

UNEP EMERGING ISSUES

GLOBAL HONEY BEE COLONY DISORDERS AND OTHER THREATS TO INSECT POLLINATORS



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Adult honey bee with a brown varroa mite riding on the thorax. Photo courtesy of Stephen Ausmus. USDA-ARS, United States, License: public domain

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Worker honey bee pollinating an almond flower in California. Photo courtesy of J. Pettis USDA-ARS, United States.

Introduction

Current evidence demonstrates that a sixth major extinction of biological diversity event is underway¹. The Earth is losing between one and ten percent of biodiversity per decade², mostly due to habitat loss, pest invasion, pollution, over-harvesting and disease³. Certain natural ecosystem services are vital for human societies.

Many fruit, nut, vegetable, legume, and seed crops depend on pollination. Pollination services are provided both by wild, free-living organisms (mainly bees, but also to name a few many butterflies, moths and flies), and by commercially managed bee species. Bees are the predominant and most economically important group of pollinators in most geographical regions.

The Food and Agriculture Organisation of the United Nations (FAO)⁴ estimates that out of some 100 crop species which provide 90% of food worldwide, 71 of these are bee-pollinated. In Europe alone, 84% of the 264 crop species are animal-pollinated and 4 000 vegetable varieties exist thanks to pollination by bees⁵. The production value of one tonne of pollinator-dependent crop is approximately five times higher than one of those crop categories that do not depend on insects⁶.

Has a “pollinator crisis” really been occurring during recent decades, or are these concerns just another sign of global biodiversity decline? Several studies have highlighted different factors leading to the pollinators’ decline that have been observed around the world. This bulletin considers the latest scientific findings and analyses possible answers to this question. As the bee group is the most important pollinator worldwide, this bulletin focuses on the instability of wild and managed bee populations, the driving forces, potential mitigating measures and recommendations.

¹ UNEP 2006, “Global Environment Outlook: environment for development (GEO-4)”. Box 5.3, p.162.

² Wilson E.O, 1999. “The Diversity of Life” (new edition). W.W. Norton & Company, Inc. New-York.

³ Wilcove D.S, Rothstein J, Dubow A, Phillips and Losos E. 1998. “Quantifying threats to imperiled species in the United States”. BioScience, 48: 607-615

⁴ Food and Agriculture Organisation of the U.N. at www.fao.org/ag/magazine/0512sp1.htm

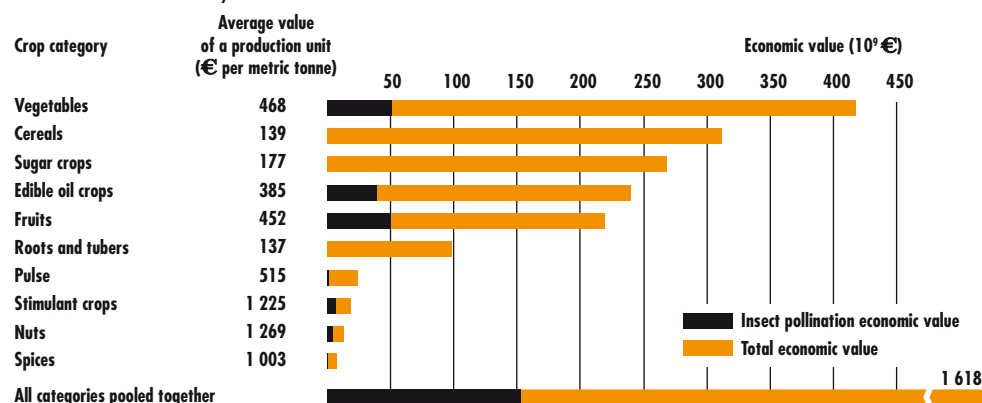
⁵ Williams I.H., 1996. “Aspects of bee diversity and crop pollination in the European Union”. In The Conservation of Bees (Metheson, A. et al., eds), pp. 63–80, Academic Press.

⁶ Gallai N. et al., 2009. “Economic valuation of the vulnerability of world agriculture confronted with pollinator decline”. Ecological Economics, 68: 810-821

1. Pollination and pollinators

Pollination is the transfer of pollen from a flower's male organs to a flower's female organs. This process is critical to fruit and seed production and is usually provided by insects and other animals searching for nectar, pollen or other floral benefits. Pollination is vital to our ecosystems and to human societies. The health and well-being of pollinating insects are crucial to life, be it in sustaining natural habitats or contributing to local and global economies (Figure1).

Figure 1: Economic impact of insect pollination on agricultural production used directly for human food worldwide



The contribution of pollinators to the production of crops used directly for human food has been estimated at €153 billion globally, which is about 9.5% of the total value of human food production worldwide⁶.

Animal-mediated pollination boosts the reproduction of wild plants on which other services or service-providing organisms depend. Some commercial plants, such as almonds or blueberries, do not produce any fruit without pollinators. For many, a well-pollinated flower will contain more seeds, with an enhanced capacity to germinate, leading to bigger and better-shaped fruit. Improved pollination can also reduce the time between flowering and fruit set, reducing the risk of exposing fruit to pests, disease, bad weather, agro-chemicals and saving on water.

Mutually beneficial relationships have developed over time between pollinator anatomy and plant flower structures – as well as mechanisms that plants use to

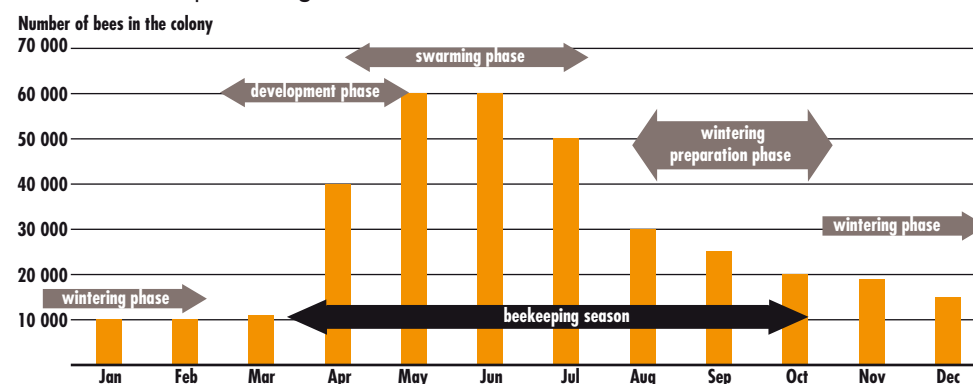
attract reproductive assistants in exchange for food rewards. These co-adaptations can be so specialized that the loss of one species threatens the existence of another. This raises troubling questions about the potential consequences of declining diversity in pollination networks⁷ – an ecosystem service that is often cited as endangered in scientific literature.

2. Variation in managed pollinator populations

Among the 20 000 known bee species worldwide, the most common domesticated bees are honey bees, *Apis mellifera*. Native to Europe, Asia and Africa, their value ranges from honey production, wax, propolis and royal jelly, to the efficient pollination of crops. Honey bees remain the most economically valuable pollinators for crop monocultures worldwide. Yields of certain fruit, seed and nut crops decrease by more than 90% without these highly efficient pollinators⁸.

It is problematic to estimate the global economic value of the pollination services provided by managed species, as it is difficult to know if crops have been pollinated by managed or wild individuals. Nevertheless, recent estimates range between €22.8 to 57 billion⁹, including apiculture markets and particularly all cash-crop yields.

Figure 2: Mean theoretical honey bee population per hive and by season in temperate regions



Data source: French Agency for Environmental and Occupational Health Safety (AFSSET), "Weakening, collapse and mortality of bee colonies", November 2008 – Updated April 2009.

⁷ Fontaine C. et al. 2006. "Functional diversity of plant-pollinator interaction webs enhances the persistence of plant communities". PLoS Biol 4(1): e1 and "Diverse Pollination Networks Key to Ecosystem Sustainability". PLoS Biol 4(1): e12

⁸ Klein A.M., Vaissière B. et al. 2007. "Importance of pollinators in changing landscapes for world crops". Proceedings of the Royal Society B: 274, 303–313.

⁹ Simon Potts, Centre for Agri-Environment Research, University of Reading in "Bees and flowers decline in step", by Richard Black, Environment correspondent, 20 July 2006, BBC News website. See <http://news.bbc.co.uk/2/hi/science/nature/5201218.stm>

Wild pollinators are also at risk

Animal-based pollination services, from wild species like the bumble bee, foster reproductive potential and genetic resilience in many ecosystems. Although conclusive data indicates that some 1 200 wild vertebrate pollinators may be at risk¹⁰, there is a lack of data on many invertebrate species that act as pollination agents.

Threats to certain invertebrate pollinator populations were reported in Europe as early as 1980¹¹, and confirmed in the 1990s. The regression mostly affected long-tongued species; this is likely due to the reduction in plants with long inner petals (e.g. Lamiaceae, Fabaceae, Scrophulariaceae). A British and Dutch study showed that in the United Kingdom (UK) and the Netherlands alone, since the 1980s a 70% drop in wild flowers requiring insect pollination has been recorded, as well as a shift in pollinator community composition¹². In the UK, many pollinator species that were relatively rare in the past are becoming rarer, while more common species have become widespread. It was also found that 71% of butterfly species have decreased and 3.4% became extinct over the past 20 years, illustrating the highest net loss compared to native flowering plants (28% decrease in 40 years) and birds (54% decrease over 20 years) in the same UK region¹³.



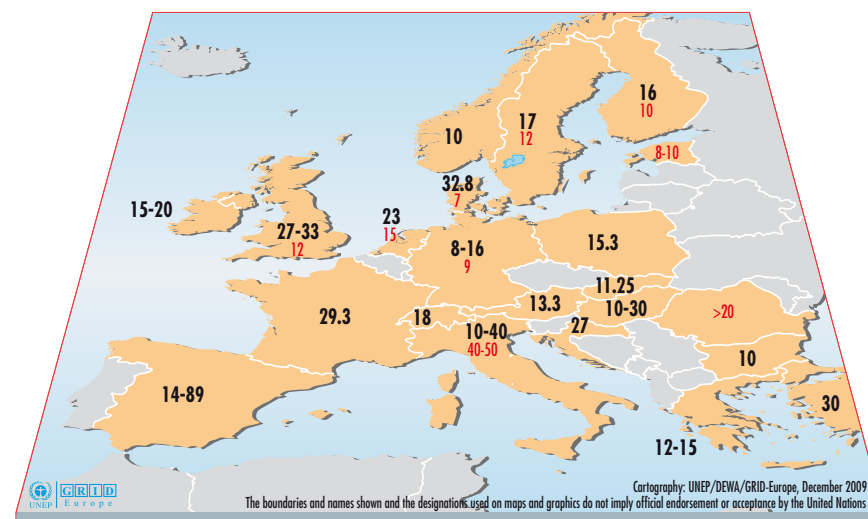
Bumblebees are highly social, like honeybees, but with smaller, less structured nests, that can consist of up to 1 000 bees. Bumblebee colonies are annual; the entire colony dies out each year and leaves only mated queens to hibernate through winter. The queen will start a new colony in spring. Bumblebees pollinate tomatoes, eggplants, peppers, raspberries, blackberries, strawberries, blueberries, and cranberries, just to name a few. Bumblebees are the only pollinators of potato flowers worldwide.

Honey bee, Apis mellifera. Photo courtesy of David Cappaert, Michigan State University, Bugwood.org

2.1 Europe

A decrease in managed honey bee colony numbers in Europe has been observed since 1965, but the pattern is diverse¹⁴. Since 1998, individual beekeepers have been reporting unusual weakening and mortality in colonies, particularly in France, Belgium, Switzerland, Germany, the United Kingdom, the Netherlands, Italy and Spain. Mortality has been extremely high when activity is resumed at the end of winter and beginning of spring.

Figure 3: European colony mortality



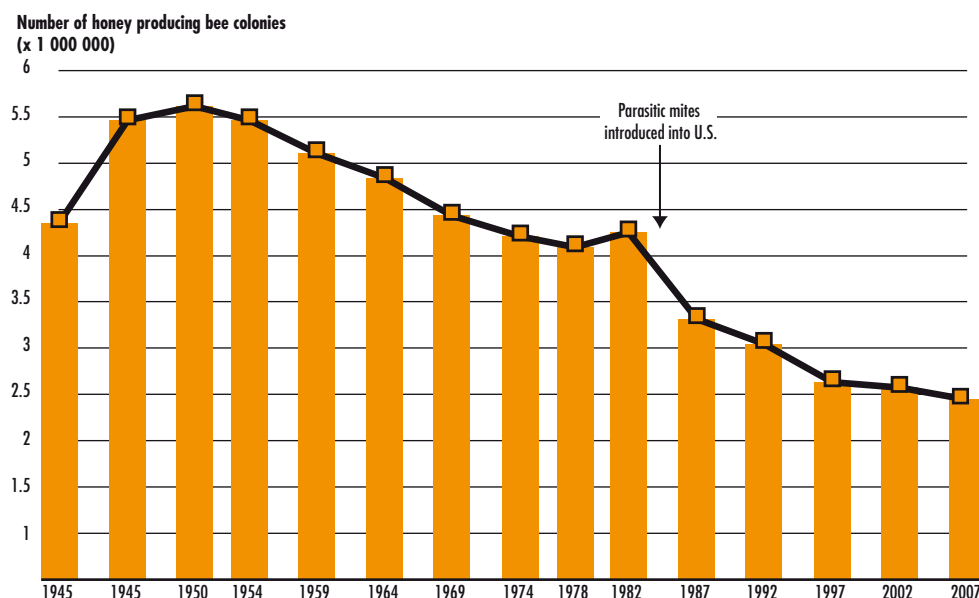
Data for colony mortality in European countries remains scarce or uneven. The most recent data compiled by the COLOSS working group indicates that winter losses are common and the main pathogen during this season is *Varroa destructor*¹⁵. Other factors such as pathogens¹⁶ or pesticides¹⁷ are also being studied. Source: In black 2007-2008 mortality (COLOSS, Zagreb meeting proceedings), in red 2006-2007 mortality (EFSA members poll)

- ¹⁰ Allen-Wardell G., Bernhardt P. et al. 2008. "The Potential Consequences of Pollinator Declines on the Conservation of Biodiversity and Stability of Food Crop Yields". Conservation Biology, vol. 12, num. 1, p. 8-17.
- ¹¹ Leclercq J. et al. 1980. "Analyse des 1600 premières cartes de l'Atlas Provisoire des Insectes de Belgique, et première liste rouge d'insectes menacés dans la faune belge". Notes Fauniques de Gembloux 4: 104 pp.
- ¹² Biesmeijer J.C., Roberts S. P. M. et al. 2006. "Parallel Declines in Pollinators and Insect-Pollinated Plants in Britain and the Netherlands". Science: Vol. 313. no. 5785, pp. 351 – 354.
- ¹³ Thomas J. A., Telfer M. G. et al. 2004. "Comparative Losses of British Butterflies, Birds, and Plants and the Global Extinction Crisis". Science: Vol. 303. no. 5665, pp. 1879 – 1881.
- ¹⁴ Potts S.G. et al. 2010. "Declines of managed honey bees and beekeepers in Europe". Journal of Apicultural Research 49(1): 15-22.
- ¹⁵ Amdam, G. V., Hartfelder, K. et al. 2004. "Altered physiology in worker honey bees (Hymenoptera: Apidae) infested with the mite *Varroa destructor* (Acari: Varroidae): a factor in colony loss during overwintering?" J Econ. Entomol. 97, 741-747.
- ¹⁶ Higes, M., Martin-Hernandez, R. et al. 2009. "Honey bee colony collapse due to *Nosema ceranae* in professional apiaries". Environmental Microbiology Reports 10, 2659-2669.
- ¹⁷ Nguyen, B. K., Saegerman, C. et al. 2009. "Does imidacloprid seed-treated maize have an impact on honey bee mortality?". Journal of Economic Entomology 102, 616-623.

2.2 North America

A significant and constant decline in domestic honey bee colony numbers has been occurring during the past decades in this region^{18, 19}. Losses of honey bee colonies since 2004 has left North America with fewer managed pollinators than at any time in the last 50 years. In this region, honey bees pollinate nearly 95 kinds of fruits such as almonds, avocados, cranberries and apples, as well as crops like soybeans²⁰. In 2000, the value of crops pollinated by bees was estimated at US\$ 14.6 billion in the USA alone²¹.

Figure 4: US honey-producing colonies



Data source: U.S. Department of Agriculture's (USDA) National Agricultural Statistics Service (NASS) NB: Data collected for producers with 5 or more colonies. Honey producing colonies are the maximum number of colonies from which honey was taken during the year. It is possible to take honey from colonies which did not survive the entire year.

Since their introduction in the 1980s (see Figure 4), various mites are linked to drastic losses of colonies. Scientists have adopted the term "Colony Collapse Disorder" (CCD) to define this multi-factor syndrome affecting beehives annually, particularly where low numbers of adult bees with food supplies such as honey and bee bread and immature or capped brood bees are present.

While little build-up of dead bees in or around affected colonies has been observed, bee loss is due to the sudden early death of large numbers of adult worker bees²², as the workforce that maintains the hive appears to consist of young adult bees. The queen is generally present and the remaining bees are reluctant to consume foods such as sugar syrup and protein supplements. It appears that dead and weak colonies are more likely to be found next to or in proximity to each other in CCD apiaries, which suggests that an infectious agent or exposure to a common risk factor may provoke CCD. During the 2006-2007 period, some 29% of 577 beekeepers across the USA reported CCD, with a loss of up to 75% of colonies²³. Experts estimated that honey bee colony losses during the 2006-2007 and 2007-2008 autumn/winter periods at 31% and 36% respectively, exceeding the 10-20% losses that are considered normal.

Colonies can die in numerous ways. CCD only accounts for about 7% of losses in the USA²⁴ and even less in Europe. The loss of queen bees seems to be a much more common cause at about 25%.

2.3 Asia / Oceania

China has six million bee colonies; about 200 000 beekeepers in this region raise western honey bees (*A. mellifera*) and eastern honey bees (*A. cerana*). In recent years, Chinese beekeepers have faced several inexplicable and complex symptoms of colony losses in both *Apis* species. Certain losses are known to be caused by Varroa mites on *A. mellifera*, sacbrood viruses on *A. cerana* and *Tropilaelaps* mites on both species. However, other factors and mechanisms are being investigated, although no data has been published to date.

¹⁸ Ellis, J., Evans, J.D., Pettis, J.S. 2009. "Reviewing colony losses and Colony Collapse Disorder in the United States". Journal of Apicultural Research. 49:134-136.

¹⁹ Aizen M. A. 2009. "The Global Stock of Domesticated Honey Bees Is Growing Slower Than Agricultural Demand for Pollination". Current Biology 19, 1-4, June 9.

²⁰ Stokstad E., "The Case of the Empty Hives", Science 18 May 2007 316: 970-972 [DOI: 10.1126/science.316.5827.970] (in News Focus).

²¹ Morse R.A, Calderone N.W. 2000. "The value of honey bees as pollinators of U.S. crops in 2000", Cornell University, Ithaca, New York.

²² "Colony Collapse Disorder (CCD) Working Group: Summary of purpose and responsibility" at <http://maarec.cas.psu.edu/pressReleases/CCDSummaryWG0207.pdf>

²³ Stokstad E., "The Case of the Empty Hives", Science 18 May 2007 316: 970-972 [DOI: 10.1126/science.316.5827.970] (in News Focus)

²⁴ vanEngelsdorp D., Hayes J., Underwood R. M. and Pettis P.S. 2010. "A survey of honey bee colony losses in the United States, fall 2008 to spring 2009". Journal of Apicultural Research 49(1): 7-14 (2010)

Beekeepers in Japan raise both *A. mellifera* and *A. cerana*, and 25% of beekeepers have recently been confronted with sudden losses of their bee colonies²⁵.

A. mellifera was introduced repeatedly in Australia during the 19th century. Natural honey bee populations that were established from managed colonies are now found throughout the country. The Varroa mite has not yet been introduced into Australia. Bee hives have been placed at 26 ports around the country, which are checked regularly for infection to better monitor the potential arrival of this threat. Another measure is the placement of empty “bait” hives to attract bees that come off ships. A lesser risk is posed by *A. cerana* which may arrive from Japan, the Republic of Korea, or Thailand²⁶. After the introduction of *A. mellifera*, and the recently arrived *Bombus terrestris*, Australia maintains strict quarantine barriers, along with thorough research and funding before the introduction of new pollinator species. Until now, there are no confirmed reports of increased honey bee losses.

2.4 Africa

Egyptian beekeepers based along the Nile river have reported symptoms of CCD²⁷. One scientific experiment involved moving certain affected colonies to another habitat. The results have shown that a clean environment with diverse vegetation, compared to the original location, has an important role in defeating the symptoms of CCD. Until now, there are no other confirmed reports of honey bee losses from Africa.

3. Driving forces of pollinator population instabilities

3.1 Habitat deterioration

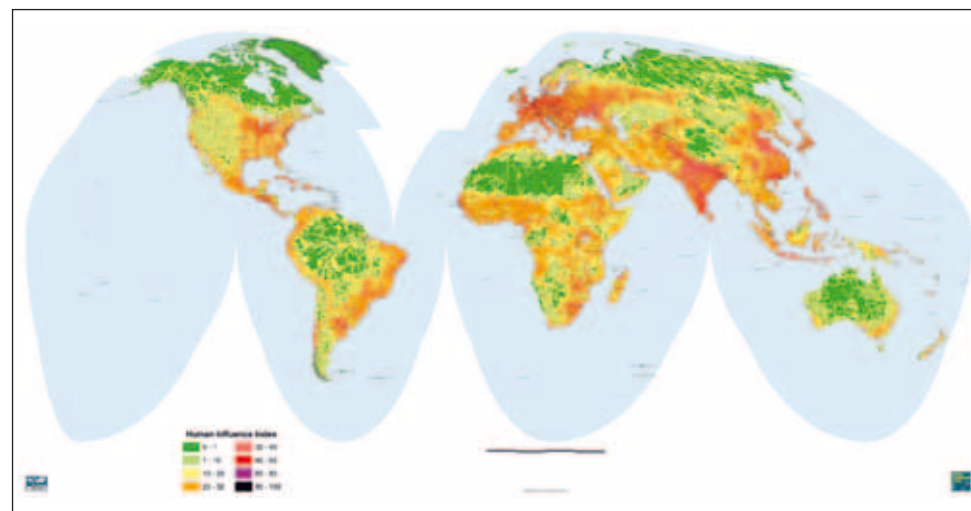
Degradation

Human activities have impacted the landscape through fragmentation, degradation and destruction of natural habitats and the creation of new anthropogenic ones. Changes in land-use and landscape structure affects pollinators, target plants and

their interactions at individual, population and community levels. Degradation and fragmentation of natural habitats are considered as key adverse changes for pollinator populations²⁸.

Firstly, this can lead to the reduction of food sources for all pollinator species. When large habitats are fragmented into small isolated patches, food sources become more scarce for resident animals. Populations may then decline to the point that they are no longer able to benefit plants²⁹. As certain wild pollinators need undisturbed habitat for nesting, roosting, foraging and sometimes specific larval host plants, they are very susceptible to habitat degradation and fragmentation in particular.

Figure 5: Human Footprint



Data Source: CIESIN, NASA, SEDAC, 2000:

Human Footprint mapping project shows the cumulative effect of six billion people on the planet, illustrating human impact on every square kilometre of the Earth. In this map, human impact is rated on a scale of 0 (minimum) to 100 (maximum) for each terrestrial biome. A score of 1 indicates the least human influence in the given biome. However, because each biome has its own independent scale, a score of 1 in a tropical rainforest might reflect a different level of human activity than in a broadleaf forest.

²⁵ Natural News 28 April 2009, “Honey bee Collapse Strikes Japan, Up to Fifty Percent of Honey bees Gone”. www.naturalnews.com/026151_Japan_honey_bees_honey.html

²⁶ Cunningham S. A. et al., 2000. “The future of pollinators for Australian agriculture”. Aust. Journ. Agric. Res. 53, 893-900.

²⁷ A. R. Hassan1 2009, “Proceedings of the 4th COLOSS Conference”.

²⁸ Thomas J. A, Telfer M. G. et al. 2004. “Comparative Losses of British Butterflies, Birds, and Plants and the Global Extinction Crisis”. Science: Vol. 303. no. 5665, pp. 1879 – 1881

²⁹ Hendrix S.D, 1994, “Effects of population size on fertilization, seed production, and seed predation in two prairie legumes”. North American Prairie Conference Proceedings 13: 115-119.

In parallel, The International Union for Conservation of Nature (IUCN) predicts a global loss of 20 000 flowering plant species within the coming decades. Undoubtedly, this will lead to the decline of co-dependent pollinators who need these plants for survival, as most species are highly dependent on habitat diversity for their survival.

Increased pathologies

In the wild, various pathogens have crossed over from commercially managed species of bumblebees used for greenhouse pollination. This has contributed to a decline in some native bumblebees. Furthermore, unhealthy ecosystems can facilitate the development of parasites which may affect both managed and wild pollinators. Consequently, the preservation or restoration of pollinators and their services requires a holistic approach from a local to landscape level that reflect the spatial distribution of resources and the foraging and dispersal movements of the relevant organisms³⁰.

Invasive Species

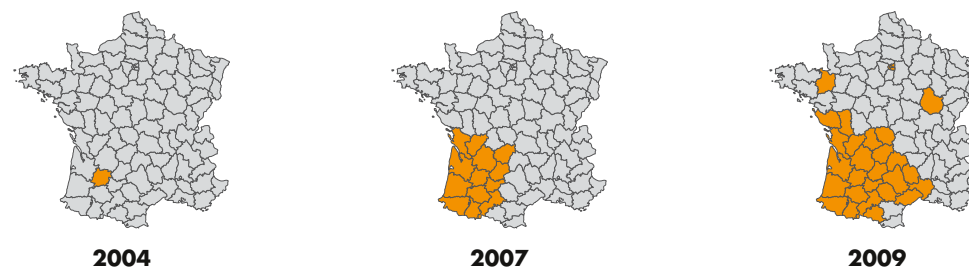
The external parasitic mite, *Varroa destructor*, is the most serious threat to apiculture globally. Recognised as an invasive species, it has shifted hosts from *A. cerana* to *A. mellifera*. About the size of a pinhead, it feeds on bees' circulatory fluid and spreads from one hive to another. The parasite can spread viral diseases and bacteria. If left uncontrolled, it will almost certainly lead to the premature death of colonies within three years. Discovered in Southeast Asia in 1904, today it has spread nearly worldwide.



Adult honey bee with a brown varroa mite riding on the thorax.
Photo courtesy of Stephen Ausmus. USDA-ARS, United States, License: public domain

Other invasive acari species are also of concern, such as the small hive beetle (*Aethina tumida*), which is endemic to sub-Saharan Africa. It has colonised much of North America and Australia and is now anticipated to arrive in Europe. This beetle and its larvae cause damage to honeycomb, stored honey and pollen. Another external mite is the parasite *Tropilaelaps clareae*, which also originated from Southeast Asia and has shifted from *A. dorsata* to *A. mellifera*. However, its distribution has been quite limited to date.

Figure 6: Invasive Asian hornet presence in France



Source: Villemant C., Rome Q. & Haxaire J. 2009. Le Frelon asiatique (*Vespa velutina*). In Muséum national d'Histoire naturelle [Ed]. 2009. Inventaire national du Patrimoine naturel, site Web. <http://inpn.mnhn.fr>

Competition from non-native hymenoptera species is also of concern for pollinators, notably the Africanised bee in the USA and the Asian hornet (*Vespa velutina*) in Europe. The Asian hornet, which mainly feeds on European honey bees, has now colonised nearly half of France (Figure 6). Research is being conducted to limit its expansion and impact on honeybees.

Pollution and other threats

Air pollution hampers the symbiotic relationships between pollinators and flowers. Although daytime insects depend primarily on vision to find flowers, pollutants affect the chemicals that flowers produce to attract insects, which destroys vital scent trails. Scents that could travel over 800m in the 1800s now reach less than some 200m from the plant, which complicates pollinators' ability to locate food sources³¹.

Electric and magnetic fields may also influence bee behaviour, as bees are sensitive to these fields through small abdominal crystals that contain lead. However, currently there is insufficient data and research to establish a causal link between the impact of these fields and bee mortality.

³⁰ Kremen C. et al. 2007. "Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change". Ecology Letters, Vol. 10, No. 4., pp. 299-314.

³¹ McFrederick Q. S., Kathilankal J. C. et al. 2008. "Air pollution modifies floral scent trails". Atmospheric Environment 42, 2336-2348.

3.2 Agriculture practices

Chemical drifts from spraying

Chemicals can poison pollinators or impair their reproduction, eliminate nectar sources and destroy larval host plants for moths and butterflies and deplete bees' nesting materials³². It is plausible that plant losses from chronic herbicide use may be driving losses of pollinator species³³. Additionally, various broad-spectrum insecticides are not only applied on agricultural fields but also in residential gardens, recreational areas, forests as well as mosquito-ridden marshes and swamps. These chemicals can be equally toxic to beneficial insects as to the target species³⁴. Chronic or sub-lethal exposure to agricultural or beekeeper-applied pesticides can weaken the honey bee's immune system, and hamper bees' ability to fight infection.



Aerial chemical spraying.

Creative Commons (CC) photo courtesy of Paul L. Nettles on Flickr. February 2008

The indirect effects of pesticides on pollinator populations, particularly the destruction of valuable plants and habitats after herbicide spraying, must also be considered. The chemical destruction of habitats can have long-term consequences particularly on the distribution of pollinators in agro-environments.

Systemic insecticides

Systemic insecticides such as those used as seed coatings, which migrate from the roots through the entire plant, all the way to the flowers, can potentially cause toxic chronic exposure to non-target pollinators. Various studies revealed the high toxicity of chemicals such as Imidacloprid, Clothianidin, Thiamethoxam and associated ingredients for animals such as cats, fish, rats, rabbits, birds and earthworms³⁵. Laboratory studies have shown that such chemicals can cause losses of sense of direction³⁶, impair memory and brain metabolism, and cause mortality^{37, 38}. Others have found that some neonicotinoids, combined with certain fungicides, synergized to increase the toxicity of the systemic insecticide over 1 000 times. However, results obtained in laboratory conditions are hard to compare to field conditions.

3.3 Beekeeping activities

Health

To date, there are 29 biological pathogens known in the beekeeping sector of industrialised countries, some of which have been the focus of recent studies on the phenomenon of bee colony mortality (see Figure 7). Introduced parasites have contributed to a reduction in managed honey bee populations, *Varroa destructor* causing the most damage. Originating from Asia, the Varroa mite reached Europe and North America in the 1980s, and has now spread almost worldwide (Figure 8).

³² Nabhan G.P. and Buchmann S.L. 1997. "Pollination services: biodiversity's direct link to world food stability", in G. Daly, ed. Ecosystem Services, Island Press, Washington, D.C.

³³ Cane J. H. and V. J. Tepedino. 2001. "Causes and extent of declines among native North American invertebrate pollinators: detection, evidence, and consequences". Conservation Ecology 5(1): 1 at www.consecol.org/vol5/iss1/art1/

³⁴ Johansen C. A., and Mayer D. F. 1990. "Pollinator protection: a bee and pesticide handbook". Wicwas Press, Cheshire, Connecticut, USA.

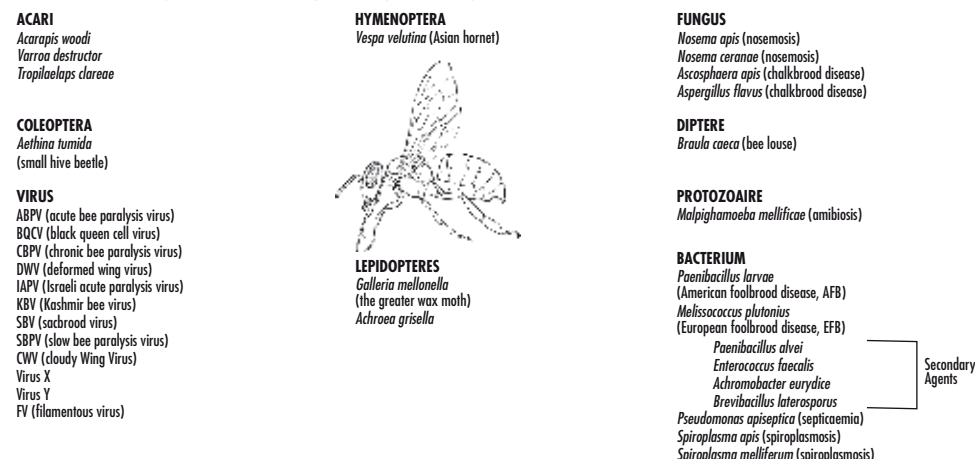
³⁵ Cox C., 2001. "Imidacloprid, Insecticide factsheet". Journal of Pesticide Reform, Vol. 21, N°1 at www.pesticide.org/imidacloprid.pdf

³⁶ Bonmatin, J.M., Marchand P.A, Charvet R, Colin M.E, 1994. "Fate of systemic insecticides in fields (Imidacloprid and Fipronil) and risks for pollinators, in First European Conference of Apidology". Udine 19-23 September 2004.

³⁷ Colin M. E., Bonmatin J. M. et al. 2004. "Quantitative analysis of the foraging activity of honey bees: relevance to the sub-lethal effects induced by systemic insecticides". Arch. Environm. Contam. Toxicol. 47, 387-395.

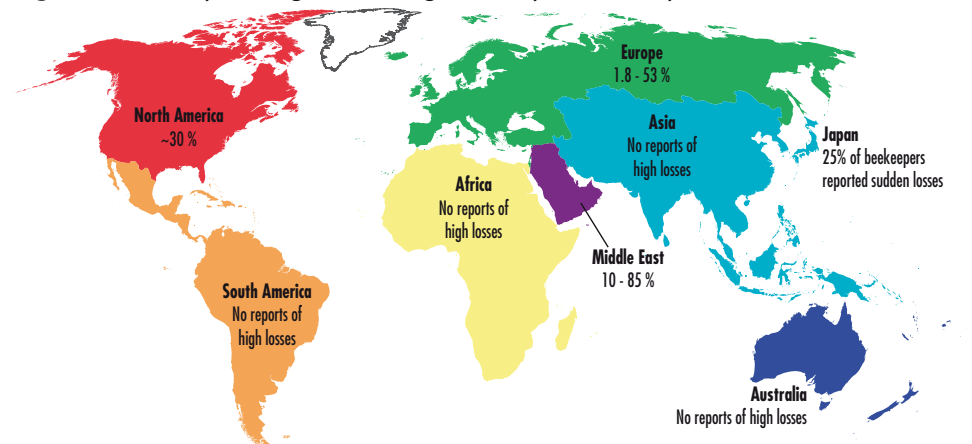
³⁸ Bonmatin J. M., Marchand P.A. et al. 2005. "Quantification of imidacloprid uptake in maize crops". Journal of agricultural and food chemistry , vol. 53, no13, pp. 5336-5341.

Figure 7: *Apis mellifera* pathogenic agents



Source: "L'abeille mellifère: maladie, parasites et autres ennemis", Coineau Y & Fernandez N, 2007.
 Rapport du groupe de travail sur les "affaiblissements, effondrements et mortalités des colonies d'abeilles",
 AFSSA, 2008

Figure 8. Yearly average of managed honey bee colony losses due to Varroa mite



The Varroa mite, *Varroa destructor*, is one of the threats to managed honey bee colonies. Elevated colony losses reported from the USA, Europe, the Middle East and Japan are related to high mite infection³⁹.

Two species of the *Nosema* parasite are widespread across the U.S. The *Nosema apis*, can be particularly problematic for over-wintering colonies, but has been largely displaced by *N. ceranae* over the past decade. While the epidemiology of *N. ceranae* is poorly understood, it has been blamed for large-scale losses recently experienced by Spanish beekeepers. It is not unusual for pollinators to suffer from widespread mortality, and for managed bee colonies to be exposed to infectious agents, notably the American foulbrood (*Paenibacillus larvae*), tracheal mites (*Acarapis woodi*), and various other fungal, viral, and bacterial diseases.

Little is known about the normal levels of some microbes and pathogens associated with bees, such as the fungi causing stone brood, flagellates or amoebae. New and increasingly virulent fungal pathogen strains are now being reported worldwide.

Chemical use

Antibiotics and chemicals used against mites (miticides) are widespread in beehive management. Frequency and method of application varies and may also hamper colony populations. Since the late 1980's, when the varroa mite was introduced, beekeepers have used miticides in beehives to control invasions primarily of varroa mites. Various types of pesticides, both grower - and beekeeper-applied, have been detected in hive matrices such as coumaphos and fluvalinate. Many of these products are known to damage colony health. Some Belgian studies have proved a direct link between colony treatment against the varroa parasite and excessive population mortality⁴⁰.

Diet

Quality food is essential for pollinators' successful larva development and also to optimise their activity cycle during the winter season. It is increasingly difficult for pollinators to obtain sufficient pollen sources for all their essential amino acids. Consequently, this can weaken the insects' immune system, making them more vulnerable to various pathogens. Some researchers have observed that where crops with low-protein pollens such as blueberries and sunflowers are grown, there is a correspondingly increased likelihood of CCD⁴¹.

Feeding colonies is common among beekeepers to strengthen natural diets or minimise the risk of starvation by boosting seasonal food shortages. Concurrently, other necessary elements in bee diets such as mineral salt and proteins must also be included by the appropriate feeder method. However, long-term effects on colonies of this type of feeding are not yet known.

³⁹ Neumann P. and Carreck N. L., 2010. "Honey bee colony losses", Journal of Apicultural Research 49(1): 1-6.

⁴⁰ Haubruge, E., Nguyen, B. K. et al. 2006. "Le dépérissement de l'abeille domestique, *Apis mellifera* (Hymenoptera: Apidae) : faits et causes probables". Notes fauniques de Gembloux 59, 3-21.

⁴¹ Joe Traynor, manager of Scientific Ag, a bee brokering firm, in "Power Pollen", Bee Culture, February 2009.

Transport

Farmers that grow pollinator-dependant crops without managed bees can expect declines in yield and/or quality if local wild and managed bee populations are insufficient. A lack of adequate pollinators may require increased crop management such as travelling hives. The U.S. has a strong tradition in moving colonies: single truckloads carry more than 20 million bees and over two million colonies travel across the continent each year. However, the prolonged confinement and temperature fluctuation is stressful to bees. It is also thought of amplifying adult bee disease agent loads because of negative sanitary effects of confinements and increased exposure to new foreign diseases and pathogens. Following colony transportation, mortality rates are often reported to reach some 10%.

Colony splitting and selection

After repeated losses over the past decade, beekeepers have split their colonies to compensate for missing bees. By recycling equipment and providing a new division supported by existing food reserves from dead colonies, various diseases or chemicals might contaminate the new colony. Re-use may also increase the presence of disease in honeycombs. The age profile of worker bees is altered by colony splitting. Older bees, which are not as efficient in providing for broods, are forced to act as nurse bees, and so they are more likely to be infested with diseases that affect adult bees.

3.4 Climate change

It is anticipated that climate change consequences, such as fluctuations in greening, flowering and aging periods, and an overall shortening of the growing season⁴², may hamper the livelihood of pollinators. Changes affecting the distribution of floral resources across space and time also influence the composition of pollinator communities. Concerning the regeneration of such communities following fire for example, bee community composition has been found to closely follow floral composition and rewards⁴³. Such changes will directly impact the mutually advantageous benefits that take place during pollination (*mutualism*). Climate change might, in some regions, also lead to a decrease in precipitation and a shift in seasonal rainfall. Consequently, reduced plant vigour, delayed plant

maturation and a decline in nectar production may occur, which may also disturb nectar-dependent mutualists. Ultimately, climate change may alter the natural synchronisation between pollinator and plant life-cycles.

4. What is being or can be done to limit instabilities?

4.1 Habitat conservation

Considering pollination habitat and fauna in ecological restoration planning can potentially increase the local abundance of pollinating species, facilitating potentially positive consequences for adjacent agro-environments. A focus on invertebrate taxonomy, monitoring and reintroduction is required as critical part of habitat management and restoration plans. Including habitat requirements for vital pollinators in habitat designations for endangered plants should be prioritised.

Farmers who value diverse habitats to support pollinators could be rewarded. Unploughed farmland set aside for several years can yield vegetation that supports considerable insect diversity and benefits nearby crops by hosting beneficial insects. Large-scale protection and management of habitat networks is needed to minimize habitat-related declines and to maximize species' capacity to adapt to changes in their local environment⁴⁴. The value of providing such resources for the livelihood of pollinators is yet to be quantified but it is unambiguous⁴⁵.

4.2 Alternative agriculture

Farmers and gardeners can rely on alternative non-toxic methods, such as natural enemies and environmentally friendly practice to control pests, insects and weeds, therefore reducing wildlife exposure to insecticides, herbicides and fungicides⁴⁶. It is important that impacts on pollinators are considered when designing and choosing methods of pesticide application, particularly during the flowering season in areas with pollinator-dependant crops.

⁴² Steltzer H. and Post E. 2009. "Seasons and Life Cycles". Science 15 May 2009 324: 886-887 [DOI: 10.1126/science.1171542] (in Perspectives)

⁴³ Potts, S.G. et al. 2003. "Response of plant-pollinator communities following fire: changes in diversity, abundance and reward structure". Oikos, 101, 103-112.

⁴⁴ Warren M. S, Hill J. K et al. 2001. "Rapid responses of British butterflies to opposing forces of climate and habitat change". Nature, Volume 414, Issue 6859, pp. 65-69.

⁴⁵ Decourtye A., Lecompte P. et al. 2007. "Introduction de jachères florales en zone de grandes cultures: atouts pour agriculteurs et apiculteurs". Cahiers Agricultures 16, 213-218.

⁴⁶ Corbet, S.A., 1995. "Insects, plants and succession: advantages of long-term set-aside". Agriculture Ecosystems & Environment 53:201-217.

Optimizing pollinator-friendly blends of plant species offers improved forage opportunities for pollinators^{47, 48}, and may also enhance pollinator migration, colonization and persistence in restoration programmes. A major objective will be to identify, test and document good agricultural practices for pollinator conservation and management through an “ecosystem approach”⁴⁹. If chemicals must be used for pest, pathogen or weed control, particular care should be paid regarding the choice of chemical, timing and method of application. While managed hives can be removed, wild populations are completely vulnerable.

4.3 Alternative pollinators

As the genus *Apis* is not the most effective pollinator for all crop species, the range of pollinators should be diversified when possible. Alternate pollinators could provide or certainly enhance pollination services. Manageable insects may be found among native species. For example, the Alfalfa leaf-cutting bee (*Megachile rotundata*) has been successfully managed in North America for specific alfalfa pollination since the 1960s.



An adult leafcutter bee foraging in sweet pea flower. Image courtesy of Whitney Cranshaw, Colorado State University, Bugwood.org.

Studies show that wild or native bees are responsible for most pollination. Consequently, conserving populations of wild bees may compensate managed colony disorders. In Brazil, solitary bees such as Africanized bees, stingless bees and bumble bees, are used as pollinators of various cultivated crops. However, solitary bees are not yet commercially available to growers⁵⁰. In Ghana, communities around the Kakum forest have adopted this practice and are using stingless bees following the African Pollinator Initiative⁵¹.

Regarding alternative pollinators and possible domestication, the following factors should be considered: sufficient numbers of available insects, willingness to nest in artificial areas potential near target crops and a maximum foraging range to enhance the quality of pollination.

4.4 Larval stage conservation

Many important native invertebrate pollinators have larval stage mobility and habitat requirements very different from winged adults. Conservation initiatives have sometimes been slow to consider the needs of different life-cycle stages and indeed, some conservation-minded researchers have advocated planting nectar plants for butterflies but then have not fostered their larval plant hosts⁵². Honey bee larvae require sufficient protein in their brood food to ensure proper development and to optimize their activities during the winter. Therefore the quantity of stored pollen within a colony in the Autumn is strongly linked to its Spring adult bee population⁵³. Another factor to consider is the provision of the larval stage breeding substrate, if different from adults, such as the larvae of nitidulid beetles breed in decaying fruits.

⁴⁷ Kremen C. et al. 2007. “Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change”. Ecology Letters, Vol. 10, No. 4., pp. 299-314.

⁴⁸ Carvell C. et al. 2007. “Comparing the efficacy of agri-environment schemes to enhance bumble bee abundance and diversity on arable field margins”. Journal of Applied Ecology, Vol. 44 , n° 1, pp. 29-40. DOI: 10.1111/j.1365-2664.2006.01249.x

⁴⁹ Greenleaf S. Kremen C. 2006. “Wild bees enhance honey bees’ pollination of hybrid sunflower”. Proc. Nat. Acad. Sci. Usa 103, 13890-13895.

⁵⁰ Vera Lucia Imperatriz Fonseca et al. 2006. “Bees as pollinators in Brazil: assessing the status and suggesting best practices”. Ribeirão Preto: Holos, Editora, 2006, 112 pp.

⁵¹ The African Pollinator Initiative at www.arc.agric.za/home.asp?pid=3493

⁵² Cane J. H. and Tepedino V. J. 2001. “Causes and extent of declines among native North American invertebrate pollinators: detection, evidence, and consequences”. Conservation Ecology 5(1): 1 at www.consecol.org/vol5/iss1/art1

⁵³ Farrar D.L. 1936. “Influence of pollen reserves on the surviving populations of over-wintered colonies”. Am Bee J 76: 452–454.

BOX 1: Guiding governance

The following relevant policies in place and ongoing initiatives regarding pollinator conservation are not an exhaustive list but rather provide essential and strong stepping stones to build on.

- The Sao Paulo Declaration (1999) was prepared as a contribution to the Convention on Biological Diversity (CBD). The Declaration recommended that CBD formally establish the **International Pollinators Initiative** based on an action framework that addressed taxonomic impediments, monitoring the status and decline of pollinators, addressing causes of decline, evaluating the economic importance of pollinators and establishing conservation, restoration and sustainable use programmes and guidelines.

Consequently, the Fifth Meeting of the Conference of Parties to the CBD established the **International Initiative for the Conservation and Sustainable Use of Pollinators**, coordinated and facilitated by the Food and Agriculture Organization of the United Nations (www.internationalpollinatorsinitiative.org) whose principle objectives are to:

- ▶ Monitor pollinator decline, and its causes and impacts on pollination services.
 - ▶ Address the lack of taxonomic information on pollinators.
 - ▶ Assess the economic value of pollination and the economic impacts of declining pollinator populations and services.
 - ▶ Promote the conservation, restoration and sustainable use of pollinator diversity in agriculture and related ecosystems."
- The **European Pollinator Initiative (EPI)**, at www.europeanpollinatorinitiative.org has representatives from 17 European regions, aims to integrate and coordinate local, national and international activities relating to pollination into a cohesive network to safeguard pollinators' services provided by across Europe. Its mission statement is: "To protect and enhance the biodiversity and economic value of pollinators throughout Europe".
 - The **North American Pollinator Protection Campaign (NAPPC)**, at www.napppc.org is an alliance of pollinator researchers, conservation and environmental groups, private industry, and state and federal agencies aiming to develop and implement an action plan to:
 - ▶ Coordinate local, national and international action projects in pollinator research, education and awareness, conservation and restoration, policies and practices, and special partnership initiatives
 - ▶ Facilitate communication among stakeholders, build strategic coalitions and leverage existing resources
 - ▶ Demonstrate a positive measurable impact on the populations and health of pollinators within five years.
 - The **Pollinator Thematic Network (PTN)**, at pollinators.iabin.net was initiated in May 2006 and is one of five Inter-American Biodiversity Network (IABIN) thematic networks. Facilitated by the Organisation of American States (OAS) for activities within the Western Hemisphere, the PTN assists with the discovery, collection, digitization, management and exchange of pollinator observation and collection data. This effort is supported by the Forgotten Pollinators Campaign (1996), the North American Pollinator Protection Campaign (1996), the Brazilian Pollinator Initiative (1998), the African Pollinator Initiative (1999), the International Pollinator Initiative of the Convention on Biological Diversity (2000; 2002) and the European Pollinator Initiative (2004).

BOX 2: Some scientific networks promoting continental and trans-continental collaboration on pollinators research.

Various key knowledge gaps on pollinators have been identified by the science community. Previous research activities were often undertaken in different locations worldwide, resulting in more competition than collaboration at times. Research is needed to address and mitigate the various causes of pollinator decline, as well as the potential remedies. Certain scientific networks aim to reduce research duplication by promoting a more coordinated international effort.

- **COLOSS** at www.coloss.org - The Prevention of Honey Bee Colony LOSSes (2008-2012) is an international European-funded COST (European Cooperation in the field of Scientific and Technical Research) network of 212 members from 52 countries with effect from December 2008. The network's primary objective is to identify factors at the individual honey bee and colony levels that cause severe colony losses and to investigate synergistic effects between them. This integrated approach between leading scientists, beekeepers and industry is helping to mitigate the detrimental impact of honey bee colony losses for beekeepers, agriculture and natural biodiversity. Its four main objectives are to:
 - ▶ Explain and prevent large-scale losses of colonies.
 - ▶ Develop standards for monitoring and research on losses.
 - ▶ Identify underlying factors and mechanisms.
 - ▶ Develop emergency measures and sustainable management strategies.
- **BEE DOC - BEes in Europe and the Decline of Colonies** (EU FP7, 2010-2012), at www.bee-doc.eu. Focus on honey bee pathology and interactions between pathogens.
- **Status and Trends of European Pollinators (STEP)** (EU FP7, 2010-2012) at www.step-project.net. Focus on pollinator loss across insects (*Apis mellifera*, *Bombus*, solitary bees, etc.).
- **Assessing Large-scale Environmental Risks for Biodiversity with Tested Methods (ALARM)**, at www.alarmproject.net is a European collaboration started in 2004, consisting of 54 partners from 26 countries, developing and testing methods for assessing large-scale environmental risks and therefore minimising the direct and indirect human effect on European terrestrial and freshwater biodiversity and ecosystems. Scientists from the French National Institute for Agricultural Research (INRA-Avignon) are participating in the Pollinator module to estimate the impact of pollinator populations on European agriculture and the economy.
- **United States Department of Agriculture, Agriculture Research Service Area-wide Programme for Improving Honey Bee Health (2007-2009)**
The project consists of four key components: operations, assessment, research and education, within a framework of a temporal-spatial scale and a three-phased implementation process. This includes 10 objectives to improve colony strength for pollination and non-chemical pest and pathogens control and colony nutrition amongst others.

Conclusion

Currently available global data and knowledge on the decline of pollinators are not sufficiently conclusive to demonstrate that there is a worldwide pollinator and related crop production crisis⁵⁴. Although honey bee hives have globally increased close to 45% during the last 50 years⁵⁵, declines have been reported in several locations, largely in Europe and Northern America. This apparent data discrepancy may be due to interpretations of local declines which may be masked by aggregated regional or global data. During the same 50-year period, agricultural production that is independent from animal pollination has doubled, while agricultural production requiring animal pollination has increased four-fold (reaching 6.1% in 2006). This appears to indicate that global agriculture has become increasingly pollinator dependant over the last 50 years.

However, human activities and their environmental impacts may be detrimental to some species but beneficial to others, with sometimes subtle and counter-intuitive causal linkages^{56, 57}. Pollination is not just a free service but one that requires investment and stewardship to protect and sustain it. There should be a renewed focus on the study, conservation and even management of native pollinating species to complement the managed colony tradition. Economic assessments of agricultural productivity should include the costs of sustaining wild and managed pollinator populations⁵⁸.



Bumble bee.
Creative Commons (CC) photo courtesy of Kristina Simms, Bugwood.org

⁵⁴ Ghazoul J, 2005. "Buzziness as usual? Questioning the global pollination crisis". *TRENDS in Ecology and Evolution* Vol.20 No.7 July 2005.

⁵⁵ Aizen M. A. 2009. "The Global Stock of Domesticated Honey Bees Is Growing Slower Than Agricultural Demand for Pollination". *Current Biology* 19, 1–4, June 9.

⁵⁶ Thomas C. D, and Jones T.M. 1993. "Partial recovery of a skipper butterfly (*Hesperia comma*) from population refuges: lessons for conservation in a fragmented landscape". *Journal of Animal Ecology* 62: 472-481.

⁵⁷ Benedek P, 1996. "Structure and density of lucerne pollinating wild bee populations as affected by changing agriculture". *Acta Horticulturae* 437: 353-357.

⁵⁸ Ingram M, Nabhan G. and Buchmann S. "Global Pesticide Campaigner", Volume 6, Number 4, December 1996.



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