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Influencing factors in creating a system to monitor honey bee (Apis mellifera) losses

A Master's Thesis submitted for the degree of
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"It is difficult in fact to think of any other multi-billion-dollar agricultural enterprise that is so casually monitored."

May R Berenbaum, Committee on the Status of Pollinators in North America

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Abstract

Bee keeping is facing serious difficulties throughout the world. Deaths of honey bees appear to have been rising for a number of reasons, including from so-called Colony Collapse Disorder, which has been reported in the United States and, more controversially, in Europe, as well as elsewhere.

Apiculture has been practiced in Europe for thousands of years and is an integral part of Europe's cultural and agricultural heritage, benefiting the ecosystem generally and the agricultural ecosystem in particular. More than 76% of the food produced for human consumption depends on the bee keeping sector and 84% of vegetable species grown in Europe depend on pollination (European parliament resolution B6-0000/2008). But it's not just humans who depend on honey bees. Wild terrestrial ecosystems also need pollination to survive.

Despite the importance and long history of bee keeping, establishing exactly how many colonies are dying and why is difficult. A lack of historical data makes it hard to establish trends. There are a number of psychological, behavioural and economic factors which influence bee keepers too, affecting the information they are willing to provide on the state of their colonies and making it even harder to paint a true picture of honey bee losses and their causes.

This paper describes some of the known and understood afflictions of *Apis mellifera* (the Western Honey Bee) and examines what is currently known about reported cases of bee deaths in Europe. It also emphasises the need for a honey bee monitoring system and examines the human factors and difficulties involved in doing this. The paper makes four recommendations: establish an international monitoring system, recognise the human factors associated with bee keeping and the way bee keepers

interpret and communicate their findings, increase understanding of and transparency in the role of chemicals in the environment, and recruit an entomologist to the European Commission.

Introduction

Honey bee mortality has been increasingly reported in Europe, the United States and around the world. The term Colony Collapse Disorder (CCD) was first used in the US in 2006 to describe the phenomenon (European Food Safety Authority Journal 2008). However a lack of historic and current comparable data makes it difficult to determine the real scale of the problem in Europe. Building a comprehensive monitoring system is complex because of the legislative diversity of within Europe, the limits of technology and the human and psychological factors inherent in bee keeping.

The first challenge is to determine whether bee deaths in Europe have been rising or not. The reports, especially in the media, suggest that they have. However reliable and comparable data are hard to find.

The second challenge is to determine the cause of any rise in bee deaths.

CCD, which specifically describes the sudden and large-scale death of honey bees in a hive for reasons that are not precisely known, has become a rather loosely applied term. The media in both the US and Europe have increasingly reported that high numbers of bees are dying from CCD but confirmed, corroborated statistics are much harder to find. Bee keepers will often use the term to describe what has happened in their hives when in reality bees have died from other, easily diagnosable, well recognised causes like *V. destructor* (see Table 2: honey bee afflictions) or exposure over the winter[1]. CCD is not yet scientifically documented on a large enough scale to draw any firm conclusions about how widespread or how much of a threat it really is.

1 Personal correspondence, Mike Brown, National Bee Unit, Central Science Laboratory, UK

The most important symptom of CCD is the rapid loss from a hive of its adult bee population (European Food Safety Authority Journal 2008). When such a collapse is discovered, no or very few adult bees are present in the hive and there is little or no presence of dead bees in or around the hive (Cox-Foster et al., 2007). Sometimes the queen may still be present, accompanied by a small number of adult bees which have recently emerged from pre-existing capped brood. All other adult bees will have disappeared. It is characteristic that a considerable amount of capped brood will be present in the comb, and there might be plentiful food stores[2], which will not have been taken by bees from other colonies. These food stores have been reported to only be attacked by common hive pests (for example, small hive beetles or wax moths) after a significant delay[3]. The presence of food indicates that starvation is not the cause of the colony's disappearance. The presence of much capped brood, for which a large number of adult workers is needed, suggests that the disappearance was sudden. Occasionally bee keepers have reported a colony in the process of collapse. They recount seeing too small and too immature a workforce to maintain the present brood. During collapse the queen is still present and the cluster is not consuming provided feed provided by the keeper[4].

An obvious question, given the lack of reliable current data on bee deaths, are whether such apparently large-scale, sudden colony losses from whatever cause have happened before. The answer is not so easy. There have been cases of colony losses in the past, some of which acquired their own names, some of which featured losses of up to 90% (Underwood and vanEngelsdorp, 2008). But historical data are spatially and temporally unreliable. Although large-scale bee-mortality events are documented, they appear to be regionally isolated and record individual events over limited periods, lacking reference to long-term data. Statistics to record normal annual over-wintering losses across countries or regions do not appear to exist. We only have data going back ten or 15 years on the normal activity of colonies. Even this may be from one small region in one year and a different region the next. Data from one country may cover one

2 Both honey and bee bread

3 From private interviews with Mike Brown and with Peter Neumann, Agroscope Liebefeld-Posieux Research Station, Switzerland

4 Eg sugar syrup and protein supplements

period of time and from another a different period of time, making them incomparable. One data set may result from a survey of 500 bee keepers and another from a survey of 50.

Scientists are left trying to determine whether recent colony losses are a real problem based on poor and patchy recent information from a comparatively small time period and from events recorded in isolation from as far back as AD950 in such diverse locations as Ireland (Flemming, 1871) Kentucky, Tennessee, Australia and Sweden (Underwood and vanEngelsdorp, 2008). (See Chapter 2, Table 1. Historical colony losses.)

For these reasons it is difficult to say whether CCD or any other major pathogen is a serious threat in Europe. Opinions vary as to whether it has already been detected, however certain sources refer to CCD as if it has been confirmed (European parliament resolution B6-0000/2008). Whether or not these colony losses are new is another question.

Clearly a unified system needs to be developed to collect comparable data on bee behaviour and mortality in Europe and elsewhere. There are significant challenges in building such a system. The European Union is legislatively diverse, with countries and regions applying different standards. National laws cannot set lower standards or transcend EU law without specific exemption. Member states must adhere to the laws of the EU but standards do vary with some countries, such as Germany, exceeding requirements and setting higher standards in their own national laws (Verordnung über die Anwendung bienengefährlicher Pflanzenschutzmittel (Bienenschutzverordnung).

Given the widespread geographic nature of bee keeping, remote sensing technology cannot be used to track the movement, behaviour and health of honey bees, so the monitoring of bees is labour intensive, requiring cooperation by many interested parties. The profile of many bee keepers requires human and psychological factors to be taken into account too. Most bee keepers in Europe are hobbyists and cannot easily be compelled to register with overseeing bodies and report their activities. Information given in surveys is often dependent on their voluntary contribution. Motivations for keeping honey bees vary and have various influences on the way bee keepers treat their bees and provide information.

This paper describes some of the known and understood afflictions of *A. mellifera* and examines what is currently known about reported cases of bee deaths in Europe. It also examines the human factors involved in establishing a honey bee monitoring system. The data used in this report are not drawn from original research, nor are they comprehensive or exhaustive. They draw on private interviews and all the published specialist research and data which was available to me.

I. The problem

Why do honey bee deaths matter?

Any species collapse is a bio-indicator of environmental health and is therefore of wider concern. However there are a number of other reasons why politicians, farmers, economists, consumers and other stakeholders should be worried about a possible large-scale decline of honey bees. Honey bees are a keystone species and as such support terrestrial ecosystems generally and agricultural ecosystems in particular. They are "in the front line of sustainable productivity through plant reproduction" (Kevan, 1999) supporting global food security and the global economy through the provision of pollination services. A large-scale loss of bees would have widespread negative effects on economies, on national trade balances, on biodiversity and wild terrestrial ecosystems and on the diet and lifestyle choice of humans.

Honey bees are vital to the ecosystem

Honey bees provide two important agricultural services: first, they produce their own goods (honey, propolis and wax); second, they pollinate crops for domestic and export markets. As much as 76% of the food humans eat is dependent on pollination (European parliament resolution B6-0000/2008), not exclusively, but mostly, by honey bees. They ensure the production of coffee, cocoa, blueberries, cotton, almonds, squash and many other products (see Figure 1.1. for relative dependence on honey bees as pollinators of some of the more valuable crops in the US). Moreover colonies will sustain up to 10,000 bees over the winter, providing a mass pollination facility exactly when it is needed in the spring[5]. Furthermore it is not just the food we eat directly that needs to be pollinated: clover, alfalfa and soya, important fodder for sheep and cattle, also depend on pollinators. Humans would not immediately starve without pollinators, because certain staples like cereals and grains do not need pollination to

5 From a private interview with Peter Neumann

grow, and these already form the basis for intensively farmed meat. However the loss of honey bees would make the production of meat and dairy produce harder. More grains would have to be grown – and transported, increasing the cost and carbon-footprint of food production – to make up for the fodder shortfall, further decreasing biodiversity and increasing monoculture. Pollination is an essential balancing mechanism in terrestrial ecosystems everywhere (Kevan, 1999).

The effects of pollinator loss are widespread

Some sources say evidence of pollinator decline across the world is growing and the effects on agriculture could be severe (Gallai et al., 2008). While honeybees are not the most effective pollinators for all crops (Williams, 1994), and while plant species do not naturally depend on only one pollinator, *A. mellifera* are nonetheless the most valuable agricultural pollinators because they are by far the easiest to manage (Kevan, 1999). For a number of other reasons, including intensive use of pesticides and the neglect of wild species of pollinators in favour of managed species, we have become too dependent on single species pollination. Aizen et al., 2008 argue that there is a disproportionate preference for honey bees as pollinators, that this in itself is creating biodiversity stresses and that steps should be taken to change the situation, particularly by reintroducing bumble bees and other bees as managed and wild pollinators.

Bees support global food security and the global economy

The value of pollination in the US, Canada and Australia, chiefly focussing on honey bees, exceeds by far the value of hive products (honey, wax etc) (Southwick and Southwick, 1992). It is difficult to put a reliable price tag on pollination services due to the complexities of quantifying agriculture in any one country (Southwick and Southwick, 1992). Moreover to reduce the importance of honey bees to a monetary value is ecologically dangerous, ignoring their essential contribution to the maintenance of biodiversity and wild terrestrial ecosystems, which are priceless[6]. However economics often stimulate the formulation of policies necessary for conservation. Gallai et al., 2008 estimate the total economic value of pollination worldwide as €153 billion, or 9.5% of the value of the global agricultural production used for human food in 2005.

Figure 1.1 shows the relative dependence on honey bees as pollinators of some of the more valuable crops in the US. Almonds and apples, ranked fourth and fifth in crop value, are particularly dependent on honey bees. A large-scale crisis in pollination services could have a negative impact on countries' trade balances. A country which today is agriculturally self-sufficient might have to increase agricultural imports if pollination services collapsed, changing their trade balance. Market forces mean the demand for – and on – bees is rising. If bee numbers fall there will be supply and demand-related cost implications as well as possible impacts on production capacity. California almond farmers currently need around 1.4 million honey bee colonies to pollinate 550,000 acres of almond trees. But by 2012, thanks to the growing domestic and export market for almonds, the amount of land needing bees for pollination will have increased to 800,000 acres (Pollinators' Decline Called Threat to Crops, Washington Post 19th October 2006). The potential damaged to ecosystems and economic systems caused by a loss of pollinators could be very great.

6 Personal correspondence with Peter Neumann

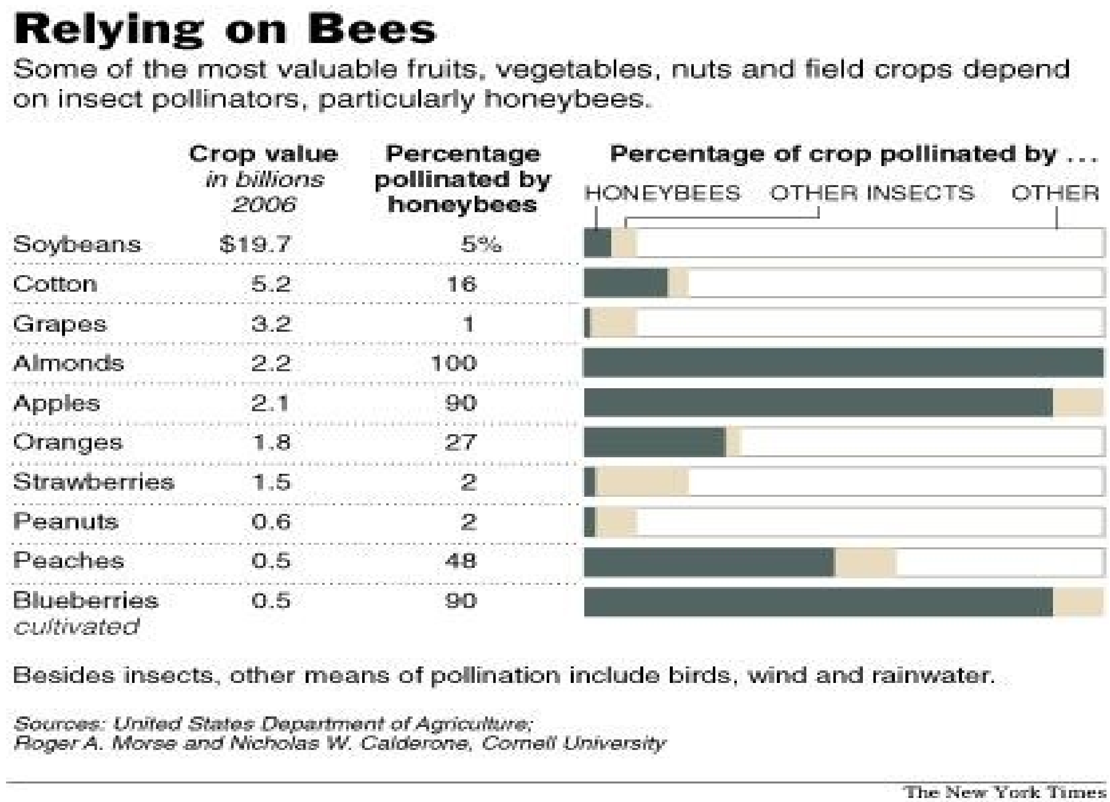

Figure 1.1: Relative dependence on honey bees as pollinators of some of the more valuable crops in the US

II. What is currently known about bee mortality in Europe

There have been reports of large-scale bee deaths in Europe, which some sources, particularly the media, are attributing to CCD. However it is difficult to verify exactly where and how big these losses are, whether they are following or bucking a trend, and what the causes are[7].

What is CCD?

CCD has been explicitly named by the European Food Safety Authority (EFSA) to explain “serious losses of bees from beehives” since 2003 and the European Parliament refer to CCD as one of the causes of the “crisis in bee health” (European parliament resolution B6-0000/2008) but there are conflicting views on whether CCD exists in the UK[8]. Some UK scientists and bee keepers say there is no CCD in the UK, although Marie Celeste syndrome, which is acknowledged to exist in England, displays the same symptoms as CCD. These sources say the single greatest threat to bee populations is *V. destructor*[9].

There appears to be a trend among bee keepers, scientists, academics and bee inspectors in concluding that *V. destructor* plays a key role in recent colony losses, particularly because virtually all managed colonies globally are infected by the mite, with a few exceptions in Australia, parts of Africa and some isolated islands. Remote parts of the Scottish highlands are also reportedly *V. destructor* free. The mite has been shown to act as a vector of other honey bee pathogens, for example viruses (Chen and Siede, 2007).

This corresponds to reports of CCD in the US where the initial infection of a hive is *V.*

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7 For known bee afflictions see Table 2: honey bee afflictions, chapter3
8 From personal correspondence with Mike Brown
9 From personal correspondence with Mike Brown and Richard Ball

destructor, followed by the subsequent appearance of viruses like DWV, KBV or IAPV (Cox-Foster et al., 2007). But if the hive is treated for *V. destructor* the both initial infection and the honey bees carrying the mites can disappear, leaving the colony apparently unaffected by *V. destructor.* The secondary infection, however, is still present, sometimes without symptoms at first, which is why a colony can apparently be perfectly healthy and the suddenly collapse.

Diagnosis becomes even more difficult when there is no evidence to analyse: often, although not all the time, when CCD is reported, bee keepers simply find their hives empty, with no trace left of the bees. On some rare occasions when early observations have been made of a colony during collapse, bees have been seen walking (unable to fly) out of the hive, often shivering in clusters in the grass, before dispersing[10].

Despite the confusion over nomenclature, certain sources show data which suggest that both the scale of bee mortalities has risen in recent years and that the number of bees has generally fallen over time:

10 From a private interview with Richard Ball

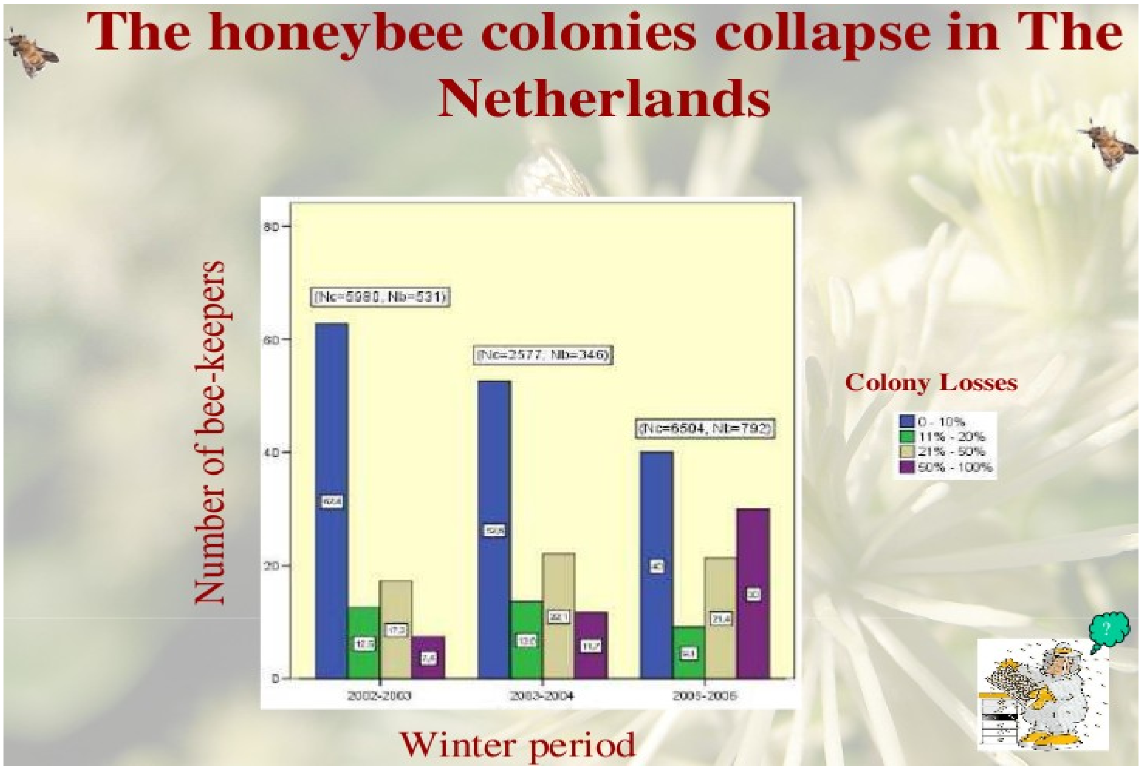

Figure 2.1: Colony loss reports (Source: Bach Kim Nguyen and Eric Haubruge, Gembloux Agricultural University, Belgium)

Figure 2.1 shows that each year from 2002 to 2006 the numbers of bee keepers reporting colony losses of 50% or more has risen whereas the number reporting colony losses up to 10% has fallen. This suggests that the scale of losses has increased.

Are variations in bee losses a factor of changing conditions or the result of poor and non-comparable data?

A lot of data seem to indicate that bees are in crisis. Figures variously appear as 90%, 50% or 30% to describe colony losses. But this only becomes meaningful if it can be compared with normal years (data on which vary) without the large-scale events which have been described, as in figure 2.2 below.

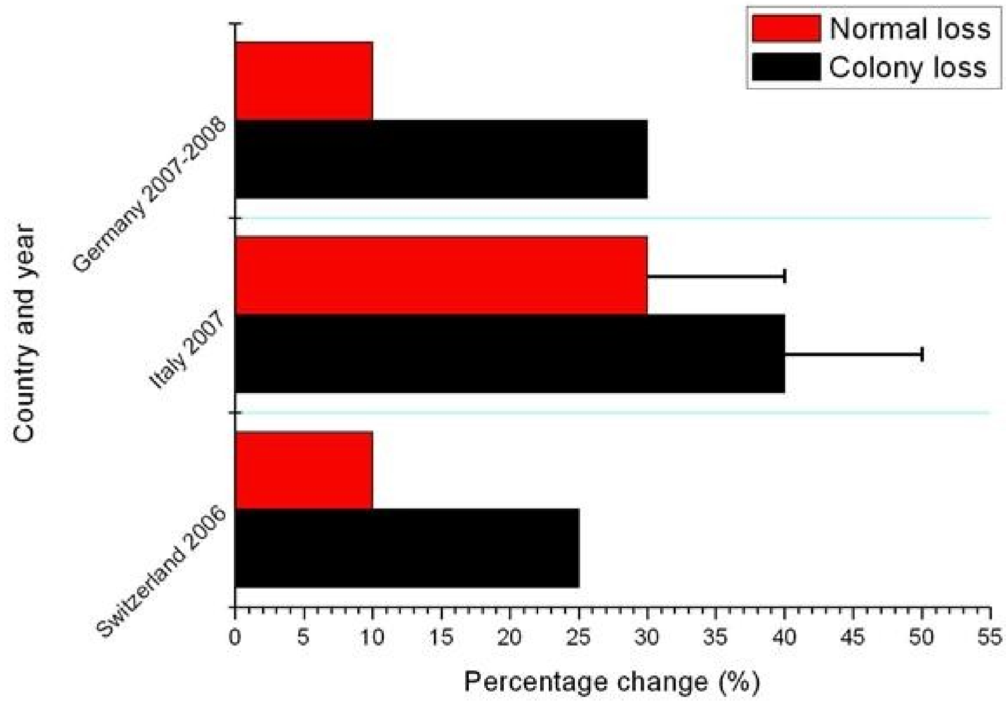

Figure 2.2: Comparison of colony losses with previous or normal years (Source: various data cited in text)

This information is not so easily available, however. Jürgen Tautz (German Bee Populations Collapse, Deutsche Welle, 14/05/2008) says that in Germany bee keepers might expect to lose 10% of hives over a normal winter but that during the winter of 2007-2008 losses averaged more than 30%[11]. Italy had already high mortality rates over 2006 at between 30% and 40% but these rose to 40-50% in 2007 (European Food Safety Authority Journal 2008). In Switzerland mortality rates of 10% are considered normal (Jean-Daniel Charrière) but in 2006 mortality rates were up to 25%. Business-as-usual losses in the UK are currently around 15% (London Bee Keepers' Association, Flowers and fruit crops facing disaster as disease kills off bees, 31/03/2007). Losses in the first half of 2008 were reported as 24.2% (European Food Safety Authority Journal

11 It should be noted that averaging losses can mask regional extremes. Losses can be as high as 90% for individual bee keepers, as reported by Underwood and vanEngelsdorp. The EFSA reported mortality rates for 2006-2007 in the range of 7-50% across Europe.

2008), which again suggests a rise.

Much of the available data is less clear, however. The Mayen Bee Research Institute investigated bee losses in certain areas of Germany and Luxembourg in 2002/2003. The data showed that mortality rates varied depending on the region and that the most dramatic losses occurred among fewer than 50% of all bee keeping operations. However data are not clear enough to show any significant trends regarding the scale or temporal comparability of bee mortalities. Another example of incomparable data exists for Southern Belgium. High mortality rates were reported, along with a general weakening of honeybees in Wallonia (Kim and Haubruge, 2007). Data simply showed that average mortality rates were 17.49% and they ranged from 0-84%.

When presented with these figures it's difficult to draw any conclusions. Often, particularly in the media, it is not clear whether figures are averaged across regions or whether they are specific. And when rates for normal mortality vary so much from country to country – or are unavailable for some countries - it is even harder to determine whether the apparently high losses are unusual. However the general trend from the data I have been able to collect seems to be increasing colony deaths in Europe.

The same can be said of US data. Figure 2.3 shows large-scale losses in the US:

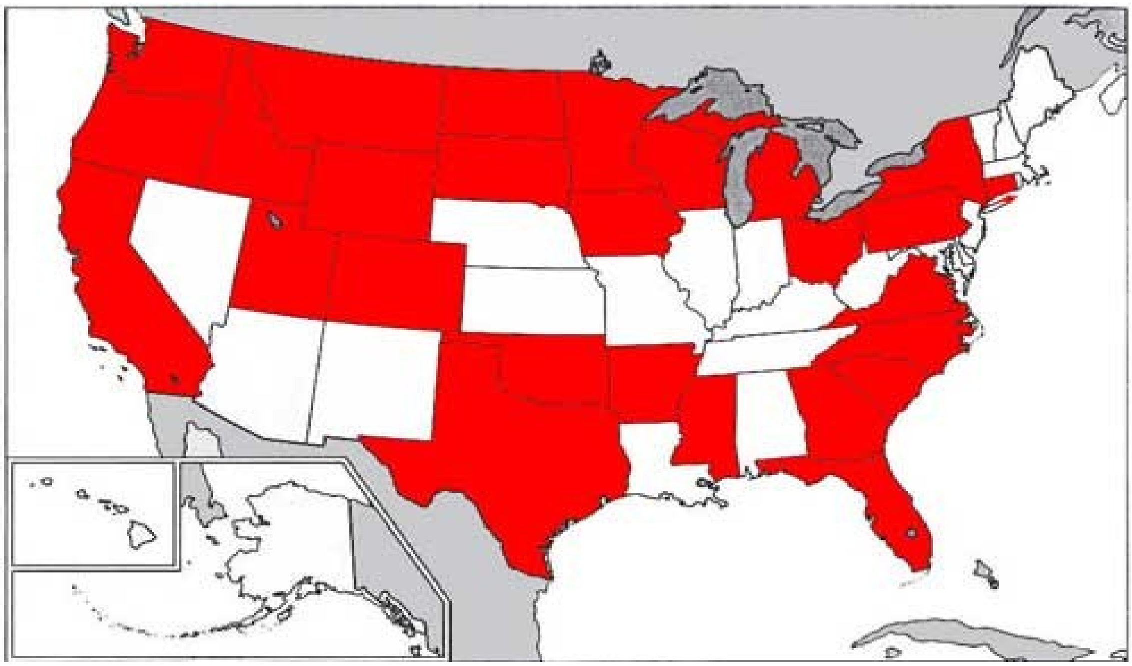

Figure 2.3: States where bee keepers are reporting significant losses from CCD
(Source: Bee Alert Technology Inc, 2007)

Figure 2.3 shows areas where high bee losses have been experienced, which gives an impression of the scale of the problem. However more detailed data are highly variable, sometimes reflecting the losses of individual bee keepers, sometimes averaged across a region and often not specified at all. And again, without historical data for comparison, it is impossible to tell whether this apparently alarming losses are a problem in reality.

Table 1 illustrates the variability of data available from around the world and shows reports of historical losses with suspected causes, when information is given.

Table 1: Historical colony losses

Year and Location	% total loss	Suspected cause	Reference
950 Ireland	“Great mortality”	Not recorded	Oldroyd, 2007
992 Ireland	“Great mortality”	Not recorded	Oldroyd, 2007
1443 Ireland	“Great mortality”	Not recorded	Oldroyd, 2007
1868 Kentucky, Tennessee		Lack of pollen, poisonous honey or hot summer	Underwood and vanEngelsdorp 2008
1872 Australia	Scale not specified	Cause not specified	Kulincevic et al., 1984
1891 / 1896 Colorado	“Large clusters disappeared or dwindled” May Disease	Various fungi, especially *Aspergillus flavus* (Stone brood)	Aikin, R.C., 1897 cited in Underwood and vanEngelsdorp 2008
1905 – 1919 Isle of Wight	90% (three epidemics)	Acarine disease; tracheal mite *Acarapis woodi*; starvation; *Nosema*	Underwood and vanEngelsdorp 2008
1903 Cache Valley, Utah	2000 colonies	Hard winter, cold spring	Oldroyd, 2007
1910 Australia	59%	Fermentation in honey	Beuhne, R., 1910
1915 Portland, Oregon	“Large-scale losses”	Cause not specified	Underwood and vanEngelsdorp 2008
1915 Florida to California	“Large-scale losses”	Cause not specified	Underwood and vanEngelsdorp 2008
1917 New Jersey, New York, Ohio, Canada	“Large-scale losses”	Cause not specified	Underwood and vanEngelsdorp 2008
1963-64 Louisiana and Texas	Scale not specified	Causes eliminated: Nosema, septicemia, tracheal mite, external parasites, paralysis virus	Kulincevic et al., 1984 and Underwood and vanEngelsdorp 2008
1964-65 California	Scale not specified	Cause not specified	Kulincevic et al., 1984
1974 Rio	Scale not	Unseasonable cold then	Underwood and

Grande Valley, Texas	specified	two weeks of rain	vanEngelsdorp 2008
1975 Australia	“Disappearing syndrome”	Dampness, poor nutrition, stress	Olley, K, 1976
1977 Mexico	“Disappearing disease”	Combined factors ie diseases, poor nutrition and genetics	Kulincevic et al., 1984 and Underwood and vanEngelsdorp 2008
1995 – 1996 Pennsylvania	53%	Cause not specified	Oldroyd, 2007
1998 – 2000 France	“Heavy losses”	Colony mismanagement, nutrient deficiencies and chemicals in environment. Known honey bee diseases mostly present.	Underwood and vanEngelsdorp 2008
2001, 2004 and 2007 US	“Heavy losses” up to 90% (individual bee keepers)	Cause not specified	Underwood and vanEngelsdorp 2008
2003 France	60%	Heat and drought	BBC, 2003
2006 Switzerland	25%	Cause not specified	ALP
2006 Italy	30-40%	Cause not specified	EFSA
2007 Italy	40-50%	Cause not specified	EFSA
2006 – 2007 Czech Republic	20%	Cause not specified	EFSA
2006 – 2007 Netherlands	15%	Cause not specified	EFSA
2006 – 2007 US	27-36% (overall)	75% causes other than CCD	Apiary Inspectors of America
2007 – 2008 France	Up to 90% (individual bee keepers)	Cause not specified	Blanchard et al., 2008
2007 – 2008 Germany	30%	Cause not specified	Tautz 2008

Historical data

Table 1 shows that large-scale mortalities are not new. Monks in Ireland reported a "great mortality of bees" in 950, 992 and again in 1443 (Flemming, 1871). Losses were reported in Kentucky, Tennessee in 1869 although without specific numbers (Underwood and vanEngelsdorp, 2008). Heavy losses were recorded in Colorado in 1891 and 1896 from 'May Disease' although actual figures are hard to find, again making it difficult to judge what is 'heavy' and what is 'normal'. Kulincevic et al., 1984, refer to losses in Australia in 1872 but do not include details. In 1903, 2000 colonies were lost in the Cache Valley in Utah, following a "hard winter and cold spring" (Oldroyd, 2007). The Isle of Wight Syndrome, the name given to three epidemics between 1905 and 1919, saw losses of 90%. Here it was reported that bees crawled, unable to fly, from the entrance to the hive. Similar symptoms are described in cases of Marie Celeste Syndrome in the UK today. Speculations as to causes for the Isle of Wight Syndrome have historically varied from climate, genetics, food shortage, poisoned honey and fungal infection (Underwood and vanEngelsdorp, 2008).

In the Stawell district of Australia in 1910, 59% of colonies were lost and many more were severely weakened (Underwood and vanEngelsdorp, 2008). Further instances of widespread losses have been reported in pockets of the US in 1915[12] (Underwood and vanEngelsdorp, 2008) and from Florida to California in the same year. In 1917, large-scale losses were documented in New Jersey, New York, Ohio and Canada.

In the 1960s in the US there were many reports of losses, some of which were attributed to unseasonable cold followed by persistent rain. High losses were also reported in Australia in 1975 and Mexico at around the same time. The usual disease, nutritional and environmental factors were ruled out. Wilson et al., 1979, concluded that in 1975 the syndrome could be found in 27 states of the US (Underwood and vanEngelsdorp, 2008).

12 Namely Portland, Oregon

During the winters of 1998-1999 and 1999-2000, heavy losses were reported in France. In these cases, known honeybee diseases were present sometimes in isolation, sometimes in combination with one another, in 76% of affected colonies (Ribiere et al., 2002). No combinations stood out over others. Blanchard et al., 2008 report that heavy losses and mortalities were reported in French apiaries in the winter of 2007-2008, with some bee keepers reporting 90% mortality rates.

Heavy losses were reported in the US in the spring of 2001, 2004 and 2007 (Underwood and vanEngelsdorp, 2008) with some bee keepers reporting losses of 90%. A survey by the Apiary Inspectors of America (Underwood and vanEngelsdorp, 2008) concluded that between 651,000 and 875,000, or 27-36%, of the total 2.4 million estimated colonies in the US were lost during the winter of 2006-2007. Of the total bee losses, approximately 25% were thought to have CCD. Taking the highest figure, this would be 218,750 colonies assumed to have been lost to CCD which is an overall loss of around 9% attributed to CCD. Other causes account for the remaining 75% of losses. And actual losses in the Rogers study, that is for individual bee keepers as opposed to averaged losses, ranged from 38% to 100% (Rogers, 2008). Again, without a baseline for normal years, it is hard to judge how serious these losses are or whether they are particularly elevated. The survey by the Apiary Inspectors of America (Underwood and vanEngelsdorp, 2008) would seem to suggest that CCD is the least of bee keepers' concerns, given that 75% of losses were attributed to other causes. It would also suggest that the attention given to CCD could be refocussed on addressing the known causes of bee losses, which may nevertheless be causing critical problems in many parts of the world, not least in Europe.

Is there any evidence that current trends are historically unusual?

It is difficult to say whether current reported losses are historically unusual because we don't have business-as-usual data to compare it with. Bee mortalities are both seasonal and cyclical and without comparable data from normal cycles as well as high mortality events it is impossible to track typical trends and the to draw anomalies. The best we can do is compile research data and the opinions of experts.

However even here there are contradictions. Aizen et al., 2008 state that there is evidence that pollinators are declining as a result of local and global degradation. However Aizen and Harder, 2009 state that the global stock of honey bees has risen by 45% over the past 50 years and continues to increase (Honeybee colonies not declining worldwide, study says, 07/05/2009, CBC News). They also say that the global growth in bee keeping has been chiefly driven by demand for honey, not the need to pollinate crops and that global honey production has doubled since 1961 (Bee Shortage Not a Global Crisis, 08/05/2009, Financial Times).

Underwood and van Engelsdorp, 2008 conclude that it is impossible to say whether the losses that have been reported for more than a century are connected to CCD.

We can conclude with certainty that large-scale honey bee losses are not new. However it is difficult to say whether current mortalities are much greater in scale or more frequent than those that have been experienced before or whether this a new threat. Current losses seem to be distinct from previous losses because they are very rapid and the bees vanish or fail to return to the hive. However it is not clear whether this last symptom is consistently present with all reported losses. In order to determine whether current threats differ from previous threats, or whether the phenomenon of current colony losses are new, we must compare the known threats with recent reports.

III. Analysis of the likely causes of bee losses

Although seasonal colony losses are normal, however the presence of pathogens[13] in the hive can exacerbate losses. Viruses and diseases have been associated with recent colony losses but it is not clear that the responsible factor (or factors) is a disease *per se*.

There have been numerous reports of large-scale bee losses and scientific investigations into the causes are ongoing but diagnosis can be difficult. Possible contributing factors include pathogens, parasites, environmental stress, pesticides, electromagnetic radiation and bee management stresses such as frequent handling and transportation and poor nutrition, possibly due to work on monoculture. The presence in the US of monoculture and contract pollination services over long distances and the relative number of cases of CCD in the US compared with Europe may suggest a causative link. This might be due to the relatively high stress and malnutrition caused by monoculture and contract pollination services which lead to reduced combined disease, pathogen and chemical exposure resistance in honey bees[14]. This chapter discusses the difficulties in diagnosing recent colony losses, briefly outlines the principle known causes of mortality and weakening of honey bees and presents a selection of the findings of research into bee deaths in the US (briefly) and Europe (largely). The chapter also presents some of the theories expressed by scientists and bee experts and discusses what might be the reasons behind these losses.

Diagnosis

It can be difficult to diagnose bee viruses because non-apparent infections can often exist in the hive without showing any obvious signs of disease (Bailey, 1967). Honey bees can also host at least four viruses at once without displaying clear pathological symptoms, which can obscure diagnosis. There are still significant gaps in entomology

13 Any disease-producing agent, especially a virus, bacterium or other microorganism.
14 Kastberger personal communication

understanding in terms of the effects of mixed infections on pathogenic processes in bees. For example, it is not known if mixed virus infections might result in genetic recombination with other co-incident viruses and, if this were to occur, whether that might lead to the emergence of new viruses (Chen et al., 2004). Problems in methodology, inability to detect latent infection and misclassification of viruses have persisted for years (Allen and Ball, 1995, Rinderer and Green, 1976).

Mortality or behavioural changes from pesticide exposure are also difficult to diagnose because the methods used to determine toxicity of pesticides to bees are imbalanced, leading to skewed results. Toxicity tests are generally designed to show the effects of insecticides 'applied on the aerial parts of plants' and are not adapted to systemic substances which are used to treat soil or seeds (Rortais et al., 2005). Many of the pesticides associated with bee deaths in recent years are systemic insecticides, which may have different effects on bees compared to previous generations of plant protection products. Toxicity testing will be discussed in chapter 5.

Known causes of mortality or weakening of A. mellifera

Table 2: Honey bee afflictions

Affliction	Definition and symptoms	References
V. destructor	Ectoparasitic mite, feeds on body fluids of honey bee larvae. Causes weight loss and reduced drone fecundity. Weakens immune response. Untreated, kills colony in 3-4 years. Vectors of DWV, ABPV, KBV and IAPV. Pyrethroid and acaride (*V. destructor* treatments) resistance reportedly growing.	Le Conte and Navajas, 2008 Zhang et al., 2007 Pettis, 2003
Nosema (apis and ceranae)	Intracellular microsporidian No obvious external symptoms Transmitted through contaminated food Causes digestive problems and dysentery, shortens life span Increases winter mortality Sometimes found in combination with viruses eg IAPV	Williams et al., 2007 Chen et al., 2007 Higes et al., 2006 Köglberger et al., 2006
Foulbrood	*American:* Bacterial pathogenic disease from *Paenibacillus* larvae Highly contagious and ubiquitous Spread by cleaning worker bees and robber bees Lethal to bee brood *European:* Bacterial disease from *Melissococcus plutonius* in association with other bacteria eg *Enterococcus faecalis* Infects the gut of bee larvae	Foulbrood disease of honeybees: recognition and control, Defra 2007

	Only dangerous to already weakened hives	
Paralysis Virus	Chronic Bee Paralysis Virus (CBPV): Bees cluster together and crawl, shivering, unable to fly Causes high mortality Ubiquitous in *A. mellifera* as of 2007 Can be symptomless at first Associated with *V. destructor* Acute Bee Paralysis Virus (ABPV): Bees cluster together and crawl, shivering, unable to fly Part of *Dicistroviridae* family Genetically related to IAPV Can exist in apparently healthy hives Associated with *V. destructor* Israel Acute Paralysis Virus (IAPV): Bees cluster together and crawl, shivering, unable to fly Part of *Dicistroviridae* family Genetically related to ABPV Associated with *V. destructor* Kashmir Bee Virus (KBV): Weakening of colony with no symptoms of brood disease or parasites Dead or dying bees, sometimes trembling, at hive entrance Upper thorax may be darkened, bees may be hairless Older bees appear oily, young appear opaque Genetically related to IAPV Associated with *V. destructor*	Blanchard et al., 2008 Celle et al., 2007
Sacbrood Virus (SBV)	Infectious, ubiquitous Affects larvae primarily and	Grabensteiner et al., 2000

	occasionally young adults *Picorna-virus* – can be exacerbated by *V. destructor* Larvae change from white to grey, then black Death occurs shortly before pupation Head development often retarded, larvae scales brittle When removed from cells, appear as water-filled sack	MAAREC
Black Queen Cell Virus (BQCV)	*Picorna-virus* Causes mortality in queen prepupae and pupae Apparently triggered by *N. apis*	Grabensteiner et al., 2006 Benjeddou et al., 2000
Deformed Wing Virus (DWV)	Causes high mortality Newly emerging bees display wing damage Affected bees unable to fly Associated with *V. destructor* and *Tropilaelaps mercedesae*	Dainat et al., 2009 Chen and Siede, 2007
Stone brood	Caused by *Aspergillus flavus* fungus Affects brood and adults Present in already weakened hives	Underwood and vanEngelsdorp, 2008
Chalkbrood	Caused by *Ascosphaera apis* fungus Affects lavae Dead larvae covered in fluffy white mould Later dry and form black or white mummies Associated with high stress conditions and prolonged use of acaricides containing fluvalinate	Matasin et al., 2002
Tropilaelaps mercedesae	Ectoparasitic mite Vector of honey bee diseases Ubiquitous Considered more dangerous to *A. mellifera* than *V. destructor* Infestations can rapidly lead to colony death Found with and without *V.*	Forsgren et al., 2008 Dainat et al., 2009

	destructor	
Pesticides	Neurotoxic Affect behavioural patterns of bees at sub-lethal doses Lethal at high doses	Underwood and vanEngelsdorp, 2008 Kievits, 2007 Rortais et al., 2004
Genetically modified crops	Exposure to *Bacillus thuringiensis* (Bt) toxin in genetically modified crops may cause harm	Natural News, 2009 Morse et al., 2006 Friends of the Earth, 2001
Wax moth	Destroy honeycomb wax, spilling or contaminating honey which can kill larvae Do not directly attack bees or larvae Only a threat if colony is already weakened	ALP
Small hive beetle	Damage honeycomb and destroy capped brood Honey becomes contaminated and ferments	ALP
Handling and chilled brood	Failure to check for pathogens, provide feed or insulate hives during cold winter weather can cause mortality or deformities	Mike Brown, personal correspondence
Breeding	Docile, productive bees with low swarming tendency are also genetically weaker, increasing vulnerability to pathogens.	Tautz. 2008 Charrière 2007
Monoculture and malnutrition	Reduced foraging opportunity causes malnutrition and compromised immunity Failure to provide winter feed can also cause malnutrition	Mike Brown and Richard Ball, personal correspondence
Climate and climate change	Temperature, storm frequency, humidity and precipitation affect honey bee behaviour and physiology. Habitat and colonies' harvesting and development capacity affected by climate	Le Conte and Navajas, 2008

	change. Distribution range of honey bees affected by climate change Competitive relationships, with associated parasites and pathogens, changed or introduced in severe climate change.	
Electromagnetic radiation	Exposure in certain ranges reported to cause disorientation, swarming and attacks on other honey bees.	Kievits, 2007 Kimmel et al., 2007
Marie Celeste Syndrome	Unable to fly, bees walk out of the hive Sometimes a queen and some capped brood are left No dead bodies remain, all disappear Complete desertion of hive	Richard Ball, personal correspondence
Colony Collapse Disorder	Complete collapse of hive Disappearance of all or most bees Queen sometimes present with small number of young adult bees No dead bodies remain Considerable capped brood remains Food stores only robbed after significant delay	Cox-Foster et al., 2007

Around 20 viruses are known to occur in *A. mellifera* (Blanchard et al., 2008) Depending on geographical location, the relative vulnerability of honey bees to certain viruses varies. The most common ones are A*cute Bee Paralysis Virus* (ABPV), *Black Queen Cell Virus* (BQCV), *Kashmir Bee Virus* (KBV) and *Sacbrood Virus* (SBV) (Chen et al, 2004). In England and Wales the most commonly reported problems with honey bees are *V. destructor, American foul brood* (AFB) and *European foul brood* (EFB), with

Nosema also causing some losses (An Economic Policy Evaluation of DEFRA's Bee Health Programme, 2008). Some of the pathogens and disorders known to *A. mellifera* are outlined below. (Please refer to Bailey and Ball,1991 and Neumann and Elzen 2004 for a more detailed overview.)

A- Known diseases

1.1: Varroa destructor – history and definition

The ectoparasitic mite *V. destructor* originally infected the Eastern honey bee *A. ceranae. V. destructor* is relatively benign in *A. ceranae* but encounters no natural resistance in *A. mellifera.* Since jumping species some time in the mid-20^{th} century it has become widespread and now kills honey bee colonies worldwide, except in Australia where it is not yet present (Le Conte and Navajas, 2008). The mite feeds on the body fluids of the honey bee larvae, pupae and adults, weakening honey bees' immune response and encouraging the development of other viral infections (Zhang et al., 2007). If left untreated *V. destructor* kills the colony within 3 to 4 years. The mites are active vectors in the transmission of viruses and bacteria, for example *Deformed Wing Virus* (DWV), *Acute Paralysis Virus* (ABPV), *Kashmir Bee Virus* (KBV) and *Israeli Acute Paralysis Virus* (IAPV). There are also reports that *V. destructor* is also becoming resistant to the acarides used by bee keepers to control them (Pettis, 2003). It is also noteworthy that the *V. destructor* treatment Apistan reduces the sperm count of drones and Checkmite+ shortens the working life of queens[15].

1.2: Extent of V. destructor

Jamie Ellis of the University of Florida said in a private interview that more than 95% of all US bee colonies are probably infected with *V. destructor*, which he says is the principal killer of honey bees in the world, including the US.

15 Personal communication, Richard Ball

V. destructor eliminated feral honey bees in the UK (except for an isolated pocket of the Scottish Highlands) during the 1990s and continues to cause problems across Europe. The mite has been present in European bee populations for 20 years, causing some to question how this could be the cause of recent colony losses. However it is reported that far fewer mites than before are now needed to cause a colony collapse, and so either *V. destructor* is becoming more virulent or bees are becoming weaker.

Kievits, 2007 says that hives cannot be collapsing exclusively due to *V. destructor*, because it is clearly visible in affected hives and does not cause rapid collapse. Mike Brown of the National Bee Unit in the UK also says that symptoms of recent colony losses differ from those for *V. destructor* but says that rapid collapse from *V. destructor* infestation can occur, especially during the summer. John Howatt, Secretary of the Bee Farmers' Association of the UK[16], recalled the spontaneous swarming and subsequent disappearance of one of his colonies in October 1992. *V. destructor* had recently arrived in Britain and his hives were later diagnosed with the mite. He believes that extreme stress caused by *V. destructor* caused his bees to abandon the hive.

V. destructor has been implicated in recent losses in Switzerland, although Jean-Daniel Charrière of the Agroscope Liebefeld-Posieux Research Station (ALP) in Bern, says this cannot be the sole culprit because although it has not been eradicated the mite is nonetheless relatively well controlled in the country (Concern mounts over falling bee population, 14th April 2007, Swissinfo.org).

Mike Brown of the NBU says that *V. destructor* is problematic for indirect reasons too. After the parasite arrived in England and Wales, the number of bee keepers declined for many years. Unable to adapt to the arrival of *V. destructor*, bee keepers either stopped keeping bees or used their own ineffective treatments to avoid spending money. Figure 3.1 shows a possible correlation between the decline in bee keepers and a drop in the number of bee colonies (with the exception of Italy where apparently numbers rise):

16 Personal communication

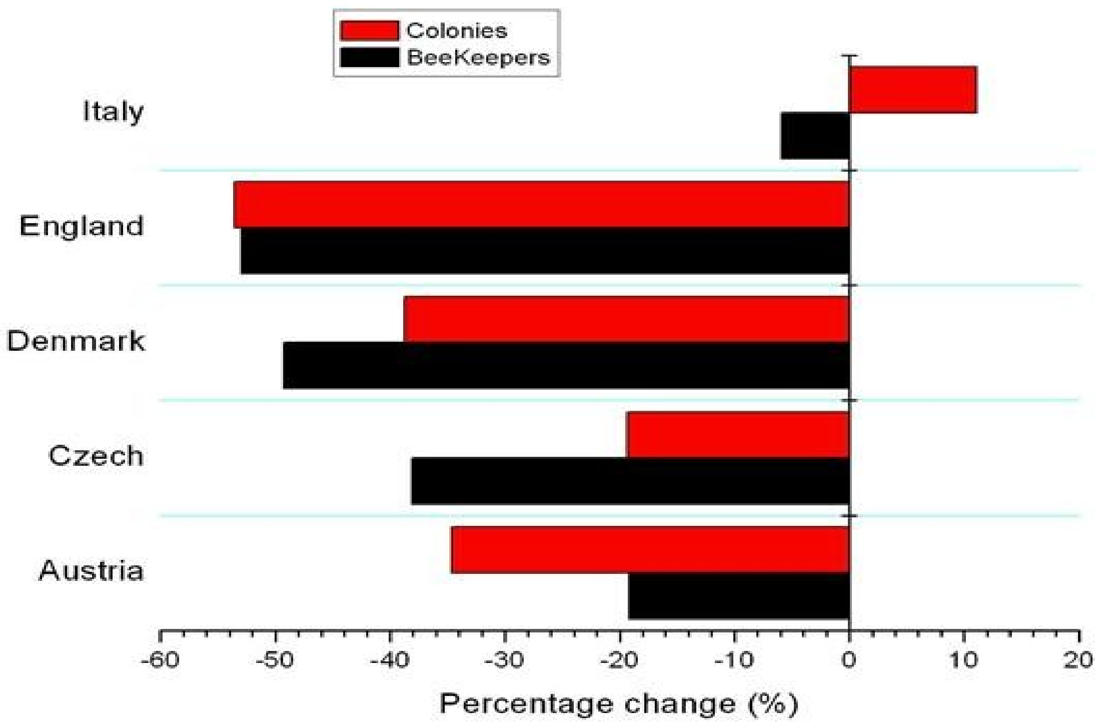

Figure 3.1: Declines of managed honeybees and bee keepers in Europe (Produced with permission, data provided by Potts et al., (in review, *Journal of Apicultural Research*)

The efficacy of *V. destructor* treatments appears to be declining too, either because the mites appear to have developed resistance or *A. mellifera* have become more susceptible. Mike Brown reported that with a recent recovery in the popularity of bee keeping by a new generation unfamiliar with best practices, anti-*V. destructor* treatments have been over- or mis-used, causing increased treatment resistance in mites and a subsequent rise in the virulence and pervasiveness of the parasite. Brown said that in continental Europe, colony collapses from *V. destructor* have been reported due to a failure to monitor closely and to detect the growing resistance of the pathogen to treatment.

1.3: V. destructor treatments

There are also theories that the medications used to treat bees for *V. destructor* are themselves causing problems. It is true that pyrethroids are toxic to bees, but there is a

1000-fold difference in the toxicity levels between mites and bees. However the substance bio-accumulates in bees and wax, and pyrethroid traces have been found in hive products. Moreover although the natural life-span of a single hive is 3-4 years, new colonies will be established during that time when bees swarm. Any existing factors in the old hive, including bio-accumulation of toxins, will be transferred to the new hive. Similarly, robber bees will transmit existing conditions from the hive they rob to their own hive[17].

2.1: Nosema – history and definition

Nosema is an intracellular microsporidian parasite which attacks the mid-guts of adult honey bees (Le Conte and Navajas, 2008). The two main species are *N. apis* and *N. ceranae.* It can be difficult to detect because there are no obvious external symptoms. However *Nosema* infection causes digestive problems, shortens the life span of the bee and thus decreases the population of the colony and reduces honey production. *N. ceranae* also causes increased winter mortality. Adult bees contract the disease when they eat contaminated food and during cleaning activities where material from infected bees is present (Higes et al., 2006).

2.1.1: Dysentery

The main feature of *Nosema*, dysentery can occur when honey bees have been unable to make cleansing flights for long periods of time, for example during cold or wet weather, and when there is a large quantity of indigestible material in the honey[18]. Bees prefer to void in flight but when confined they will void in the hive. If large numbers of the colony do the same thing, food stores become contaminated and the hive quickly collapses and dies. If the bees conduct cleansing flights at low temperatures their wing muscles cannot function effectively. In these cases they will die outside the hive.

17 Personal communication, Richard Ball

18 Dark honey contains a greater amount of indigestible material. bee keepers can remove the honey during the winter and replace it with sugar syrup.

2.2: Extent of Nosema

Nosema is one of the most common diseases in adult honey bees. Historically only *N. apis* had been found in *A. mellifera*. However recently *N. ceranae* has been detected in the European honey bee first in Taiwan and Spain (Higes et al., 2006) and subsequently worldwide (Klee et al., 2007). Köglberger et al., 2006 referred in passing to the detection of *N. ceranae* in apiaries in Germany and also found *Nosema* spores in 57% of apiaries tested in Austria in May, 46% in July, 33% in September and 31% in winter (November-December) samples in 2005-2006. By comparison 69% of deceased hives were found to be infected with *Nosema* in the sample period May-July 2004 and 11% infection rate in winter 2003-2004 (Köglberger et al., 2006). Blanchard et al., 2008 found that 30% of studied apiaries in France were infected with *Nosemosis* (*N. apis* and/or *N. ceranae*) and that out of the 5 apiaries testing positive for IAPV, 3 also tested positive for *Nosema*.

40% of US summer colonies surveyed by Rogers in 2006-2007 were found to have *Nosema* spores. Chen et al., 2007 question whether or not *N. ceranae* is a new emerging pathogen for *A. mellifera* in the US, concluding that the disease was found to be more widespread in the US than previously thought.

3.1: Foulbrood – history and definition

3.1.1: American foulbrood (AFB)

AFB is a highly contagious bacterial pathogenic disease which occurs across the globe and is caused by the spore-forming bacterium *Paenibacillus* larvae. The name refers only to the place it was first detected, not to its geographic distribution. As workers conduct normal cleaning operations of infected cells they inadvertently spread the spores throughout the colony. Brood food becomes contaminated. Nectar which is stored inside contaminated cells also contains spores and so honey becomes infected. As the colony weakens they may become vulnerable to raids by robber bees, who take infected honey back to their own hives and so spread the infection. AFB spores are highly resistant and can persist for over 40 years in both honey and in bee keeping equipment which is why many apiary inspectors recommend hives diseased with AFB to be either burned completely or flame scorched. The disease only affects bee larvae and not adults but it is highly contagious and lethal to bee brood (Beebase, UK).

3.1.2.: European foulbrood (EFB)

This is also a bacterium which infects the gut of the bee larvae. EFB is caused by *Melissococcus plutonius*, in association with other bacteria (e.g. *Enterococcus faecalis*). It generally establishes in weakened colonies in spring and is at first benign. It is less pernicious than AFB and is normally only dangerous if the colony is already under strain for other reasons. Heavy losses can occur but a supply of pollen from outside the hive is usually sufficient for colonies to overcome the disease (Beebase, UK).

3.2: Extent of Foulbrood

Rogers 2007 found this to be epidemic in some areas studied in the US in 2006-2007 with some resistance to common treatments. The study concluded that unmanaged or poorly managed honey bee colonies have no chance of survival of AFB over the winter.

4.1: Paralysis viruses – history and definition

There are a number of paralysis viruses, all of which can become highly pathogenic to honey bees, causing trembling and paralysis that can be seen at the hive entrance. No treatment is yet widely available although recent reports suggest that scientists in Israel are testing a new cure.

4.1.1: Chronic Bee Paralysis Virus (CBPV)

CBPV is the causal agent of chronic paralysis, which is known to cause high mortality in honeybee colonies (Ball and Bailey, 1997). Bees cluster together, trembling, crawling and unable to fly. Individual bees, some of which may lack hair, stand at the hive entrance. In 2007 the condition had been detected on every continent in the European honeybee *A. mellifera*. It is possible for the virus to exist to a moderate degree without manifesting any symptoms (Blanchard et al., 2008). Because of the presence of *V. destructor* mites in hives showing symptoms of CBPV, it has been suggested that mites may help to disseminate the virus (Celle et al., 2007).

4.1.2: Acute Bee Paralysis Virus (ABPV)

ABPV is part of the same *Dicistroviridae* family (Blanchard et al., 2008) as Israel acute paralysis virus, Kashmir bee virus and Black queen cell virus. Genetically ABPV is closely related to IAPV (Blanchard et al., 2008). It can often be diagnosed in apparently healthy hives, having been transferred by *V. destructor* mites for whom the hives may already have been treated, which explains the otherwise apparently healthy appearance of the hive. The virus then remains and weakens the colony. ABPV and DWV have been confirmed as major contributors to bee mortality in hives infested with the *V. destructor* mite (Bakonyi et al., 2002, Chen et al., 2004, Celle et al., 2007).

4.1.3: Israel Acute Paralysis Virus (IAPV)

Part of the *Dicistroviridae* family (Christian et al., 2005), IAPV was first recognised in Israel in 2004, in the US in 2007 and in France in 2008 (Blanchard et al., 2008). In investigations conducted by Blanchard et al., 2008, all apiaries which tested positive for IAPV also tested positive for *V. destructor,* suggesting a possible vector relationship between the *V. destructor* mite and IAPV.

4.1.4: Kashmir Bee Virus (KBV)

Like *V. destructor*, this is a natural disease of *A. ceranae* which has jumped species and its virulence has been made possible by association with the *V. destructor* mite. Various symptoms include a weakening of the colony with no apparent presence of brood diseases or mites; increasing numbers of dead or dying bees in front of or inside the hive; dying bees may be trembling and display uncoordinated movements; the upper thorax may be darkened and bees may be hairless; recently emerged bees may appear opaque as if pigmentation had not been completed and older bees may appear oily. Like ABPV, KBV is also genetically closely related to IAPV (Blanchard et al., 2008).

4.2: Extent of paralysis viruses

Most paralysis viruses are found to varying degrees all over the world. In Austrian samples taken in 2005 in tests designed to determine the virus status of seemingly healthy bee colonies during different seasons, ABPV was minimal in May (2.1% infection) but high in July (56.5%), September (52.2%) and in winter (38.6%). KBV was not found at all and CBPV was found in only one specimen during the winter period (Köglberger et al, 2006). ABPV was also detected in bees from colonies infested with *V. destructor* and presenting high winter mortality (Bakonyi et al, 2002, Blanchard et al, 2008). 40% of French apiaries studied by Blanchard et al., 2008 were diagnosed with ABPV, sometimes in combination with other diseases. All IAPV-positive apiaries also tested positive for *V. destructor,* three out of the five apiaries testing positive for IAPV also tested positive for *Nosema* and three also tested positive for ABPV. KBV was also detected, but only in the samples where IAPV was found and not in isolation.

5.1: Sacbrood Virus (SBV) – history and definition

SBV is an infectious disease caused by multiplication of the (picorna) *Sacbrood virus* primarily in larvae and prepupae but occasionally also in adult bees. Honeybee larvae change colour from white to grey and eventually to black. Just before pupation, the larvae die. Head development is often retarded, larvae scales are brittle and when removed from their cells they appear as a water-filled sack (MAAREC). It's ability to multiply in young adults without showing obvious outward signs of disease enables it to exist in a colony for a long time. Outbreaks occur most commonly in spring and early summer or when foraging is limited. SBV can be exacerbated by *V. destructor* (Grabensteiner et al., 2000).

5.2: Extent of SBV

SBV appears to be the most common of all the honey bee viruses, appearing in colonies on all continents (B. V. Ball). In the study by the Austrian Agency for Health and Food Safety (AGES) SBV was found at high levels consistently throughout the warm seasons, with 44.7% detection in May, 71.7% in July and 50% in September in the whole of Austria. Low rates were detected during the winter period, at 20.5%.

6.1: Black Queen Cell Virus (BQCV) – history and definition

BQCV is a picornavirus which causes mortality especially in queen prepupae and pupae. It is apparently triggered by *N. apis* infestation (Grabensteiner et al., 2006).

6.2: Extent of BQCV

BQCV has been found to be the most common cause of death of queen larvae in Australian apiaries (Benjeddou et al., 2000). In the AGES study for Austria, BQCV was found at high levels in May (66%) and relatively high in July (45.7%), with moderate levels in September (32.6%) and low levels in winter (13.6%). BQCV was found in both *Nosema*-positive and *Nosema*-negative samples throughout the year.

7.1: Deformed wing virus (DWV) – history and definition

Newly emerged bees displaying wing damage which results in an inability to fly and high mortality. Often discovered to be in conjunction with *V. destructor* (Chen and Siede, 2007) or *Tropilaelaps mercedesae* (Dainat et al., 2009).

7.2: Extent of DWV

This virus is among the most common found in Europe and elsewhere (Blanchard et al., 2008). In most areas it is difficult to find colonies which are not infected, especially in autumn[19]. The AGES study found the highest rates of DWV infection in the winter samples, with 43.2% incidence with the minimum rates in mid summer (10.9% in July). Infection grew from summer towards winter and fell from high rates in winter to moderate levels in spring, with May and September returning 25.5% and 23.9% respectively.

8.1: Stone brood – history and definition

Stone brood is caused by the fungus *Aspergillus flavus* and affects both brood and adults. It is not usually present unless the colony is already weakened by other factors. In 1960 Burnside isolated, cultured and reproduced symptoms similar to CCD with a strain of *Aspergillus* fungi (Underwood and vanEngelsdorp, 2008).

8.2: Extent of Stone brood

Stone brood is widespread in weakened colonies around the world. Matasin et al., 2002 report detection in Croatia in 1982.

19 Personal correspondence, Peter Neumann

9.1: Chalkbrood – history and definition

This is caused by the *Ascosphaera apis* fungus and affects honey bee larvae. Dead larvae inside recently capped cells are covered in a fluffy white mould. Later they become dry and form black or white mummies. When the disease is far enough advanced, these mummies can be easily seen at the entrance to the hive as nurse bees remove them from their cells. *Chalkbrood* has been associated with improper and prolonged use of acaricides containing fluvalinate and also with highly stressed conditions (Matasin et al, 2002).

9.2: Extent of Chalkbrood

Chalkbrood was reported to be ubiquitous in the US in 1975 (Matasin et al., 2002) and subsequently in Hungary and Croatia.

B – Other possible causes of mortality

1. Genetically modified crops

A number of media reports suggest that honey bees could be suffering toxic effects from genetically modified crops, particularly those involving the *Bacillus thuringiensis* (Bt) toxin (Bees, Honey and Genetically Modified Crops, 2001, Friends of the Earth, Genetically Modified Crops Implicated in Honeybee Colony Collapse Disorder, Natural News, 2009). However Morse et al., 2006 consider the need for insecticides in non-genetically modified crops and find that use of genetically modified crops have a less negative effect on the environment in terms of toxicity.

2. Pesticides

Pesticides have potential, mostly neurotoxic, consequences on the behavioural patterns of honey bees. Complex behaviours govern foraging, the structure and construction of the hive, the maintenance of temperature and humidity for the brood by nurse bees and for the preservation of honey and pollen, the assessment of locations for a new swarm and the protection of the hive against predators. These innate behavioural patterns, which ensure a hive's survival, depend on the integrity of a nervous system where each synapse is important. Pesticides may affect these behavioural patterns (Rortais et al., 2004, Kievits, 2007). Because bees forage in a large circumference around the hive, they can easily fly into areas that are being or have recently been sprayed.

Moreover pesticides are often implicated in honeybee mortality because many of the chemicals used on the plants which are bee-pollinated are toxic to bees. A study by Cornell University in 1993 points out the highly variable LD50 doses of Phosmet - a non-systemic organophosphate insecticide (Imidan 50WP in Europe) used on pome fruit (apples, pears, quince etc) and potatoes in Southern Europe - in mammals and concludes that the pesticide is very toxic to honeybees[20].

Although tests usually focus on finding the dose which is lethal to honeybees, sub-lethal doses can also cause problems, either because they bio-accumulate to lethal levels or because they have behavioural effects. Colonies placed near crops of sunflowers treated with imidacloprid, a neonicotinoid systemic insecticide, displayed disrupted foraging. Colonies dwindled and died as foragers failed to return to the hive (Bortolotti et al., 2003). Bee keepers have raised concerns over the toxicity of systemic insecticides for honey bees, given that in order to work as prescribed, the active substance must remain active long term and in the parts of flowers visited by foraging bees.

Waller et al (1984) found that the possibility of chemical transfer into the hive is higher with systemic insecticides than with non-systemic insecticides. Schmuck et al (2001)

20 A Pesticide Information Project of Cooperative Extension Offices of Cornell University, Michigan State University, Oregon State University, and University of California at Davis, 1993.

and Bonmatin (2003) found that although the concentration levels found in nectar and pollen are low, the relative toxicity of the new molecules of systemic insecticides and their metabolites are very much higher than those of the past generation of pesticides. When honeybees consume even small amounts of pesticides they can show sub-lethal toxic effects. These might be cognitive disruptions and behaviours, including orientation abilities, foraging and food collection, interfering with the ability of the bee to return to the hive. Because of the mutual dependency of hives and bees, even sub-lethal effects might have lethal consequences.

In the spring of 2008, certain regions of Southern Germany reported abnormal bee deaths of approximately 11,000 colonies, which the Federal Office of Consumer Protection and Food Safety (BVL) in Germany said was caused by Clothianidin, an insecticide used to treat maize seed and rapeseed. The insecticide was found not to have properly adhered to the seeds in some batches, causing it to spread. The sowing equipment was also thought to contributing to the spread of the pesticide and subsequent exposure to bees.

EU laws require thorough and extensive toxicity tests for pesticides. However in order to avoid bee losses, it appear that a) certain active substances are more problematic for pollinating insects and b) improper handling may have unforeseen effects on bees. An increased understanding of those factors is important for future legislative actions on bee protection.

3. *Wax moth*

Wax moths do not directly attack bees or their larvae. However they eat the honeycomb wax. As they destroy the honeycomb, stored honey can spill out or become contaminated and this can kill bee larvae. Under normal conditions in the temperate conditions that prevail in much of Europe and the US most hives will only have serious problems with wax moths if the colony is already weakened from other factors (ALP).

4. *Small hive beetle*

Native to Africa south of the Sahara, the small hive beetle has been detected in the US, Australia and Portugal[21]. Damage to colonies is primarily due to the beetle larvae tunnelling through honeycomb with stored pollen or honey. They damage the comb and can destroy the capped brood. Honey becomes contaminated by larvae defecation and fermentation due to larvae activity (ALP). The beetle is acclimatised to relatively warm, dry conditions and so is generally thought unlikely to spread throughout Northern Europe without substantial climate change[22]. However imports of bees into Europe from affected zones have nonetheless been halted as a preventative measure.

5. *Tropilaelaps mite*

Like *V. destructor*, the *Tropilaelaps* mite is an ectoparasite and a vector of various honey bee diseases. It is at present found only in Asia and one introduction has been reported from Africa (Ellis and Munn, 2005) is considered to be more dangerous to *A. mellifera* than *V. destructor.* It is found both in combination with *V. destructor* and in isolation. Infestations can rapidly lead to colony death (Dainat et al., 2009, Forsgren et al., 2008).

6. Handling and chilled brood

Bee mortality can be caused by poor handling by bee keepers failing to check hives for pathogens or failing to provide feed. Some bee keepers may believe a natural, hands-free approach is best and decide not to check hives or treat for normal afflictions, which can also result in large-scale losses[23]. Chilled brood is a term to describe the consequences of poor handling by the bee keeper. Brood needs to be kept warm. Nurse bees will cluster over the brood to maintain a constant temperature. If a bee

21 Personal correspondence, Peter Neumann

22 Personal correspondence, Kastberger

23 Personal correspondence, Mike Brown

keeper opens the hive on a cold day to inspect the queen or remove honey and prevents nurse bees from clustering for too long, the brood can become chilled, causing deformities or death. Even without mishandling by bee keepers, however, a sudden drop in temperature during the spring when the colony is becoming active and building its strength can have the same effect.

7. Breeding

Le Conte and Navajas (2008) say that the hybrids and other races that are imported into France, for example, (a practice that is long-established) are often less well-adapted and more susceptible to disease than local races. A bee keeper in Aix-en-Provence reported to the BBC in 2003 (Plight of France's Honey Bee) that in the past, bee keepers kept local species of honey bee which were well-adapted to the area. More recently, some keepers have imported alien species and cross-bred them with local breeds in order to increase honey yield. However without historical data it is difficult to correlate the import of new species with bee losses. Jürgen Tautz of the University of Würzburg believes that intensive bee keeping may be causing problems (Mobile phones and dying bees, Der Spiegel, 2007) . Raising dense colonies of bees allows pathogens to spread more quickly and narrows the genetic pool for a population which weakens the species. Jean-Daniel Charrière (ALP) says bees have been engineered to be increasingly dependent on bee keepers, as well as to be more docile. An externality of these intended results is that the bees have also become genetically and physically weaker.

> “Most of the 19,000 bee keepers in Switzerland do it as a hobby. If we keep losing bees for the next few years they could become discouraged and drop everything. Bees, at least those in the Northern Alps, cannot survive without bee keepers.” (Concern mounts over falling bee population, 2007, swissinfo.org)
> **Jean-Daniel Charrière**

Tautz (German bee populations collapse, Deutsche Welle, 2005) also believes the practice of breeding docile bees, which are easy for bee keepers to handle, also creates a weak immune system, making them vulnerable to parasites. According to Tautz the number of mites necessary to destroy a hive in 2008 was one tenth the number it took in 1998. An imbalanced diet due to monoculture has also weakened their resistance to disease. And they are less able to resist the effects of the insecticides used to support monoculture.

8. Monoculture and malnutrition

When farmers spray wild flowers as weeds and favour monoculture, the range of nutritional food for bees shrinks. Where monoculture is extreme and bees are brought in under contract pollination conditions, they can fail to get the nutritional range they need. However malnutrition can also occur during the winter months if bee keepers fail to provide enough feed in the hive[24].

Monocultures such as those found in large areas of the US are not generally found in Europe. However impacts on biodiversity from monoculture, fertilisers, pesticides and forest clearing were mentioned as particular causes for concern in a speech by Stavros Dimas, Member of the European Commission, Responsible for the Environment on a sustainable bio fuels policy for the EU in. Monoculture is highlighted as a danger of CAP set aside policy, if land conversion is not carefully monitored, particularly in France and Germany (A Sustainable Bio-Fuels Policy for the European Union, Goethe Institute, 07/06/2006).

The Italian region of Lombardi has a strong tendency towards monoculture (GFA Consulting Group), but this is in cereals and milk products, neither of which affects bee foraging in terms of forced pollination services but could have an impact in a reduction of habitat if bees are present in the area. In the Marche region of central eastern Italy, intensive agricultural production with a loss of crop rotation and increasing monoculture

24 Personal correspondence, Richard Ball, Mike Brown

are reported as recognised environmental threats by the GFA Consulting Group which conducted a survey on Italian agriculture and rural development for the European Commission. Monoculture plantations of nut and carob trees in Sicily and large-scale, invasive monoculture in the north east region of Veneto are reported by the GFA Consulting Group. And agriculture in the Valenciana region of Spain has a tendency for citrus monoculture (European Union Rural Development Plan – 5 Regions of Spain).

9. Climate and climate change

Local changes in climate affect honey bees on several levels. Temperature, storm frequency, humidity and precipitation have a direct effect on the behaviour and physiology of honey bees. Changes in climate can affect the quality of floral environments, either increasing or decreasing the capacity of a colony to harvest and develop. Climate alterations can affect the distribution ranges of honey bees and, if the difference is severe enough, can even change or introduce new competitive relationships, potentially with associated parasites and pathogens.

A. mellifera has the potential to adapt to hot climates over time but the rate of climate change predicted by the IPCC 2007 may not allow for this (IPCC Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change). The European honey bee is highly adaptable even in the face of climate change, humans play a decisive role in helping honey bees to survive in hostile environments and in preserving their biodiversity. Global warming conditions have been shown to encourage the growth of the Africanised honey bee outside its current distribution range, making it more likely to form feral colonies and more able to adapt to changes than other bee species. This could present a threat to *A. mellifera.* If bee ecotypes are no longer suited to their biotypes, feral colonies will need to evolve rapidly to survive without human assistance (Le Conte and Navajas, 2008).

10. Electromagnetic radiation

The role of electromagnetic radiation in bee mortality has been examined (Kievits, 2007) and is a popular topic in the media (Electronic smog 'is disrupting nature on a massive scale', 2008, The Independent). Bees experimentally exposed to electromagnetic waves became disoriented and exposed hives lost forager bees. The question is to what extent can electromagnetic waves disrupt the normal behaviour of honey bees, including orientation, foraging and swarming. In reality bees are not exposed to waves of the intensity used in the experiment and there was found to be no large-scale correlation between bee mortalities and electromagnetic radiation (Kievits, 2007)[25].

Dr Ulrich Warnke, University of Saarland (Electronic smog 'is disrupting nature on a massive scale', 2008, The Independent), states that bees exposed to electrical fields generated by power lines have been seen to kill each other and their young and that those exposed to signals in the same range as mobile phones lose much of their homing ability[26].

Der Spiegel reported in 2007 (Mobile phones and dying bees) that researchers at the University of Koblenz-Landau studied the influence of high-frequency radiation on bee populations. Kimmel et al., 2007, of the University of Koblenz-Landau, examined the influences on honeybees of electromagnetic radiation during two months in 2006 and found that non-ionizing radiation does have a negative effect on bees' ability to return to the hive. Der Spielgel said it is still unknown whether electromagnetic signals have a potential effect on bees. However the conclusion of the study was that further research is warranted.

Jürgen Tautz expresses scepticism about the electromagnetism theory but also believes it should be further researched on the basis that honey bees are highly sensitive to

25 Hives in urban zones where there is a higher density of mobile phone aerials are noted to be usually healthy while hives affected by CCD tend to be in rural areas

26 I report this for completeness only. There is scepticism of the role of electromagnetism as a cause of CCD among entomologists I have spoken to.

changes in the earth's magnetic field. He believes however that other stress factors would first have to weaken bees in order for electromagnetic radiation to have a significant effect.

11. Marie Celeste Syndrome

This is the term used by some bee inspectors in the UK to describe CCD-like symptoms. Unable to fly, bees have been seen walking out of the hive, sometimes leaving a queen, food and capped brood, sometimes not. They disperse quickly, leaving no dead bodies behind. Richard Ball described the same symptoms in a hive in England. Figure 3.2 shows the hive after the desertion event:

Figure 3.2: Hive after desertion event (Source: Richard Ball 2009)

Recent colony losses or CCD

The symptoms of many recent colony losses are unusual, especially the presence of the queen and capped brood without the rest of the colony[27]. The normal activity of a hive is focussed on the queen. When a colony leaves a hive under normal circumstances it is highly planned and the queen will stop laying around two weeks before the hive swarms. This is because any capped brood would then be left behind. Sometimes, under conditions of extreme stress, a colony can organise and swarm within an hour[28] but the queen will be at the centre of this. For both the queen and capped brood to be abandoned suggests a degree of spontaneity that is outside the normal observed behaviour of honeybees. This is a key characteristic of what is being called CCD.

Whether recent colony mortalities are an entirely new phenomenon or are a combination of existing stress factors in various packages is hotly debated. A number of bee experts, academics and scientists believe that the bee deaths are due not to one single factor but to a combination of factors which are weakening honey bees' resistance to all kinds of threats, as when the human immune system is compromised, a simple cold or a bout of pneumonia may prove fatal[29].

Jamie Ellis believes that there is no single cause of colony collapses, although he does believe that *V. destructor* is a principle factor. The weakening of the immune response caused by *V. destructor*, he says, is also causing bees to be less resistant to pesticide toxicity rather than the pesticides themselves becoming more toxic. Agence française de sécurité sanitaire des aliments (afssa) concludes that the role of *V. destructor* is a major apparent contributor to observed losses in France in 2005-2006. Although there are no national statistics, the evidence in the affected hives points to the gravity and ubiquity of *V. destructor* (afssa).

Rogers concludes that colonies are dying because of Multiple and Various Causative

27 Personal correspondence, Richard Ball
28 Personal correspondence, Kastberger
29 Personal correspondence, Jamie Ellis

Agents Syndrome (MVCAS). Stress and malnutrition from monoculture and large-scale contract pollination services, particularly in the US, long-term exposure to *V. destructor*, increasing resistance to anti-*V. destructor* treatments, and the transmission of other viruses through *V. destructor* and *Tropilaelaps* mites have all combined to lower the resistance of *A. mellifera* to diseases and pathogens. In Wallonia in Southern Belgium, Bach and Haubruge found that *V. destructor,* American foulbrood and the quantity of food in over-wintering hives were the influencing factors on colony collapses.

Williams et al., 2007 speculate that *N. ceranae* may be one of many factors contributing to present elevated levels of bee mortality in Canada and the central US. They say that recent survey and experimental work suggests *N. ceranae* is a serious threat to the global bee keeping industry. Le Conte and Navajas postulate that sharply falling honey bee numbers in Spain are caused by *N. ceranae*. But Chen et al., 2007 say there is no direct correlation between *Nosema* infection and CCD and recent work has concluded that *N. ceranae* is not the likely cause of colony collapses (Underwood and vanEngelsdorp, 2008).

Paralysis viruses, particularly IAPV, have been correlated with colony losses in the US (Cox-Foster et al., 2007). However Blanchard et al., 2008 stated that it was not possible to establish a causal relationship between IAPV and the severe winter losses which occurred in France, unlike the CCD-related cases described by Cox-Foster et al., 2007. The exact role of IAPV in winter mortalities in France are not known. ABPV is thought to be too virulent to be the primary cause of major colony collapses because the infected bees die before contaminating other hosts or vectors (Kievits, 2007).

In 1993 bee keepers in France notified authorities that their bees were disappearing. The symptoms seemed to match those of major colony collapses elsewhere[30]. Losses were first noticed on sunflowers treated with Gaucho but continued even when new, untreated crops were sown in rotation on the same land. It was suspected that contamination had occurred, because the pesticides concerned are persistent in soils

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30 Symptoms did vary, however. In some cases bees did not disappear but clustered together in shivering heaps on flowers or next to the hive. Foraging stopped, they swarmed before building royal cells, many fertilisations failed, and some swarms abandoned the queen.

(Kievits, 2007). However the role of systemic insecticides may have been exaggerated by the media: AFSSA found that since the use of imidacloprid for the coating of sunflower seeds had been forbidden since 1999 and imidacloprid and fipronil used in maize seeds were banned from 2004, significant agricultural pesticide residues were not found in any of the apiaries (German bee populations collapse, 2008, Deutsche Welle). The ban on imidacloprid and fipronil in France seemed to stabilize populations, initially supporting the theory that systemic insecticide were causing elevated bee mortality. However in 2008 end-of-winter mortality rates went up again with up to 60% of hives reported missing (German bee populations collapse, 2008, Deutsche Welle), suggesting at least that other factors may be involved, if not ruling out the role of pesticides in the mortality events. Rogers says that there is no evidence to date that links any single PPP to the high levels of bee losses seen in many countries, however given the sub-lethal and bio-accumulative effects, the exact role of pesticides on recent colony losses is difficult to establish.

The role of monoculture in bee mortalities is also difficult to determine without knowing the exact locations of large-scale colony deaths. High mortality has been reported in Italy, but a correlation with Italian monoculture cannot be established without geographic determination of colony collapses. The relative seriousness and scale of the phenomenon in the US has been attributed to intensive apiculture and contract pollination. Hives will be transported hundreds of miles to work on a single-crop orchard for a week, before being transported again to repeat the cycle a number of times. This causes both stress and malnutrition which weaken the bees to further threats[31].

In 2003 losses in France were connected to the heat wave in the same year with honey production that year reportedly reduced by half and mortality up to 60% (Plight of France's honey bee, 2003, BBC). This was at least partly attributed to the effect of the heat on plants that would normally be pollen sources for the bees. Other recent bee mortalities could also be influenced by climatic conditions. In the UK in the last two years summers have been comparatively cold and wet, reducing the ability of bees to

31 Personal correspondence, Kastberger

forage, conduct cleaning flights and for the queen to mate[32]. A queen will mate several times in flight. If she is restricted in her mating flights, she will lay a disproportionate number of drones, whose only purpose is more mating. With a lack of worker bees, the colony becomes unsustainable. Wet or cold weather and close confinement also allows faster spread of disease and the spread of dysentery.

The scale and probable cause of colony losses is difficult to verify without hard data. It would appear that *V. destructor* plays an important role, with other viruses, particularly paralysis viruses, implicated. Other factors could also play a role, but without reliable, comparable data, this cannot be determined.

32 Personal correspondence, Richard Ball

IV: Bee monitoring system

Very little is clear in terms of what is causing bee deaths although a number of diseases and conditions seem to overlap. Data are very mixed, following different assumptions and protocols and with huge gaps. The picture we get is one of confusion. Measuring bee losses accurately is vital for us to know whether or not we have a problem. And clear, comparable data are essential for formulating proportionate policy and for directing research funding to the areas which need it.

Moreover there are a number of conflicting psychological factors which need to be taken into account in building a honey bee monitoring system. A common theme among all bee keepers is a sense of fascination and admiration towards the bees, and a sense of connection. However with much larger operations the relationship can become more businesslike, the bees being viewed more as commodities. This may result in laissez-faire attitudes, which may even be mercenary or cavalier towards the bees, and a feeling that certain numbers are expendable. But in other cases it can result in a greater sense of responsibility because the business depends on their welfare. These seemingly contradictory attitudes need to be taken into account when building an accurate monitoring system.

This chapter will examine the challenges in building a honey bee monitoring system.

The problem of measurement

Because of a lack of archived data, we don't know the relative stresses that each factor causes so future actions are hard to structure. Unfortunately data collection is very difficult, particularly as there is no comprehensive register of all bee keepers in Europe. At least one and sometimes several bee keeping associations exist in all EU member states. They tend to be regional. Some gather information on the normal or anomalous status of colonies, others do not. Some, which have in the past been sources of data and research, have closed in recent years, apparently because of a lack of funding or membership.

In the US the situation is similarly diverse. The state of Florida requires anyone keeping bees to register on a state-wide database, with the result that data collection here is good. But Florida is the only US state to legally insist on such a register[33]. There are discussions as to whether this should also be made mandatory in Europe, however several barriers exist. People can be reluctant for their names to be on data bases although this can vary according to their location, history and culture. In Britain, resentment and a perception of lack of credibility of data-collecting authorities grew after a series of problems with the management of Foot-and-Mouth Disease and BSE and so many bee keepers tend to be unwilling to share information on the condition of their colonies with rural and agricultural agencies. Moreover the British government's response to the 9-11and, specifically, the July 2005 bombings has lead to a feeling among many Britons of being intrusively observed. There have also been a number of instances in recent years of public data being leaked. All of this have resulted in a general suspicion about the way authorities use and fail to protect data.

This combination of factors makes it difficult to pull together the information necessary to gauge the problem and formulate a response. The problems of measurement are:

- We need to know what we want to measure
- We need to understand the motivations of bee keepers
- Appealing to their sense of conservation may be counter productive
- We need to know who to speak to
- Many will resist new practices
- We need to give the right incentives

What we need to measure

It appears that *V. destructor* is an important factor in bee mortalities and that other factors are implicated as a result of initial weakening of colonies by *V. destructor*. Further weakening may be caused by handling, stress and malnutrition, increasing

33 Personal correspondence, Jamie Ellis

vulnerability to infection by *V. destructor* and other factors. However a major barrier in understanding this topic is the lack of collated, comprehensive, historical data on bee mortality. While recent selective information is available on losses or incidence (sometimes without complete loss) in specific countries from specific conditions, data on overall losses, where they exist, are limited by country and often go back just a few years. Consistent data on normal, healthy colony cycles and behaviour is needed to compare with existing patchy data on isolated losses. Only then will it be possible to determine the scale of current losses.

The challenge of persuading bee keepers to share their information

COLOSS (Prevention of honey bee colony losses), an international COST-funded network (Action FA0803) compiling data on bee losses in Europe, China and the US, is working to establish international standards for monitoring and diagnosis, comparable between countries and years. However data are contingent on a number of factors inherent to the nature of bee keeping. Bee keeping itself is highly labour intensive and the collection of data relies on the cooperation of individuals. Their willingness to supply the necessary information varies according to personality, personal experience and motivations, perceived risk and perception of authority and regional legislative application. But in order to get a balanced picture, it is not necessary – or possible - to survey every bee keeper: a sample is sufficient if represents the various profiles of different kinds of bee keepers.

For example, hobby bee keepers tend to adhere to a general profile. Hobbyists are often above 50 years old and, in Britain at least, are roughly equally split between men and women. Men will often start bee keeping operations and women, who tend to be more intuitive with brood cycles and gentler in handling, will largely take over, with men helping with the heavy work Commercial bee keeping tends to be male dominated because of the heavy lifting involved. Young bee keepers are relatively rare[34].

34 Personal correspondence, John Howatt

Motivations vary

The profile of bee keepers depends on the scale of their operations and their motivation and understanding the sources of motivation is important in attempting to explain the adoption of any environmentally-related practice (Toma and Mathijs., 2007). Motivations for bee keeping may vary from ecological conservation, lifestyle, social or financial[35]. Those who are motivated by the concept of conservation tend to see their role as ecological custodians. These bee keepers are often motivated by enjoyment of the work and the lifestyle. Those whose motivations are financial logically want to generate income and support or grow assets. Social motivations include a wish to be seen as 'different'. According to interviews carried out in the UK, bee keeping is seen by some as a way to escape societal uniformity Some want to be involved in producing food because they like the idea of self-sufficiency or locally grown produce. Some want to ensure pollination for the crops they are growing. And many are simply fascinated by the idea of bees and what they represent. The secretary of the British Bee Farmers' Association, when asked why he keeps bees, said 'it's not for the honey – I don't even like honey. I do it because bees are fascinating'. Others have a vision of bee keeping as a 'country pursuit', balancing pollination services of their garden crops with the preservation of biodiversity. Some of these people also take part in voluntary movements to re-establish other traditional country practices like hedge-laying and dry-stone-walling. The practice often seems to be associated with an holistic view of nature and the balance of life. The key is that bee keepers are not 'average' members of society. This can have important implications for those who want to monitor bee activity.

Some bee keepers who fall into this category are happy to take part in surveys while others are too busy or don't see it as a priority. But many don't want to be bothered or are suspicious that the state is being nosey about their private activities. They fear that being registered on a national database will make their personal information accessible to government bodies. This fear is often groundless when pursued, since the information being supplied is often already registered or available on driving licenses. However this largely emotional response is an important consideration in planning

35 Personal correspondence with Richard Ball, John Howatt and various bee keepers

monitoring activities. Bee keepers in Britain also worry that such information will be used to charge them more income tax, if they are producing and selling honey[36].

Small-scale bee keepers are often retired professionals or workers who enjoy bee keeping in the same way that they might enjoy gardening. They enjoy their free time away from the voice of authority. Although they are often willing to receive advice from associations, this may make them reluctant to be overseen by a monitoring system. Small-scale bee keepers and the amateur associations representing them can be critical of commercial operations and practices.

Another common theme, although one which has different implications depending on the type of bee keeper, is a history with bees. Hobby bee keepers often say their interest in bees stems from childhood when an uncle or parents kept bees. With the distractions of education, career and family it was not until middle age or retirement that it occurred to them to take it up themselves. These people can view their hobby as the rediscovery of an old craft. They are often keen to learn by engaging with other bee keepers and through associations. They can therefore be very responsive and eager to help but their practices and information can be flawed due to inexperience and personal bias. Hobby bee keepers with low numbers of hives tend to have more oversight and sense of responsibility towards their bees. Those who are retired may have more time and willingness to respond to surveys but they may also feel unwilling to submit detailed information about their practices, having perhaps been answerable to an institution during their working lives and now, finally, being 'free', want to be free of such responsibilities too.

Commercial bee keepers present additional challenges

Commercial or semi-commercial bee keepers (40+ hives) tend to have slightly different motivations to small-scale hobby bee keepers with two or three hives. Commercial bee keepers can be ex-hobbyists whose operations grew 'organically'. They are often

36 Personal correspondence with John Howatt

following several generations of bee keepers. Their income comes from bees and they have inherited expertise. While invaluable, this expertise can make them reluctant to be part of an overseeing body which might try to tell them how to run their operations. Large commercial enterprises can also mean the bee keeper has less time to monitor each hive and so diseases and other disorders can go undetected until they get out of hand. However bee keeping is at least partly, if not fully, their livelihood and so it's in their interest to treat the bees carefully. What the combination of these factors would mean in the context of a monitoring system is unclear – perhaps it would depend on the perception of the role of the system. If made clear that the beneficiaries are the bees and therefore the bee keepers, this could engage their cooperation. With the bee keepers who have inherited the craft, this could still fail to be an incentive because they would feel that they still know best and that they don't need outside interference. Past behaviour is one of the most intractable barriers to changing behaviour (Kollmuss and Agyeman, 2002).

Appealing to their sense of conservation may be counter-productive

The concept of conservation as a motivating factor for bee keeping could be counter-productive when the perception is anthropocentric, ignoring or misunderstanding the role and needs of eco-systems and rather seeing nature in a romanticised, humanistic way. This can be the case with 'green' bee keepers who reject the use of chemicals for treating infections, avoid inspecting hives , believing it causes stress to the bees, and do not collect honey for the same reasons, which can lead to the spread of infection in the hive when pathogens are present. 'Green' bee keeping bodies are often particularly critical of what they perceive as intensive, exploitative and chemical-happy handling. However it is interesting to note that the British Bee Farmers' Association recorded half the colony losses compared to those reported by the amateur Bee Beekeepers' Association (BBKA), whose members include 'green' bee keepers. Such statistics can be misleading, of course.

This conservationist perspective can be both damaging in itself and can lead the parties involved to reject information or influence. However generally those whose motivations are concerned with conservation and lifestyle issues are also motivated to adopt conservation practices because this is in line with their attitudes and values (Greiner et al., 2008) These are core ethics to be considered when formulating a monitoring system.

Conversely, farmers who are strongly motivated by economic or financial and social goals appear to be influenced by external drivers like government incentives to implement conservation practices. This has been noted by the Swiss federal government, who provide financial assistance to farmers who set aside land as ecological conservation zones. However those who generate income from bee farming have an extra incentive to make sure their bees are healthy, and so may be willing to cooperate with a monitoring system in ways that hobbyists are not. It is essential to know who bee keepers are in order to get information and cooperation from them.

We don't know who to ask

Not knowing who or where bee keepers are makes it difficult to collect information. In many countries, the authorities rely on voluntary registration and participation. When it is known where bee keepers are, many will not want to participate in surveys because they see them as a waste of their time or they resent being asked to provide a third-party with information about what they do in their own time.

Bee keeping associations often find greater willingness in their members to provide information, however many bee keepers are unwilling to join associations and register their operations for a number of reasons. The motivations for joining an association are generally information and advice, particularly at the beginning (some bee keepers leave the association after learning the basics because they feel they no longer need advice) and in some cases for insurance[37], particularly for insuring food produce and against foulbrood..

37 Personal correspondence, John Howatt and Richard Ball

Perception of risk affects behaviour

We can gain an insight into the probable perceptions of bee keepers by examining the work of Greiner et al., 2008. The adoption by farmers of conservation practices is normally influenced by the characteristics and circumstances of the individual farmer and of the practice in question, particularly its relative advantage over existing practices. A farmer will adopt a new practice if it is clear that this will help them to achieve their goals, be they economic, social or environmental. The choice to do so carries risks because alternative courses of action have uncertain consequences. Beliefs about the probability of uncertain outcomes and evaluation of possible consequences are entirely personal (Anderson et al., 1988). There appears to be a collation between risk perception and preferences and information (Abadi Ghadim et al., 2005). So the likely response of bee keepers to a monitoring system or advice on their practices would depend partly on personal experience and character and partly on the way the system is portrayed and information is given. People commonly form risk perceptions through intuition, unconscious quick, emotional 'gut instinct' rather than conscious, measured thought (Gardner, 2008). However land management decisions are likely to be considered rather than rash and bee keepers whose income depends on bees can also tend towards considered reaction. Particular effort in a bee monitoring system would need to be focused on bee keepers who would tend towards more human, emotional reactions because of their particular profile. Greiner et al., 2008 found that perceptions about the riskiness of new technologies and techniques are of particular importance in the design of effective and efficient conservation policies and programmes, and that risk perceptions and risk management strategies in farmers have strong regional, industry and context connotations (Flaten et al., 2008, Martin, 1996). These factors are critical considerations, given the variable profile of bee keepers and given how broad the geographic scope an effective monitoring system would need to be.

Risk, or the perception of it, may affect behaviour in a variety of ways. Research has indicated that perceived societal risk of global warming influences the intention to address global warming (O'Connor et al., 1999; O'Connor et al., 2002; Bord et al., 2000). A lack of perceived threat, therefore, can be directly related to a lack of behavioural response among the general public.

Similarly, a lack of perceived risk from bee mortality will certainly lead to a certain inertia among bee keepers – to join associations, to implement anti-*V. destructor* practices or treatment, or to respond to monitoring programmes. A general reduction in the risk perception of *V. destructor* may have combined with media elevation of the (supposed) immediate dangers of CCD, new generation pesticides and GM crops. People will react steeply to current events and then gradually reduce their response and risk perception over time, according to Dr Timothy Bates, Professor of Psychology at the University of Edinburgh. Richard Ball says that bee keepers have become bored of the concept of *V. destructor*. There is a tendency to want to attribute colony losses to some reason other than this 25 year old condition. Media stimulus is often very effective in generating a response and bee keepers may be subliminally encouraged by hearing about CCD, pesticides and GM to report losses in such a way that supports these theories[38].

We need to give the right incentives

Clear and realistic information could raise the perception of risk of inaction among bee keepers and therefore stimulate willingness to cooperate. Awareness of the problems should also have a direct impact, since O'Connor et al., 1999 and O'Connor et al., 2002 found that higher levels of education positively influenced willingness to take individual actions to mitigate climate change. Perceived responsibility for causing and tackling climate change were also found to be important, as were institutional relationships (Bibbings, 2004; Darier and Schule, 1999; Stoll-Kleemann et al., 2001).

Many other factors can lead people to give false information and these need to be understood in building a monitoring programme. People often attempt to justify their actions or inactions by distancing themselves from responsibility, which may influence the way bee keepers report bee losses. Not only is CCD new whereas *V. destructor* is old and tired in peoples' minds, but if colonies are dying as a result of something undefined and apparently out of control, there is no question of culpability of the bee

38 Personal correspondence, Dr Timothy Bates, Professor of Psychology, Edinburgh University

keepers themselves, for failing to check for *V. destructor* or otherwise mishandling their bees. Moreover the scale of losses could be misrepresented because only bee keepers experiencing very large losses may be motivated to report them. Those with medium or slightly more than normal losses have less incentive to act. And certain programmes like the German Bee Monitoring system tend to underestimate losses, only including GAP (Good Agricultural Practice) bee keepers and therefore not reflecting median levels of responsibility in bee keepers.

There are also economic incentives. Where compensation programmes are in place, some bee keepers may mis-report numbers or causes of bee deaths for financial gain. Deutsche Welle reported on 17th May 2008 that thousands of German bee keepers were claiming compensation after scientists said the neonicotinoid Clothianidin was responsible for bee deaths in Baden-Württemberg. The Bundesamt für Verbraucherschutz und Lebensmittelsicherheit has suspended authorisation of neonicotinoids because of the perceived hazards to bees (Maize seed may now be treated with "Mesurol flüssig" again) , so there may be grounds for concern over these pesticides. However there is also a clear incentive for bee keepers who have lost some or all of their bees to blame pesticides without checking for other causes like *V. destructor* or mismanagement.

As in most human activities, bee keepers are motivated by other economic considerations too. Clark et al., 2003, Poortinga et al., 2004 and Verplanken et al., 1998 found that in the context of energy use, habit and economic influences appear to be particularly strong. Brandon and Lewis, 1999 found that financial motivations most commonly underline energy conservation. In the study of driving behaviour, Bamberg and Schmidt (2003) found that perceived personal costs and benefits followed by force of habit determined car use whereas environmental conscience did not exert a significant influence. Moreover several findings in the US and Britain (Bord et al., 2004; Fortner et al., 2000; O'Connor et al., 2002) show that individuals are willing to adopt actions that cost nothing or save money – like recycling or improving energy efficiency in the home – but not change their habits or adopt actions that increase their personal costs. Among bee keepers, Richard Ball reported an inclination to resist new and more effective *V. destructor* treatments (Apivar), despite existing treatments being obviously ineffective, on the grounds of cost. Other bee keepers dose their bees less frequently than necessary in order to save money.

These findings suggest that both conscious and sub-conscious drivers, tangible benefits and sometimes emotional reflexes have a strong impact on the way that people naturally behave and make choices. In many cases, concern for the environmental is very low on individuals' priority lists. The interested parties in the problem of bee losses include farmers, scientists, policy makers and economists as well as bee keepers. Many stakeholders view the problem of bee losses as an environmental one, however it's important to remember that individual drivers are often first economic, lifestyle, social or emotional and only later environmental. Higher success in building a monitoring system and shaping policy may derive from targeting these other 'worldly' values than from appealing to parties' morality.

V: Legislative framework

Those responsible for building a monitoring system need to work closely with policy makers to reduce potential legislative gaps. It appears that lack of coordination has meant that there are gaps in legislation where bees are not protected, where conflicts of interest arise or where one law designed to address environmental issues causes damage to honey bees and other pollinators. This chapter will discuss what laws, guidelines and support various governments provide, what some of the conflicts are and it will examine the relevant legislative framework on which a honey bee monitoring system would be built.

A: US

There have been a number of attempts to bring pollinators under legislative framework in the US. A Pollinator Protection Act was introduced to the House of Representatives in March 2007, proposing funding for research into honey bees and CCD, however this bill never passed into law (Pollinator Protection Act). A Senate companion bill was also introduced in June 2007 proposing to support research into CCD, the decline of native bees and their role as pollinators. A Pollinator Habitat Protection Act, addressing continued loss of pollinator habitat due to development and adding pollinators as a specific conservation target was introduced in June 2007 but was never voted on and went no further.

The 2008 Farm Bill, however, did pass into law in May 2008. Among other provisions, the bill pledged US$10 million per annum for the next five years for grants to support research into honeybee and native bee biology, causes and solutions for CCD and bee ecology, toxicology, pathology and physiology. It also pledged US$7.25 million per annum up to 2013 to build research capacity within the USDA Agricultural Research Service to examine CCD and other threats to pollinator health. However none of the research funding language in the Farm Bill is mandatory (Xerces Society Farm Bill 2008

PDF).

B: Europe

The situation is not dissimilar in Europe. In 2008 Astrid Lulling, on behalf of the Committee on Agriculture and Rural Development, submitted a "resolution on the situation in the beekeeping sector" (European parliament resolution B6-0000/2008). The resolution called for further research and funding resources, the establishment of apicultural set-aside and buffer zones around monoculture to protect habitat, to examine further the effects of plant protection products on bees, the research bee diseases and to propose financial aid to apiaries in difficulty from bee mortalities. However like the US protection acts, this resolution has gone no further[39].

However some research is already under way. A European Commission and German Federal Ministry for the Environment initiative (The Economics of Ecosystems & Biodiversity (TEEB)) includes a study on the health and economic importance of bees and other pollinators. This is due for completion in 2010 and may help to guide future policy.

Comparatively little enacted legislation at EU level is directly relevant to the protection or status of honey bees. However two exceptions are the amendment to Council Directive 82/894/EEC on the notification of animal diseases within the Community and the European Parliament Council Decision concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC (P6_TC2-COD(2006)0136).

39 Personal correspondence, Peter Neumann

Notification of animal diseases

In 2003 two parasites were added to the list of notifiable honey bee diseases in the EU, the small hive beetle and the parasitic mite *Tropilaelaps*. To prevent the further introduction and spread of these diseases, imports of live honey bees and bumble bees are, with a few exceptions, not allowed, and imported bees must be examined for signs of the parasites on arrival in the EU (Amendment to Council Directive 82/894/EEC on the notification of animal diseases within the Community). Making the small hive beetle and the *Tropilaelaps* mite notifiable diseases is useful as the *Tropilaelaps* mite in particular may be a future threat (Forsgren et al., 2008, Dainat et al., 2009). However research has shown that existing threats are coming primarily from conditions like *V. destructor, Nosema* and IAPV which are already ubiquitous in Europe. These are not notifiable diseases (Council Directive 82/894/EEC) and are therefore not being checked for in incoming consignments.

The placing of plant protection products on the market

There are issues to be addressed concerning the way compliant levels for pesticides are set, which is directly relevant to the drafting of guidelines, resolutions and ultimately legislation on pesticides. On January 13th 2009 the European Parliament adopted a new resolution on the placing of plant protection products on the market (Amendment to Council Directive 91/414/EEC) . The resolution calls for a specific provision concerning seeds treated with plant protection products to be included in the regulation and declares that Member States should have the possibility of taking protective measures, should they find that treated seeds constitute a serious risk to human or animal health or to the environment. The immediate lethal effects on honey bees of pesticides and the longer-term lethal or sub-lethal impacts[40], are now tested under the regulation but the assessment of bioaccumulation is based on measured data on bioconcentration in aquatic species. Research into the manner of bioaccumulation in honey bees may be necessary since their physiology is not the same as aquatic species (P6_TC2-

40 resulting from chronic exposure over several days of repeated contact or ingestion and the sub-lethal effects which do not kill the insect but which may affect behaviour

COD(2006)0136).

Some initiatives and recommendations are counter-productive

The European Commission's Food Quality and Safety in Europe unit referred in 2007 to the Specific Targeted Research Project (Fewer Chemicals, Higher Yields) to increase maize monoculture across Europe as a way to decrease the use of chemical fertilisers. While this may decrease pesticide exposure for honey bees, it may create another problem with loss of habitat and malnutrition.

A reported lack of entomologists and overall capacity in the European Commission (Kievits, 2007) means that future policy may either contradict or otherwise fall short of what is really required.

Individual states have enacted certain laws and guidelines and have provided national funding for the bee keeping sector.

A number of states in Europe (and at least one in the US, Florida being the only US state which requires all bee keepers to register on a database[41]) set their own independent laws and standards.

For example, in Germany, the Federal Office of Consumer Protection and Food Safety (BVL) took unilateral action (as provided for under the amendment to Council Directive 91/414/EEC) and suspended authorisation for all neonicotinoids in May 2008. Authorisation for the product for treating rapeseed was put back into force in June 2008 after it was found that problems resulting from maize seed were not transferable to rapeseed. Another plant production product, Mesurol flüssig, containing the active substance methiocarb, was re-authorised after suspension in May 2008 with new, restrictive quality standards for treating plants and seeds (Maize seed may now be treated with “Mesurol flüssig” again, BVL, 09/02/2009).

41 Personal correspondence, Jamie Ellis

Germany also has a bee protection ordinance (Verordnung über die Anwendung bienengefährlicher Pflanzenschutzmittel 1992) requiring that plant protection products which pose a threat to bees should be labelled as 'dangerous to bees' and giving directions on the usage in order to minimise the threat to bees.

In Switzerland (which is of course not governed by EU law) the federal government has supported research and training in the bee sector for many years. It finances the research centre at Liebefeld-Posieux with around 900,000 CHF per annum (€591,459) and reserves 100,000-150,000 CHF (€65,717-98,577) per annum for the education of bee keepers and further information campaigns. In March 2007, following concern over recent large-scale bee losses, the Swiss parliament accepted the Motion Gadient (Mo. Conseil national (Gadient). Promouvoir l'apiculture en Suisse) calling for more support for bee keeping in Switzerland. Due to this motion, additional research and education of bee keepers was initiated.

Following the standard set by individual states at EU level

The European Parliament is in some areas following the example set by countries like Switzerland (Plan Bee encourages governments to set aside safe places for bees to buzz). In order to be eligible for agri-environmental payments from the government, Swiss farmers must put aside at least 7% of their land to ecological compensation areas. These are controlled semi-natural habitat where no pesticides or manure can be used and mowing is restricted. The aim is to restore biodiversity (National Report of Switzerland on Environmental Services and Financing for the Protection and Sustainable Use of Water-Related Ecosystems). The Committee on Agriculture and Rural Development forwarded a resolution to the European Parliament in 2008 (European parliament resolution B6-0000/2008) calling for the Commission to encourage the setting up of similar ecological compensation zones in order to ensure sources of pollen and nectar for bees, and the creation of buffer zones around monoculture.

VI: Conclusions and recommendations

The problem with declining honey bee numbers is difficult to verify with hard, reliable, comparable data.

Investigations into reports of rising bee deaths do not seem to have provided any clear indication of obvious causes, either exclusively or in combination. Some deaths have been connected to pesticide exposure, others show evidence of acute paralysis viruses or *Nosema* or *V. destructor* but the causes don't seem to be the same from one case to another, or from one country to another. The findings by the Apiary Inspectors of America (Underwood and vanEngelsdorp, 2008) that 75% of bee losses in 2006-2007 were caused by factors other than what they have termed CCD suggests that a proportionate focus of research funding and scientific investigation should be on other known bee afflictions. This and other research and expert opinion suggests also that the cause of many bee deaths is not a new, unknown threat but an increased vulnerability to threats that have been known for some time.

Such considerations should be taken into account when considering pesticide exposure as a cause of bee mortalities. Our level of understanding about how new generation plant protection products may be dispersed into the environment is insufficient. Nor do we fully understand the consequences of different methods of application. The dosage guidelines and authorisation procedures of some plant protection products may not adequately take into account broad environmental and biodiversity effects of other animals.

In order to address the problems of bee losses we need – and currently lack - hard data to allow policy makers to see clearly where funds and research are needed and where and how direct action is necessary.

In the light of this, this study makes four recommendations:

1. Establish an international monitoring system

The problem with bee losses is not just European but international, requiring collaboration. If each country sets up its own monitoring system independently there are likely to be problems with information sharing and data standardisation. International cooperation among countries which use different methods of data collection, have different standards and cannot be compared, wastes time and money. It is critical that a clear, agreed institutional infrastructure be established from the beginning.

2. Recognise the human factors

Such a monitoring system also needs to take into account the human factors inherent in bee keeping because they affect the way bee keepers interpret and communicate their findings. Clearly only a proportion of bee keepers need to be monitored, but care needs to be taken to ensure the full profile of bee keepers is represented in the sample.

It is important to recognise the motivations which exist for humans generally and different types of bee keepers specifically. An effective monitoring system can be built when it accounts for the sub-conscious and often emotional ways in which people react to new ideas and the relative attractions of tangible benefits compared to intangible, apparently risky alternative actions.

3. Increase understanding of and transparency in the role of chemicals in the environment

The method of applying common farming pesticides, as well as the dosage, may need to be better understood. Moreover it may be necessary for the toxicity testing procedure, which forms the basis for laws on pesticide authorisation, to be independently reviewed with an understanding of the behaviour and physiology of bees, taking into account the differences between systemic and non-systemic insecticides.

4. Recruit an entomologist into the European Commission

There are reportedly no full-time bee experts in the Commission. Without the guidance and advice of entomologists, it is very difficult to ensure appropriate and proportionate policy developments. Interest groups, like chemicals companies whose voices are loud, may otherwise disproportionately influence legislative decisions. Resident experts would help to guide priorities and ensure consistency in the monitoring and protection of honey bees. Some member states' national laws, for example Germany's, specifically cover the protection of bees. This can raise the standard of national legislation on the protection of bees above that of the EU, which may not prioritise appropriately, even where bee and pollinator protection is specifically covered. It would be beneficial to ensure consistent and appropriate legislation on the protection and monitoring of honey bees.

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Work Experience

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