must be less sustainable than not using frames. Natural comb hives such as the horizontal/long format top-bar hive (hTBH, see Figs. 1 & 2)[7] and the vertical/tiered format top-bar hive of Abbé Émile Warré (vTBH, see Fig. 3)[8], provided that they are not repeatedly opened, are examples of hives that are inherently more sustainable regarding heat retention. Compared with framed hives they reduce energy consumption. They save some stress on the bee, or at least save wasting the bee's efforts on repairing the damage to nest integrity that frames cause. However, both TBH formats are not necessarily sustainable everywhere on the planet. The horizontal format performs less well in colder climates and the vertical format has not only yet to be tested at climatic extremes, but also is probably unsuitable for hanging in trees, which is how horizontal TBHs are often deployed in the tropics.

Figures 1 & 2. A horizontal format top-bar hive (top); Phil chandler working on a comb from a horizontal format top-bar hive (bottom). (Photos, courtesy Phil Chandler; www.biobees.com.)

Figure 3. 'Exploded' view of The People's Hive of Abbé Emile Warré showing a stand, the floor with alighting board, two hive elements with top-bars, the top-bar cover cloth, the quilt filled with wood shavings and the roof.

For my being made fully aware of the implications of framed beekeeping, I am indebted to books by Johann Thür[9] and Abbé Warré[8]. Thür gives a persuasive argument for observing the principle of retention of nest scent and heat (*Nestduftwärmebindung*) in hive design and resurrects the hive of Abbé Christ (1739-1813) which was identical in concept to Warré's. Later in this series of articles I will discuss a type of frame, originally designed for a Warré hive, that minimises violation of the nest heat retention principle and may offer at least an interim solution in countries where the law requires combs to be very easily removable and replaceable.

Figures 4-7. hTBH combs: new comb on top-bar (top left); comb with brood below (top right); examining a new comb already with brood (bottom left); wax makers building comb (bottom right). Photos: Courtesy Phil Chandler.

Thermal and hygrological issues – 2. Covering the nest

What is the most sustainable arrangement at the top of the nest? Heat dissipation here will be high because warm air rises, but in hot or even temperate climates the top of the brood nest also needs protecting from solar radiation. The hollow tree overcomes the problem as it is both a solar shield in the midday sun and contains rotting wood that insulates and absorbs moisture. In hot climates, apart from placing hives in the shade, beekeepers try to overcome the problem of thermal control at the top of the hive by fitting an insulated crown board and a roof with well ventilated cavity, for example, a gabled roof with wide-aperture eaves and gable summit ventilation.

As moving away from dependency on petrochemicals, a non-renewable resource, is a desirable feature of sustainability, using synthetic insulating materials in a hive cannot be the most sustainable solution. For insulation, it should be possible to devise insulating quilts based on renewables. The most interesting nest heat retention configuration I have seen, and use myself on my Warré hives, closely simulates the situation in the hollow tree trunk. It comprises a 100 mm deep wooden box 'quilt' closed with hessian below and filled with any kind of plant fibre: straw, sawdust, shavings, leaves etc. This filling also absorbs and buffers water vapour flows and is changed each spring. The discarded contents are used to suppress weeds round the hive. The quilt rests on coarse-weave hessian that is in immediate contact with the top-bars. This is soon propolised and can be gently peeled off without annoying the bees. (This paragraph was unfortunately omitted from the version published in *The Beekeepers Quarterly*.)

Figure 8. Warré vTBH comb with some drone cells bottom right.

If hives cannot be kept in the shade of trees or vines, the aforementioned gabled roof would be indicated. Access by mice to the quilt is prevented by an internal board. This arrangement works well with the Warré quilt in continental Europe. It remains to be seen whether it works in northern sub-tundra climates where Warré beekeeping experiments are starting in 2008. There, the board might usefully be perforated or replaced all or in part with a metal screen. The question at issue here is whether a quilt should be impermeable to water vapour if there is a high risk of condensation and freezing above the bees. Otherwise, it is highly sustainable because all materials are renewable. All the wooden parts can be made from recycled wood if available. There is no plywood in the construction. Plywood has a higher embodied energy than plain wood and contains synthetic resins for bonding.

In the next article I shall conclude thermological and hygrological concerns by discussing the design of the hive body and the floor. What freedom we can give a colony to build the kind of comb that meets its natural inclinations will also be discussed.

Part 2 of Towards Sustainable Beekeeping, The Beekeepers Quarterly, 92 June 2008

In Part 1 of this series we considered the 'triple bottom line' of any sustainable operation, namely its social, economic and environmental aspects. In drawing up the balance sheet, a satisfactory outcome regarding all three is essential for sustainability. And to those aspects we added a fourth that is crucial to the success of our beekeeping, namely how we treat the bee itself. Thus we gave priority to bee-appropriateness or bee-friendliness, beginning with discussing the thermal and hygrological issues to be considered when providing a shelter for bees. We presented top-bars as a more bee-friendly comb support than frames, and the arrangements for covering the brood nest.

Here we conclude thermological and hygrological concerns by discussing the design of the hive body and the floor, primarily in the context of a vertical top-bar hive. We also discuss what freedom we give to the bees when they build their comb.

Thermal and hygrological issues – 3. The hive body

Considered thermally, the ideal shape for a divisible/expandable hive is cylindrical as it presents the smallest external surface to the environment. A hollow tree or a log hive approximates well to this shape. And, as Günther Hauk has pointed out, everything about the bee speaks roundness: hanging and flying swarms; the nest; the queen cell; the economical packing of round cells resulting in the hexagon shape; the catenary shape of combs; the winter cluster[10]. But roundness is not easily practicable when the material chosen is wood, so the square is the next best choice in the hierarchy of thermally efficient shapes.

The ideal composition of hive walls depends to a certain extent on what renewable materials are available locally. Usually the solution will be wood or some other plant material. Considered just in terms of the materials used, the skep, made of bound straw, has an ideal wall composition because of its insulating and vapour permeability qualities. Indeed, it may even approximate the closest to the conditions of a hollow tree: a domed, cylindrical cavity lined with vapour permeable and insulating material: rotting wood in the case of the tree. There are problems with skeps though. They can engender the barbaric and wasteful practice of sulphuring colonies at harvest time. Their limited rigidity restricts colony size. And they generally have to be given a secondary shelter, ranging from the simple, transportable and renewable hackle to the resource intensive bole. Matthias Thun overcomes all these problems with his composite straw/wood hive that is robust, extendable/divisible, will accept top-bars. Samples of these have lasted over 50 years[11]. His impression is that bees feel better in straw hives. To achieve maximum robustness and weathering the straw used should ideally be rye, high in silica, and cleamed with a clay-dung mixture. Otherwise a secondary housing is needed.

In embodied energy terms, when we consider what it takes to get wood from standing tree to seasoned plank ready to make into hive walls, it seems likely that rye straw has the advantage, even in some of the places where wood is plentiful. However, until straw-hive apiculture is more accessible, wood will be the material of choice for most. And we should also not forget, that in some regions it will continue to be clay.

Even if the choice is wood, it matters a lot which method is used to turn it into a hive. In regions where the appropriate technology is log hives, for example in Jumla, Nepal, wooden hives made from planks are not viewed with favour, as they would not only have to be planked laboriously with an adze, or by hiring two sawyers, but also be joined somehow (Fig. 9). Straw is not the appropriate choice here either as it is highly valued as livestock bedding etc. and is prone to rodent damage. Thus the log hive remains the viable option and indeed performs well thermologically at the high altitude (circa 3,000 m) because of its thick walls.

We come now to a bee-appropriate design for wooden hive bodies. Water vapour passes through wood if it is not obstructed by certain kinds of paint and wood gives enough insulation in all but the coldest climates. The desirable thickness depends partly on the expected ambient temperatures. In warm or hot climates about 20 mm would be a minimum if only for the sake of robustness.

Figure 9. Colony in side-access log hive, Jumla, Nepal. Photo: Naomi Saville

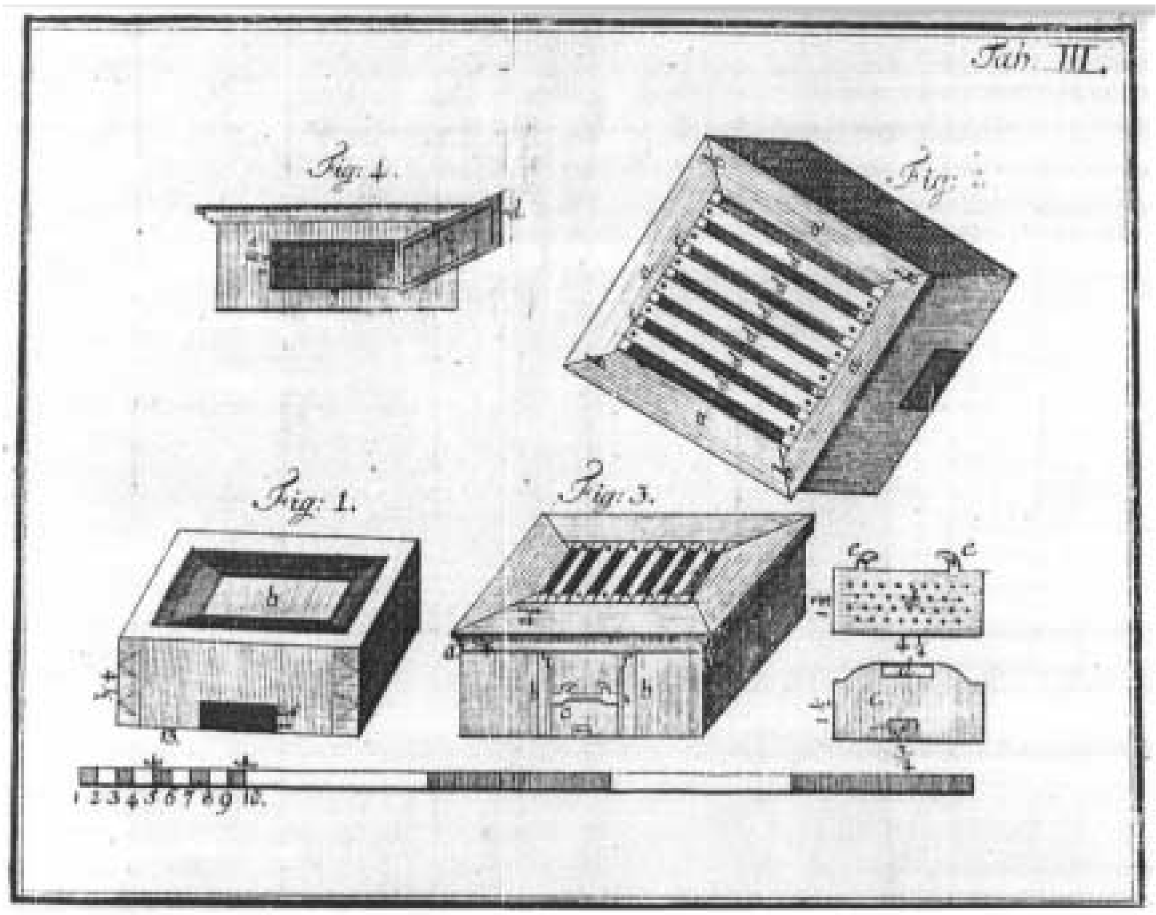

Figure 10. The hive-body box of J. L. Christ's tiered, top-bar magazine hive. Each box, ca. 300 mm square internal plan, has an entrance which can be closed, a shuttered window at the back and six top-bars. The entrance of only the bottom box is kept open[13].

Concentrating now on the vertical, tiered top-bar hive, such as those of Christ (Fig. 10, above) or Warré, a sustainable option for very cold climates might be a combination of a thicker wall, some renewables-derived insulation protected from the wet and with appropriate internal dimensions. A large bee swarm hanging freely is about 30 cm wide. In winter, a Langstroth has a cluster diameter of 20 - 35 cm[3]. If a hive is sized to just fit such a cluster – say 30 x 30 cm – there should be occupancy and therefore warming of most of the width of the inside. Such a size cuts down on voids for convection currents and helps prevent the condensation and mould commonly associated with the walls and outer combs of wide-bodied hives. However, this measure alone does not suffice for very cold climates. Here walls should be thicker, i.e. at least 25 mm, possibly as much as 38 mm in sub-tundra regions. As the boxes are narrower, the extra weight is manageable. Thickening the hive wall approaches the situation in the hollow tree.

A narrow inside is bee-friendly for another reason; it places the bulk of the winter fuel supply, if not all of it, above the cluster which naturally works upwards into its stores and in extreme cold is unable to move sideways. Colonies can starve with peripheral combs of stores only a few centimetres away.

How deep should the box be? If the comb is to be removed and replaced, as required by law in some states, it must not be inconveniently deep. But it also must not be so shallow that the brood nest is excessively divided by top-bars. Warré experimented with some 350 hives of several different designs before settling for a depth of 210 mm, which gives a comb depth of about 195 mm allowing for bee space[8]. This happens to be only a few millimetres more than the brood comb depth in a National hive. Jean-Marie Frèrès accidentally rediscovered the importance of the depth of 210 mm. He made several hive bodies 300 mm deep. The bees rapidly built comb to an average depth of 193 mm then stopped. Allowing for bee space and a top-bar he realised the wisdom of Warré's choice of 210 mm[14]. The apparent smallness of a hive element of only 300 x 300 x 210 mm internally is made up for by vertical expansion.

Whether or not to insulate a hive also depends partly on the severity of a typical winter. Too much insulation loosens the cluster and thus could increase activity and consumption of stores. Or it could nullify some of the benefit from in*sol*ation, which at that time of year falls more horizontally, i.e. on the hive walls. So there is a balance to be struck. Insulating again raises the problem of choice of sustainable insulating material (see Part 1). An alternative to pieces of polystyrene wrapped with plastic sheeting is preferable, for example some sort of natural fibre. One solution is a double-walled hive such as that of William Broughton Carr (WBC). But this greatly increases complexity, material use, capital cost and inconvenience for the beekeeper. Furthermore, Warré was surprised to discover in his experiments that colonies in his double-walled hives consumed 2 kg more honey from November to February. For extremely cold climates, excess use of resources would also be the case with single-walled hives wintered in bee houses, but not the case if hives are wintered in a cellar that has been constructed for other purposes such as winter storage of foods. Another traditional solution is surrounding the hive with straw bales protected from precipitation, in which case the obvious question is why not make the hive of straw in the first place?

Thermal and hygrological issues – 4. The floor

The floor must allow adequate ventilation and access during peak foraging as well as the shedding of any condensed moisture. If a solid floor is used, it helps if the inside surface slopes slightly downwards towards the entrance.

Many have found that *open* mesh floors for controlling Varroa have also increased ventilation and thus reduced winter mouldering of combs. Does the advantage of expelling some of the live Varroa justify introducing ventilation conditions that are far outside the control of the bees, especially in winter when they should be conserving energy, and thus stores? Is the higher complexity, cost and ecological footprint, especially of the metal mesh with its high embodied energy, sustainable?

Varroa does better in a cooler hive, so if mesh floors are used, the drawer needs to be closed[15]. This also helps the bees with their thermal control. Given a small but adequate entrance, the bees can create the airflows inside the hive that they require. The drawer, being inaccessible to the bees, accumulates hive debris which is a breeding ground for wax moth and micro-organisms, especially when condensation forms on it during nectar flows. Keeping it clean requires extra apiary visits and labour, thereby reducing the sustainability of the overall operation.

On balance, a solid wooden floor is probably the most sustainable solution. The entrance aperture needs to be sufficient to cope with ventilation requirements and maximum foraging traffic, whilst not tying up too many bees in defending it or risking 'leakiness' to robbers. Warré, who kept bees in France, experimented with various widths and found 120 x 15 mm the most satisfactory. However, that might not be wide enough in regions with more abundant forage and larger colonies. Experimentation and reference to local beekeeping experience would be necessary.

Natural comb

Most beekeepers will find it impractical to let the bees build entirely natural comb, for example by using, instead of frames, a perforated board or even top-bars without starter strips. Aside from the constraints of the cavity size and shape, the comb produced in this way has its architecture entirely determined by the bees, including comb spacing, cell size distribution and undulations. Beekeepers usually prefer to guide the bees' comb building to some extent. This can range from plain top-bars to top bars with a beading of wax along their undersides as starter (see Figs. 11 & 12), to top-bars with starter-strips of foundation, to frames with starter-strips of foundation, to frames filled with wired foundation.

Figures 11 & 12. Natural comb in Warré hives viewed from below. Left: box only two-thirds completed (one broken comb); Right: filled box with some combs crossing to adjacent bars despite use of wax starter-beads on top-bars.

A full sheet of foundation is the most bee-unfriendly option as it predetermines cell-size. This has two aspects: drone comb and worker comb. Drone comb is usually regarded as unproductive because hives with it have been found, albeit in experiments where it was given artificially, to store less surplus honey[16]. Drones consume stores. So, following Langstroth[17], drone comb building is discouraged by using worker size foundation and, more recently for Varroa control purposes, capped drone brood is removed or drone pupae forked out.

While we do not know the long term importance of a natural population of drones to long-term health of colonies we should be willing to question these practices. We do know that a beekeeping landscape well populated with drones helps maximise the frequency, and thus quality, of queen mating. At worst, a poorly mated queen will fail prematurely as an egg layer and, at best, the workers will supersede her because they can detect when a queen is poorly mated[18]. Multiply-mated queens produce colonies that are better able to resist the development of American foulbrood after artificial inoculation with *Paenibacillus larvae* spores[19]. Genetically more diverse colonies of honey bees, i.e. with a higher number of patrilines, are better able to maintain stable brood temperatures[20], and are fitter and more productive[21]. Furthermore, it is believed that drones contribute a lot of the food energy they consume to warming the nest. Whilst the importance of their role in thermal regulation is a matter for research, if this is true then it potentially frees up more workers to go foraging.

Letting the bees determine worker cell size may also be important. Some argue that foundation embossed to give cells larger than in natural comb has impacted bee health, particularly as regards resisting infestation with *Varroa destructor*. The 'small cell' school holds that bees are better able to tolerate Varroa if the cell size is reduced, initially by using special small-cell foundation[22]. Certainly it has been shown that Varroa infestation is lower with smaller cells[23, 24]. However, regimenting bees with foundation is hardly bee-friendly whatever its cell-size and a paper published after this series of articles has called the efficacy of the small-cell approach into question[54]. A possible course of action is to let bees find their own mix of cell-sizes by preparing top-bars or frames with no more than a beading or lamina of plain wax. The extra wax production might use some of the incoming nectar that would otherwise add to the honey surplus, but it is likely to maximise the health of the bee population in colony and landscape. Furthermore, Warré noted in his experiments that bees drawing natural comb took no longer to complete a comb than those given foundation. But, if the instinct to build free comb has become weakened, wide starter strips of foundation may be needed, at least initially.

Using foundation adds a lot to the complexity, cost and ecological footprint of beekeeping through the milling, wiring and redistribution involved. It may also contain chemical residues and viable foulbrood spores. Frames, too, are rarely made by the beekeeper himself but in a factory somewhere. There is much more wood wasted in their manufacture than with hive bodies and they greatly increase the footprint and cost of beekeeping.

Without any kind of wax starter, be it bead or lamina, the bees are entirely free to orientate their comb according to their requirements in the cavity presented. If comb orientation in relation to the earth's magnetic field is at all important, as seems to be the case[25], freely built natural comb would allow this. In which case it would also make sense to minimise the amount of iron in the hive.

In the next part in this series we shall discuss the bee's need for seclusion, their foraging and colony density, feeding and a holistic approach to the problem of bee diseases and pests.

Part 3 of Towards Sustainable Beekeeping, The Beekeepers Quarterly, 93 September 2008

In the last issue, part two of this series concluded our consideration of the thermal and hygrological issues of sustainable, bee-appropriate beekeeping and discussed how to provide for manageable natural comb. In this part we look at how to minimise the stress on bees regarding their needs for seclusion and appropriate nutrition. Both these factors affect colony health which is the essential theme of this article.

To recap: we are aiming for beekeeping which provides a satisfactory economic benefit to the beekeeper whilst fairly sharing the honey with the bees, which enhances our environment and which is therefore beneficial to society. If we keep bees in a way that accords best with the nature of the bee, i.e. that is bee-friendly, our own inputs will be minimised and thus the sustainability of our operation maximised.

Seclusion or intrusion

Disturbance unsettles colonies. Probably the commonest form is the intentional disturbance by the beekeeper himself. Every opening of the hive that lets the heat out forces the bees to repair the damage – repairing broken comb and repropolising – and to restore the 'thermal structure' of the colony by extra heat-production activity. In winter, the cluster can take as much as three days to return to normal[26]. Depending on the extent of comb manipulation, even in summer the restoration of the pre-opening condition could take as much as a day.

The repair work is done at the expense of other activities, and certainly increases energy consumption, thereby reducing stores and/or a honey surplus. Opening a colony already coping with the challenges of pests and disease may tip the balance towards its succumbing to them. Thus, to be bee-friendly, such interventions should be minimised whilst maintaining good management, and could involve just one hive opening in the real sense per year, namely at harvest. A vertical top-bar hive, such as that of Warré[8], makes possible this low frequency of intrusion because new elements are added only below the brood nest, i.e. by nadiring. In nature the brood nest grows sideways and downwards, and combs can extend to 1.5 metres tall. Adding boxes below allows the colony to expand indefinitely and does not let the heat out of the brood nest because the latter can be lifted intact together with its covering. A simple manual lift allows a single operator to do this without any obvious disturbance to the bees[27]. Full boxes of honey are removed from the top, if possible only once, namely at the end of the main nectar flow.

Even a *horizontal* top-bar hive can be worked to some extent without letting the heat out of the brood nest as it is worked from the back, i.e. away from the entrance, and the top-bars, which abut one another, retain the nest heat. Combs can then be harvested or moved further back and new space given.

However, the extremely infrequent disturbance possible with the vertical top-bar hive is not possible where it is believed, or there is a legal requirement that, to control disease, bees must be induced to construct comb in frames that can be removed for inspection. Moveable frames are a relatively recent phenomenon in the history of beekeeping. Could they be a contributor to the rise of bee diseases and epidemics? Such a question could be answered by a well conducted, ideally multi-regional, research programme.

Controlling swarming is another reason colonies are disturbed at frequent intervals. But bee-appropriate management accommodates the bee's instincts. Arguably the most inconvenient of those instincts is swarming and we use all sorts of methods to reduce or manage it. Certainly swarming and our management of it can impact all three aspects of the sustainability of an operation: economic, environmental and social. We double up on equipment at least for a while and natural swarms could be a public nuisance. So just letting the bees fly is not good practice. Some management methods that avoid frequent opening of the hive include various kinds of swarm traps fitted at the hive entrance. These have the disadvantage of being relatively labour intensive. Bait hives with swarm lures are another option (Figs. 13 & 14). To work well they should be a few metres off the ground in a prominent location; be about 40 litres capacity; have had bees in before; have an entrance of about

12 square centimetres at the bottom; face southward; and be over 300 metres from the parent colony[28]. Provided they are checked regularly, there is no need to use actual hives for this purpose.

One trigger of swarming can be minimised by giving plenty of space for the brood nest ahead of demand. This is easily done by the bottom-expansion method described above, ensuring that at least one element is present below the growing brood nest. No weekly comb inspection is needed. Indeed, inspection might even provoke swarming. We shall return to the matter of swarming in a later article in the context of breeding.

An empty element at the bottom of the colony also allows disturbance during feeding to be minimised. A container of feed can be placed on the floor. No heat is let out of the brood nest. Indeed, the colony appears rarely to notice the intrusion.

Figures 13 & 14. Bait hives: (left) made of recycled tongue-and-groove timber prominently sited on the roof of a garden shed ; (right) two Warré boxes in use as a bait hive with another bait hive of recycled timber to their left.

Beekeepers accustomed to opening hives frequently will probably find the bee-friendly, non-interventionist approach advocated here difficult to adjust to. Admittedly, after even a few years of frame beekeeping experience, no opening can be a little frustrating at times. So what are the alternatives for surveillance? Firstly, consider the history of the colony: the date of hiving and weight; its expansion rate; whether it has swarmed etc. Secondly, there are the conditions in the environment: has the weather been so bad soon after hiving that the bees could not forage and are likely to need emergency feeding? Thirdly, observe the activity at the hive entrance. Is the colony foraging at the same rate as others in the apiary? If not, depending on its history, it could be a failing colony. Does the proportion of foragers returning with pollen look about right? If not, there may not be a laying queen. Would you expect there to be one already or was it not so long ago that it swarmed? A lot of information can be gained from entrance activity. Is it purposeful or are the bees scurrying around as if looking for something? Storch's excellent book on the hive entrance is worth reading[29]. Fourthly, we can heft the hive to check the status of stores. This can be done by just lifting one side a fraction, or by using a simple weighing device. Fifthly, listen to the colony by putting an ear to the box. Can you hear the normal bustle of a good sized colony or is it very faint. Are queens tooting and quacking at one another? If you have cause for concern about queen status compare the sound after a sharp tap. Is it a 'hiss' that's gone in a second or a prolonged grumbling? And finally, novices, while gaining confidence, might start with a hive with a shuttered window in each box such as the Frèrès-Guillaume version of the Warré hive. It is less sustainable though, because of the high embodied energy of glass and the increased construction complexity.

Figure 15: Observing the hive entrance ('Der Bienenfreund' (1863) by Hans Thoma, with the kind permission of Staatliche Kunsthalle, Karlsruhe; the cover picture of H. Storch's book[29])

We should also consider unintentional disturbances. This will only be brief as the manuals on beekeeping usually cover this particular nuisance quite well. Intrusion by people other than beekeepers, namely vandalism and theft, of course reduce an operation's economic sustainability. If we can, we keep our hives well screened and away from thoroughfares. Roger Delon, who kept over 600 modified Warré hives in the Vosges/Jura region, found that he needed to padlock and chain them under communal steel roofs in fours with concrete blocks set in the ground as anchors![30] The extra materials and cost were clearly necessary to make beekeeping viable in that locality, but it seems hardly sustainable in the full sense.

The risk of major disturbance, even destruction, of colonies by animals varies a lot according to locality and therefore local knowledge amongst beekeepers would be the first point of reference. Beekeepers have always sought to protect their hives from such disturbance, if only for the sake of economic sustainability. Protection from farm livestock is generally easy. But the list of intruders that present more of a challenge is almost endless: insects (wasps, small hive beetle), rodents (mice), birds (woodpeckers), mammals (bears). Solutions include insect lures, fencing off apiaries, wire netting the hive, putting it on a platform accessible only by ladder, hanging it in trees or keeping it in a building. The more elaborate the defences, the less sustainable the operation and there may come a point where the extra materials used make its continuation at a given site hard to justify on environmental, let alone economic, grounds. Interestingly, the logo of Bees for Development is a top-bar hive in a tree (beesfordevelopment.org). What could be simpler?

Finally, extraneous vibration is a source of disturbance worth taking into consideration. Passing trucks or trains shake the ground. Even heavy rain or hail on flat, metal-clad roofs has been identified as a cause of colony disturbance. Such roofs are more likely to transmit this vibration to the colony than sloping roofs made only of wood. If it happens in winter, it could loosen the cluster and risk increasing consumption of stores.

Forage and colony density in the landscape

Beekeepers should not need to be told to put their hives where there is enough nectar (and/or honeydew) and pollen within flight range throughout the flying season. Visscher and Seeley observed a median foraging range of 1.7 km and 95% was within 6 km[31]. Foraging of up to 14 km has been reported[32], but the benefit/cost ratio decreases as the distance increases. From time to time surveying what is available and what the bees are visiting within a mile or two radius seems prudent as it could inform stocking density.

Food availability over a whole season largely depends on floral diversity and the consequent wide range of flowering times. But in our cultural landscapes floral diversity and quantity are severely declining, helped by the use of herbicides and the over-manicuring of marginal land and hedgerows. We can expect this to impact bees as much as it does other species that depend on flowering plants. In my own locality, dominated by grazing, my bees could have abundant clover. Certainly the fields are sown with clover mixes, but local farmers, in their struggle to combat dock, manage to eradicate their clover at the same time.

Obviously the bees need a sufficient quantity of nectar and pollen, in the latter case it may be as much as 25 kg. per season[33]. Less obvious for maximal bee health is the requirement for *diversity* of pollen, and possibly also of nectar. Pollens vary greatly in quality, especially as regards the amino acid composition of their major nutrient, protein. Pollen varies in its capacity to supply natural antagonists of bacteria/fungi and antibiotic substances[34], for example, certain fatty acids[35]. Lack of pollen diversity decreases the colony's antimicrobial defense faculties and it becomes more susceptible to disease. A balance of pollens allows one pollen to make up shortcomings of another, for example too low a protein or fat content or too high a mineral content[36]. Indeed, honeybees are generalists in their pollen gathering, evening out and diversifying it[37].

It is usually not practicable for beekeepers to compensate significantly for poor floral diversity and/or abundance by planting, as they usually lack control of sufficient land to make an appreciable difference. However we can have a certain amount of influence, such as by planting suitable herbaceous plants, shrubs and trees; lobbying for agriculture that has regard to biodiversity and only purchasing products from such an agriculture. We could encourage neighbouring landowners to plant appropriately, for example when we give/sell them a sample of the honey we produce. A neighbour of one of my apiaries delights in the profusion of honey bees that visit his ornamental heathers and poached egg plants. The time is ripe to raise awareness of bee plants while the plight of the honey bee is so frequently in the media.

How many hives should a single apiary have? Too many in relation to floral resources will risk stressing the bees and thus their health. Competition from feral colonies will exacerbate this. Maximum densities of ferals in an area with no managed colonies have been found to range from 7 to as high as 12 colonies per km^2, although estimated pollen and nectar resources would have supported far higher numbers[38]. But those low numbers may result from another factor determining feral density, namely minimising spread of disease or infestation due to drifting. Seeley reports as low as one colony per km in forest dwelling ferals that have co-adapted with Varroa[39]. Probably only few beekeepers would accept such a low stocking density and may thus look for a compromise. But for most, judging exactly how many hives a site should hold will usually be a somewhat subjective procedure involving weighing up forage quantity and quality as well as competition from known colonies nearby. The experience of previous beekeepers at a particular site will no doubt help decide. The aim is to avoid over intensification because, as in any branch of husbandry, disease rates are directly correlated to stocking density.

Let us encourage extensive, i.e. low-intensity, beekeeping carried out by a larger population of beekeepers and made possible by much simpler equipment that requires far less intervention. 'Small is beautiful'. Top-bar hives, especially that of Warré, make an increase in small-scale beekeeping a real possibility.

Figure 16. Garden apiary of three Warré hives

Feeding

Should a sustainable beekeeper feed his bees? Ideally, no. Bees are supposed to feed us, not we them. So routine feeding is not the ideal option. However, there are bound to be emergencies when a colony, through no fault of its own, i.e. through no inherent genetic weakness or failing queen, falls on hard times. It may be because of a long patch of bad weather or through some manipulation that the beekeeper has done, such as artificial swarming to make increase. These are the times when we can justifiably feed.

The need routinely to feed can be eliminated by always leaving sufficient honey for the bees. This seeming erosion of the harvest, and therefore of our profit, can be minimised by using a hive in which colonies winter very economically. Warré consistently found that his hive needed 12 kg stores for winter whereas his Dadants needed 18 kg. This has since been confirmed by others. The better thermal performance of the Warré hive largely accounts for the difference.

What to feed is a source of endless controversy amongst beekeepers. The sustainable option is not to feed sugar or corn syrup. They are usually products of intensive monocultural agriculture and are processed in a chemical refinery before being transported long distances. The energy consumption, environmental degradation and pollution involved do not justify their use. Routine sugar feeding entails procurement, additional equipment, preparation, distribution and cleaning – all of which add complexity, cost and labour to the operation. If sugar must be used, then the gold standard would be organically certified, refined, i.e. crystallised, sugar. The choice of the actual plant source for sugar, whether cane or beet etc, depends on its relative environmental, social and economic impact. Food miles, supporting sustainable livelihoods and fair trade should all come into the equation.

If sugar is not fed, then it leaves only honey as the possible primary energy source. Honey is the natural choice. A sustainable beekeeping operation retains sufficient comb or extracted honey to satisfy emergency feeding. Life cycle analysis has shown that, compared with sugar, honey is the sustainable and ethical sweetener[40]. A compromise would be to feed a sugar and honey mixture which in Demeter beekeeping guidelines is enhanced by the addition of chamomile tea and a trace of salt.

But two objections to feeding honey to bees immediately come to mind. One is that the honey used, even honey from the same apiary, may contain sufficient foulbrood spores to spread infection. This objection is based on the 'germ theory of disease', i.e. that micro-organisms *cause* disease. In contrast there is the view that if, through our husbandry, we create the conditions for disease, for example by over intensification, frequent hive opening and other stresses, then the micro-organisms, which are generally ubiquitous in small amounts, will find conditions in which to proliferate. The micro-organisms, i.e. the symptoms of the disease, will start to manifest, whereas beforehand, only ultra-sensitive detection methods yet to be invented, would detect them. Sustainable beekeepers have the opportunity to create bee-friendly conditions in which bees can cope with challenges from micro-organisms by using their own defences. Obviously, one condition would be not to feed honey from a colony known to have had foulbrood. Its spore burden may be way beyond the capacity of the recipient colony's defences, especially as it is already most likely under stress through having to be fed artificially. Foulbrood has been seen as nature's way of weeding out weak stocks. Brood that has been chilled in spring provides an opportunity for foulbrood to get a hold.

The other objection is that, compared with honey, sugar has been found to increase colony survival over long northern winters, especially where honey stores have a relatively high pH, ash, conductivity and/or protein content, for example from honeydew or heather. But it really depends on how well the bee is adapted to its local forage. For example, a less thrifty bee imported from the south will quite likely require its winter food to be imported from the south too in the form of sugar.

Similar arguments apply to the choice between feeding pollen or pollen substitutes. If pollen diversity and quantity are low, the question must be asked as to whether the site is at all suitable for sustainable beekeeping.

If a beekeeping operation can be managed so as to rely on nectar and pollen then it will be supported by marginal land, gardens, trees and crops that need pollination. No additional land needs allocating to produce food for bees.

Diseases and pests

We have so far discussed shelter (parts 1 & 2), natural comb (part 2), seclusion, nutrition and colony density as factors that we can optimise to create healthy living conditions for bees. Another highly important factor is comb renewal. Given the choice, queens prefer to lay on new comb and beekeepers have long recognised that good management calls for systematic renewal of comb. But in framed beekeeping, systematic comb renewal is not easy. Either one goes to the extreme of a Bailey comb change or one seeks to replace two or three combs in the brood nest each year. Both involve intervention by the beekeeper and it is all too common to let combs in decent shape stay there for years. But in Warré's vertical top-bar hive, comb renewal is inbuilt into the way the hive is expanded in spring. Hive elements are added under the two already containing the colony. In the following months, as new comb is added below that of the previous year, the brood nest moves gradually downwards onto the new comb.

Despite our best efforts to make conditions for our bees as ideal as possible, there is an additional factor that commonly demands our intervention if our bees are to thrive. This is the destructive pressure from Varroa. As already discussed, managing Varroa by maintaining extremely low colony densities will not appeal to many. Instead, we try to make conditions in the hive unfavourable to Varroa. One way is by using chemicals. These increase in acceptability to the organically inclined in the sequence: synthetic pyrethroids, thymol, organic acids and powdered sugar.

There are two primary reasons against putting synthetics into hives. The first is the burden on bee health through the direct effects of the chemical or through their having to detoxify or otherwise deal with it in their metabolic processes. The other is the impact on human health through ingesting chemicals via the honey produced, for example 3-phenoxybenzaldehyde, a degradation product of tau-fluvalinate[41]. Other reasons include the associated increase in the complexity of the operation and labour involved; the increase in its ecological footprint through these chemicals having to be manufactured, a process that usually produces a far greater weight of waste than the weight of product produced; and the increase in cost of production of honey which is especially high if patented acaricide delivery systems are used.

Bought foundation usually introduces a complex spectrum of wax soluble chemicals into hives. All the foundation manufacturers whom I contacted on this matter when writing this article said they do not monitor wax residues. However, just how serious is the contamination of foundation by pesticides introduced by beekeepers only became apparent after this article was published in *The Beekeepers Quarterly*[55]. Toxicology recognises the potential health burden from small traces of substances migrating from manufactured products including from plastics and from finishes. We should keep them away from our hives. To avoid chemical introduction via foundation, it should be home made or from a clean source, for example Demeter (organic) certified. Such wax fetches a higher price as it is preferred by cosmetics manufactures for its low residues content[42].

Of chemicals put in hives, those used to control Varroa take up the greatest portion by weight. To what extent can we do without them? One approach, namely using foundation with a reduced cell-size, was mentioned in part 2 but in bee-friendly beekeeping we are not using foundation. Dusting the bees with powdered sugar keeps mites at tolerable levels but needs doing regularly which means opening the brood nest, something to be avoided if possible. Some colonies on frames without small-cell foundation survive with no chemical treatment but such reports are not yet the rule[19]. Feral populations are recovering or have recovered in regions where Varroa has been introduced[44]. This has been attributed to a reduction in Varroa virulence as the bee and mite co-evolve[39]. Another factor suggested for feral recoveries is interruption of the brood cycles by natural swarming. This gives a clue to a sustainable Varroa management strategy. French commercial Warré beekeepers have found that artificial swarming gives satisfactory control. At peak foraging time in warm settled weather, all the bees are swarmed into a new hive. The brood is left on the site of the old hive and the new one is taken to another apiary out of flying range. Returning field bees repopulate the brood combs and raise a new queen. Egg laying and therefore Varroa reproduction is interrupted in both halves[45].

Certainly in the long term, to step off the treadmill of Varroa treatments, mite and bee will need to co-adapt and this means tolerating a mite population that is sufficient for mite and bee fully to interact with each other. Beekeepers in several countries are well down the road to co-adaptation, but their colony losses would be unacceptable to some. Even so, I believe it is the only sustainable solution to the Varroa problem.

Whether breeding Varroa tolerant strains is viable vis-à-vis the degree of monitoring and breed-purity maintenance involved remains to be seen[46].

If chemicals have to be used just to keep colonies alive while co-adaptation is taking place then it needs to be part of integrated pest management, i.e. monitoring Varroa burdens and treating only when absolutely necessary and at the most appropriate time. The organic acids are preferable for their documented low residues. Essential oils, such as thymol, are less acceptable because of their absorption into wax. But any intervention just further postpones the achievement of co-adaptation.
European beekeeping has not yet had to deal with the challenge of small hive beetle (SHB). It appears that strong colonies with no crannies to hide in will cope with the SHB challenge. Top-bar hives with their natural comb may prove well suited to this.

Figure 17. New natural comb in a Warré hive box

And if disease manifests we cull the hopeless cases, artificial swarm into a clean hive those cases that merit it and, if it is a minor ailment, let the colony remedy the matter itself. In the extreme case of culling and burning, the economic loss with a top-bar hive is a lot lower than with one filled with frames and foundation. Above all, we do not keep diseased colonies that we try to prop up with antibiotics.

Part 4 of Towards Sustainable Beekeeping, The Beekeepers Quarterly, 94 December 2008

In the first three parts of this series we have looked at sustainable approaches to how we give shelter, seclusion and nutrition to our bees and how we manage comb construction, colony density, pests and diseases. We have kept the bee-friendliness of our interventions in mind as the key to successful beekeeping whilst at the same time having regard to the environmental impact and socioeconomic benefit of our operation. Overriding principles throughout have been minimising consumption by keeping the operation as simple as possible and enabling the bees to take care of their own nutrition and health. We have identified the top-bar hive as the simplest and identified two basic types: the horizontal/long format often referred to as the Kenyan top-bar hive, and the vertical/tiered format designed by Abbé Émile Warré and named by him 'The People's Hive'.

The Delon frame

Although beekeeping with frames can never be as sustainable in the real sense compared with only top-bars, many of the principles of bee-appropriateness and sustainability that we have discussed could nevertheless be applied using frames. For those who have committed themselves to frames re-equipping would increase consumption and thus undermine the advantages to be gained. A phased transition would be more appropriate, replacing hives as they become unserviceable with top-bar hives. Older beekeepers long experienced in the use of frames, which we have to admit are there for the convenience of the beekeeper, and who may feel that it is too late to re-equip, should nevertheless find some hints in these articles as to how to make their operation more sustainable.

There are also beekeepers in countries where the law requires combs to be easily movable. Although top-bar combs can be removed and replaced, more care is needed and the inspectors may not take too kindly to having to go through an apiary full of top-bar hives. In which case, a compromise is available, especially with the Warré hive. Roger Delon developed a modified top-bar on which was fixed a 'U' shape of 3 mm stainless-steel wire that surrounds the remaining three edges of the comb[30]. The wire is 'invisible' to the bees to the extent that it eventually becomes embedded in the comb and the natural retention of nest heat is safeguarded. The only objections to this on the grounds of sustainability is that stainless-steel has a high ecological footprint and the construction of Delon frames increases the complexity and cost of the operation (Fig. 18). The all wooden half-frame of Gilles Denis is another option which came to my attention after writing this article[56].

Figure 18. Delon frame

Management and harvest

Allowing the bees to build natural comb is part of top-bar hive beekeeping, but, especially with the horizontal format, the beekeeper may nevertheless destroy the brood nest structure, either inadvertently or to suit his own whims. Natural brood nest development in a top-bar hive is described and beautifully illustrated by Dennis Murrell who experienced the importance of the integrity of the brood nest for bee health[47]. Dave Cushman has also recognised the importance of nest structure for bee health and for framed beekeeping describes the simple precaution of marking all the tops of the frames with a line drawn diagonally from corner to corner of the brood box to help avoid any misplacement[48].

The most bee-friendly approach is to minimise intrusion into colonies, but if we wish we can learn a lot about what is going on in colonies by hive entrance observations. An excellent guide to this was published by Storch[29]. A lot more information can be gained if an open mesh floor is being used to control Varroa, in which case the drawer which is 'read' from time to time should be left in all year, at least in cool climates, cleaned regularly and positioned no less than 50 mm below the mesh. Benefits need to be weighed though. Such a floor increases the complexity, cost, labour and ecological footprint of the operation.

Top-bar hives of both kinds allow all the normal beekeeping operations including artificial swarming, splits and uniting. A good policy is to get rid of weak colonies by choosing which queen to kill or letting them fight it out. One strong colony produces more honey than two weak ones.

Top-bar hives of both kinds have no need for a queen excluder, thus save on cost, materials and labour. In the Warré hive, the queen moves down with the brood nest as the season progresses and the upper boxes are left full of honey. Some have noticed that in hives in which in principle the queen has access to the whole hive the honey does not granulate so quickly.

No bee escapes, blowers, fume boards, fumes, extra supers, uncapping knives, extractors or bottling tanks are needed when harvesting honey from a top-bar hive. With the horizontal format, bees are simply brushed off the combs and the comb cut into a bucket with a lid. With the Warré hive the bees in the topmost box are smoked into the one below with natural smoke. If the box contains little or no brood it is taken for harvest after making it bee tight for transport (Fig. 19). The next box is treated the same way and so on until the brood nest is reached. Honey is drained or squeezed from crushed comb. This avoids the exposure of fine droplets of honey to air as occurs in extractors and helps conserve the subtler aspects of flavour and bouquet.

Figure 19. Honey harvest from a Warré hive (Photo: Steve Ham, Spain)

Breeding and making increase

As well as the economic value aspect of sustainability, namely harvesting honey and other hive products, we do not forget the impact of beekeeping on the environment and its more general benefit to society. It is interesting to note a recent intensification of interest in the latter aspect, not only in the media but also from the recent UK government survey of beekeepers, which among other things was interested in finding out to what extent they would no longer replace colonies that are lost.

That there have been larger losses than usual in many countries in recent years is beyond dispute. For example the average colony survival in USA over the 2007/8 winter was estimated at 64%, slightly higher in the UK. All sorts of reasons have been put forward including aspects of management, for example the practice of trucking thousands of colonies from state to state, which cannot possibly be regarded as either bee-friendly or environmentally sustainable. But a central aspect of management has rarely come under scrutiny, namely breeding. In part two we mentioned the importance for bee health of having plenty of genetically diverse drones and thus the need to dispense with drone-suppression measures. Here we will look at how queens are raised.

Artificial queen breeding

In a lecture series on bees in 1923 Rudolf Steiner warned about the problems that artificial queen breeding would introduce in 50-80 years[49]. A beekeeper who was contributing to the lecture series queried this and was told that the effects of modern breeding would not show up at first. Steiner was referring to something more subtle, namely the forces in the hive that had hitherto been organic were becoming 'mechanised' and he said that the intimate relationship between a colony and its queen that has been raised naturally cannot be achieved with a bought queen. Breeders and their customers used to profitable honey crops from their queens will no doubt think this statement absurd. But might there be something in it? The aforementioned 64% winter survival rate is propped up by medicating colonies and feeding them imported sugar. Take away those props and what would it be? And Steiner was not alone in his time in warning that artificial queen breeding produced inferior colonies: Emile Warré, a beekeeper with direct experience of artificial breeding, said that the colonies from such queens were more prone to disease[8].

Whilst the queen breeding aspect should certainly not be overplayed, it seems worth keeping it in mind as a factor in bee health, especially since considerable public money is being diverted into trying to discover why colonies are dying out. So let us look at it in some detail and at the 'mechanisation' of breeding. It increases in the series progressing from queens raised in the natural process of swarming, to splits made where no swarming impulse has started, to modern queen breeding including grafting larvae etc, to artificial insemination, and ultimately to recombinant DNA technology, which has been suggested as a way of creating queens capable of producing colonies with disease resistant traits.

There is a distinct difference between a normal queen whose larva is raised from hatching in copious amounts of royal jelly in a specially prepared round, domed cup hanging vertically, and an emergency queen whose larva is initially raised in an almost horizontal hexagonal cell from an egg or larva that had been destined to be a worker. Beekeepers have long known that colonies often supersede such emergency queens with normal ones. The two types of queen may look the same but the bees can tell the difference. All commercial queens are emergency queens, only they are usually raised in round cells from the outset after grafting the larva. To introduce such a queen to a colony, the colony needs to be brought to the point of 'desperation' to receive a queen. And once introduced it is liable to be replaced by a queen that the colony has produced itself, one in which the 'intimate relationship' that Steiner mentioned has a chance properly to unfold. For a further discussion of modern queen breeding see Günther Hauk's *Towards Saving the Honey Bee*[10].

The physical basis for the intimate relationship between queen and colony may by highly complex, but one obvious factor is queen substance. It is difficult to tell whether research into queen substance is still in its early days, but it seems likely. Indeed, queen substance, in particular queen mandibular or retinue pheromone, has been found to comprise nine chemicals and there is evidence that it contains others as yet unidentified[50]. And with 170 odour receptors having been detected in honey bees, it seems not improbable that the chemistry of the intimate relationship between queen and colony will turn out to be even more intricate. We can justifiably ask the question: is the receptor-pheromone chemistry and its responses something we can instantly 'switch on' by introducing a queen to a colony or does it take time for the various classes of worker to adjust their behaviours to the spectrum of pheromones available? If the latter, then the longer-term exposure of the colony to the maturing queen may be essential for full development of the intimacy of the relationship.

A few other aspects of artificial queen breeding deserve mention in this context. Purchased queens are rarely from the same locality as the one in which they are used and are thus not locally adapted strains. In husbandry there was a great wisdom in the development of landraces, i.e. breeds adapted to the locality in which they were raised. And recognition of the value of local adaptation partly motivates efforts to restore the European black bee, *Apis mellifera mellifera*, in its original habitats. The race evolved to cope with the climate and forage of the region without needing the prop of imported sugar, and was/is no doubt rich in locally adapted sub-types. Using a locally adapted bee is the sustainable option, especially as it does not require a whole industrial breeding infrastructure and the carbon-inefficient supply system that goes with it. But if that is the case, then the whole task of breeding falls on the beekeeper, or at least on very local co-operatives of beekeepers. A consequence of this is that importing even the black bee, that according to some ideal or model has been reassembled from the available genetics, is unsustainable. Indeed it very often may not turn out to be sustainable in practice except in regions whose geography would allow the establishment of drones that allow maintenance of racial purity.

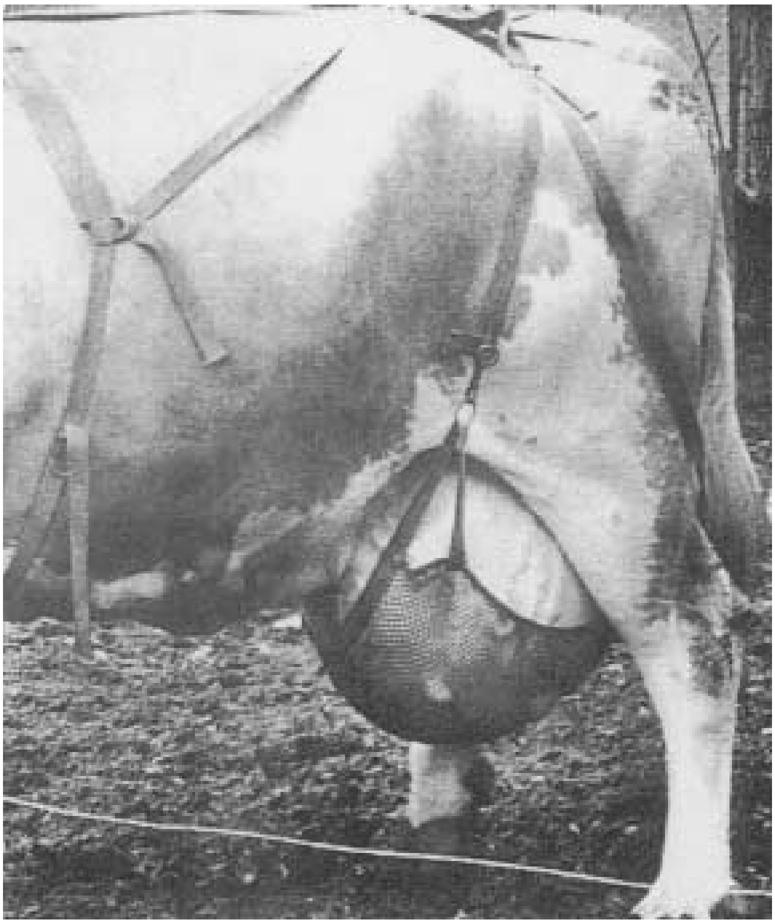

Figure 20. Taking breeding too far?

In situ breeding with the whole colony

To maximise the intimacy of new queen and colony by raising queens from normal queen cells, it follows that we must breed queens while working with the swarm impulse. Once occupied queen cells are present, a colony is split whilst ensuring that the part without the queen has one or more queen cells. Conventional practice requires removing all but one or two cells from the split. However, this risks selecting a less vigorous queen. Bees have managed to select their own queens without our help for millennia, so should we not let the maturing queen and the bees decide? The answer depends on whether the beekeeper wants bee colonies to be under his total control for his own profit and convenience or whether he sees the bee as also having its own intrinsic value (see below) as part of the natural landscape. In the latter case it may be better not to interfere too much in letting the bee adjust its genetics to what is coming towards it in terms of changes in available forage, climate, pests and diseases. Too much artificial selection risks reducing the genetic variability and thus the future options for tackling new challenges.

I digress briefly here to clarify the term 'intrinsic value' by contrasting it with 'instrumental value'. Bioethicists identify several stances of man in relation to nature. One extreme sees man as having dominion over nature, valuing the natural world as an instrument for his purposes. The other extreme sees the natural word as having its own independent intrinsic value and man interacts with it in a relationship that is not one of *domination* but of *participation*. A vivid example of the instrumentalisation of a creature is the cow bred to such an extreme for milk production that she needs a 'bra' to support her udder (Figure 20, above). An example from breeding domestic fowl would be the elimination of broodiness, and from bees, of swarminess.

In beekeeping in a more bee friendly way we try to find a balance between the two approaches. Thus, if we avoid intensively targeted selection for the various queen traits that have appealed to beekeepers from time to time, such as supersedure tendency, docility or hygienic behaviour etc. it does not mean abandoning selection altogether. Selection can still continue while cultivating the intimate relationship between queen and colony. If a colony is not developing normally in comparison to others, despite good foraging conditions, then it can be culled or, if not diseased, united with another. And if a colony available for breeding shows undesirable behaviours outside the normal range compared with the beekeeper's other colonies, for example it is excessively defensive, then it can simply be ruled out as a source of a new queen.

Working with the swarming impulse whilst retaining a high degree of control over the outcome is of course more convenient with frame hives because of the relative ease of access for inspection and subsequent manipulation. However, in this series of articles we have been considering top-bar hives as being more bee friendly than frame hives. Colonies in top-bar hives can be split just as they can in frame hives. Even so, it should be obvious that neither form of top-bar hive easily lends itself to intensification of queen breeding, i.e. raising many queens from a single colony. In the horizontal (long) top-bar hive a split for raising a new queen is relatively easy as the hive can be simply divided and rotated to put the queenless half with the foragers and queen cells in one half whilst leaving the other half with the old queen[51]. In a vertical top-bar hive such as a Warré hive, splits involve working with whole boxes as the combs are not easily moved about. Two examples of such splits are illustrated in the videos on the website of the commercial Warré beekeeper, Gilles Denis[52]. Denis also raises queens using Warré hives equipped with semi-frames[53]. Incidentally, both kinds of top-bar hive use no queen excluder. The queen is in principle free to wander over all the comb. Could this freedom facilitate the intimate relationship between colony and queen?

Swarming

The splits described above result in artificial swarms and, even though they use queen cells that are part of the natural swarming process, they nevertheless involve a degree of interference in the normal process of multiplication. Like a colony, a natural swarm also has a more intimate relationship to its queen than is likely to be produced in an artificial swarm. At the very least, this relationship comprises the quantity and mix of bees, i.e. the ages of the bees and thus their stages of development and corresponding functions in the colony. And I have been struck by the speed with which a natural swarm fills an empty Warré hive box with comb and builds up a vigorous colony. I prefer to start new top-bar colonies with natural swarms. But this is clearly not an option for everyone. It requires much more vigilance at the apiary and in non-rural areas risks annoying neighbours.

It is not always practicable or safe to take a swarm, for instance if it is high in a tree. So in order to minimise losses of swarms, some inexpensive bait hives can be distributed in the vicinity of the apiary and inspected frequently. Ideally the hives should be in an elevated prominent position at about 3 m from the ground, 300 m or more from the apiary, have a volume of about 40 litres and an entrance size of about 12 square centimetres[54]. It should also smell of bees. This can be achieved by coating the inside with beeswax and the entrance area with propolis. Bait hives have been made from all sorts of containers. An ingenious solution involving a piece of drainage pipe from which the swarm can be simply lifted and transferred to a Warré hive is shown in Figure 21.

Figure 21. Drainpipe bait hive (Photo: Steve Ham, Spain)

Swarms will nevertheless be lost. But in what sense is this a loss? It certainly reduces the profitability of beekeeping, but it also has the potential to restock the landscape with feral colonies, most of which, at least in the UK, were wiped out by Varroa. Thus an apparent loss is partly mitigated by the contribution to the environment.

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