Global Pollinator Decline: A Literature Review

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A scientific report about the current situation, recent findings and potential solution to shed light on the global pollinator crisis

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1. Introduction

We are currently enduring the 6th mass extinction, losing between 1 - 10 % of biodiversity per decade[1], mostly as a result of habitat loss, pest invasion (exotics), pollution, over harvesting and disease[2]. Why care ? Biodiversity losses aren't only affecting natural ecosystems but also the services they provided and some of them are vital for human societies amongst other the presence of oxygen into the atmosphere, renewing of soils (from bacteria, worms, …) and pollination – the transfer of pollen from one flower to another – is critical to fruit and seed production, and is often provided by insects and other animals on the hunt for nectar, pollen or other floral rewards.

Until very recently, most farmers considered pollination as one of nature's many "free services", so taken for granted that it has rarely figured as an "agricultural input" or even as a subject in agricultural science courses[3]. This assumption has apparently become obsolete as these changes are already being illustrated, need to be monitored and mitigated in the near future, posing threats to the integrity of biodiversity, global food webs and even ultimately to human health.

The Food and Agriculture Organisation (FAO) of the U.N.[4] estimates that of the slightly more than 100 crop species that provide 90 percent of food supplies for 146 countries, 71 are bee-pollinated (mainly by wild bees), and several others are pollinated by thrips, wasps, flies, beetles, moths and other insects. In Europe alone, 84% of the 264 crop species are animal-pollinated and 4 000 vegetable species have their life assured thanks to the pollination of the bees[5]. Pollinators are essential for the reproduction of many wild flowers and crops: for one out of every three bites eaten, one can thank a bee, butterfly, bat, bird or other pollinator[6]. As Simon Potts, (University of Reading) says: "*The economic value of pollination worldwide is thought to be between £30 and 70 billion each year*" [i.e. 45 - 100 billions €]. Any loss in biodiversity is a matter of public concern, but losses of pollinating insects may be particularly troublesome because of the potential effects on plant reproduction and hence on food supply security. Many agricultural crops and natural plant populations are dependent on pollination and often on the services provided by wild, unmanaged, pollinator communities[7].

Several researches have highlighted the different factors leading to pollinators decline[8] such as modern agricultural practices and use of pesticides, habitat fragmentation, climate change, also to a lower extent lack of floral diversity, competition from non-native species, diseases, predators and parasites. This literature review seeks to update the state of knowledge on this issue, in light with the recent declines. The recent episode of Colony Collapse Disorder (CCD) that is affecting north America where about a third of honey bees disappeared in several months, shed a new light on the matter and is a reminder of the level of threat posed by the losses of pollinators for both natural ecosystems and crops production. One latest finding about CCD highlighted a bee disease called Israeli acute paralysis virus as strongly associated with the beekeeping operations that experienced big losses, although members of the research team emphasized that they had not proved the virus caused the die-offs.

2. Current pollinators declines

2.1. Status in Europe

A recent collaboration (2006) between british and dutch scientists showed that in the UK and the Netherlands, a 70% drop of wild flowers that require insect pollination has been recorded as well as a shift in pollinator community composition since the 1980s[9]. In UK, Stuart Roberts from the University of Reading points out that "pollinator species that were relatively rare in the past have tended to become rarer still, while the

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

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

3 Food and Agriculture Organisation of the U.N. at www.fao.org.

4 Idem

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

7 Free, J.B., 1993. "Insect Pollination of Crops", Academic Press

8 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. [online] URL: www.consecol.org/vol5/iss1/art1

9 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.

commoner species have become even more widespread". J. A. Thomas *et al.*[10] have found that 71% of butterfly species have decreased and 3.4% became extinct over the past 20 years, illustrating the greatest net loss compared to native vascular plants (28% decrease in 40 years) and birds (54% decrease in 20 years) of the same area in the UK. Most species of non-migratory butterflies that reach the northern margins of their geographic ranges in Britain have declined over the last 30 years (as they have elsewhere in northern Europe[11]).

2.2. Colony Collapse Disorder (CCD) in North America

Background

In North America, a significant decline in commercially managed honeybee colonies during the winter and spring of 2006-2007 led to the losses of about one third of honeybees. This event is called Colony Collapse Disorder (CCD). CCD has affected honeybees in 35 states of the United States. Some beekeepers report losses in their colonies as high as 80 to 100 percent. If left unchecked, CCD has the potential to cause a $15 billion direct loss of crop production and $75 billion in indirect losses (see following details and [12]).

About 1/3 of the North-American diet comes from food – fruits, vegetables, seeds and nuts – that rely on animal pollinators, which include beetles, butterflies, flies, bats, hummingbirds and bumblebees[13]. Honey bees are essential crops pollinators in the United States: they are indispensable farmhands, pollinating some 95 kinds of fruits and vegetables[14]. In 2000, the value of American crops pollinated by bees was estimated to be US$ 14.6 billion[15].

"[…] *latest decline are part of a larger trend, with honey bee colonies down 50% in the past 50 years*" said Senator Barbara Boxer[16] (US Senate Environment Committee chair). "*Because native and honey bees pollinate so many crops, this decline, if not stopped, could impact many crops dependent on animal pollination and cause both increased prices and shortages of many food crops including almonds, avocados, cranberries, apples, and soybeans*" said Boxer.

According to the Committee on the Status of Pollinators in North America[17], the introduction of parasites particularly *Varroa destructor* and the *varroa mite* have clearly contributed to the reduction of honey bee. They also highlight that in early 2005 a change in regulation led to the first importation from outside north America of honey bees since 1922, thus increasing the risk of pest and parasite introduction. There are other possibilities such as "*antibioticresistant pathogens (American foulbrood); pesticide-resistant mites; and the encroachment of Africanized honey bees, particularly in the South Eastern United States*"[17].

The symptoms of CCD

Colony Collapse Disorder (CCD) is described as a multifactorial syndrome which has been leading to low number of adult bees in the hives which still held food supplies and immature bees (brood). The loss of bees seems to be the sudden early death, in the field, of large numbers of adult workers[18]. In 2006-2007, some 29% of 577 beekeepers across the country reported CCD and losses of up to 75% of their colonies[19].

The following symptoms were reported[20]:

- Complete absence of adult bees in colonies, with no or little build up of dead bees in the colonies.
- Presence of capped brood.
- Presence of food stores, both honey and bee bread

In collapsing colonies:

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10 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.

11 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.

12 Oldroyd B. P., 2007. "What's Killing American Honey Bees?", PLoS Biol 5(6): e168 doi:10.1371/journal.pbio.0050168.

13 Holden C., "Report Warns of Looming Pollination Crisis in North America", Science 20 October 2006 314: 397 [DOI: 10.1126/science.314.5798.397] (in News of the Week)

14 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)

15 Morse R.A., Calderone N.W., 2000. "The value of honey bees as pollinators of U.S. crops in 2000".

16 Senator Barbara Boxer, a California Democrat, introduced on Friday June 29 2007 "The Pollinator Protection Act", a bill to increase funding for research on honey bees and native pollinators, whose numbers have been in decline in recent decades.

17 Status of Pollinators in North America, summary, National Academy of Sciences (June 2007), http://books.nap.edu/catalog/11761.html, p.4

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

19 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)

20 Fall Dwindle Disease: A preliminary report, December 2006. http://www.ento.psu.edu/MAAREC/pressReleases/FallDwindleUpdate0107.pdf

- Insufficient of workforce, mostly consisting in young adults bees
- The queen is present
- The cluster is reluctant to consume provided feed, such as sugar syrup and protein supplement.

CCD Causes

According to Frazier *et al.* (2007) , the causes of CCD are not yet known. The potential causes investigated by “The CCD working group” are, but are not limited to:

• **Chemical residue/contamination** in the wax, food stores and bees. Due to the evolution of resistances to chemicals of mites and other pathogens, beekeepers may be increasing dose rates or trying cocktails of chemicals exposing commercial honey bees to levels of chemical residue that are inimical to worker longevity.

• **Pathogens** in the bees and brood. For example, European Foul Brood (caused by *Mellisococcus pluton*) , and American Foul Brood (caused by *Paenibacillus larvae*) on larvae and pupae,

• **Parasite load** in the bees and brood. For example, *Varroa destructor* on adult bees.

• **Nutritional fitness** of the adult bees

• **Level of stress** in adult bees as indicated by stress induced proteins

• **Lack of genetic diversity** and lineage of bees making them more vulnerable to the development of epidemics ,

Examples of topics that The CCD working group is not currently investigating:

• **Agricultural insecticides**. American agricultural systems are dependent on the use of pesticides. Where insecticides are used, honey bee losses are common, and where bees are required for pollination, careful management is required to minimize bee losses.

• **Changed agricultural practise**. Due to reduced honey yields nation-wide, beekeepers seek alternative income beyond honey production (for example colonies for almond pollination, crop that is totally dependant on bee pollination”. Anecdotal evidence suggests that CCD is more common in businesses in which bees are trucked large distances and rented for pollination.

• **GMO crops**. Some GMO crops, specifically Bt Corn have been suggested as a potential cause of CCD . While this possibility has not been ruled out, the weight of evidence reported here argues strongly that the current use of Bt crops is not associated with CCD.” [28] CCD symptoms do not fit what would be expected in Bt affected organisms and there is no strong evidence that GM crops cause acute toxicity to honey bees , , . For this reason GMO crops are not a “top” priority at the moment. According to Galen P. Dively (2007).

• **Radiation** transmitted by cell towers: The distribution of both affected and non-affected CCD apiaries does not make this a likely cause. Also cell phone service is not available in some areas where affected commercial apiaries are located in the west. For this reason, it is currently not a top priority.

21 Frazier, M., D. vanEngelsdor, and D. Caro, (2007), Edited by the CCD working group at www.agr.state.il.us/programs/bees/CCD.pdf

22 Bailey L (1983) Melissococcus pluton, the cause of European foulbrood of honey bees (Apis spp.). J Appl Bacteriol 55: 65–69.

23 Ashiralieva A, Genersch E (2006) Reclassifi cation, genotypes and virulence of Paenibacillus larvae, the etiological agent of American foulbrood in honeybees - a review Apidologie 37: 411–420.

24 Oldroyd BP (1999) Coevolution while you wait: Varroa jacobsoni, a new parasite of western honeybees. Trends Ecol Evol 14: 312–315.

25 van Baalen M, Beekman M (2006) The costs and benefi ts of genetic heterogeneity in resistance against parasites in social insects. Am Nat 167: 568–577.

26 Evans JD, Aronstein K, Chen YP, Hetru C, Imler JL et al. (2006) Immune Pathways and defence mechanisms in honey bees Apis mellifera. Ins Mol Biol 15: 645–656.

27 O'Callaghan M, Glare TR, Burgess EPJ, Malone LA (2005) Effects of plants genetically modifi ed for insect resistance on nontarget organisms. Ann Rev Ent 50: 271–292.

28 Dively, G., P., (2007), Summary of Research on the Non-Target Effect of BT Corn Pollen on Honeybees http://www.ento.psu.edu/MAAREC/CCDPpt/NontargeteffectsofBt.pdf

29 Malone LA, Pham-Delegue MH (2001) Effects of transgene products on honey bees (Apis mellifera) and bumblebees (Bombus sp.). Apidologie 32: 287–304.

30 Huang ZY, Hanley AV, Pett WL, Langenberger M, Duan JJ (2004) Field and semifi eld evaluation of impacts of transgenic canola pollen on survival and development of worker honey bees. J Econ Ent 97: 1517–1523.

31 Malone LA, Burgess EPJ, Stefanovic D (1999) Effects of a Bacillus thuringiensis toxin, two Bacillus thuringiensis biopesticide formulations, and a soybean trypsin inhibitor on honey bee (Apis mellifera L.) survival and food consumption. Apidologie 30: 465–473.

• **Cool brood**. If the brood is incubated a little outside the ± 0.5 °C of 34.5 °C range (nest temperature maintained by bees), the resulting adults are normal physically, but show deficiencies in learning and memory[32,33]. If colonies were unable to maintain optimal brood nest temperatures, CCD-like symptoms might be apparent.

The working group on CCD is now concentrating on three different hypotheses [34]:

- Reemerging pathogens responsible for CCD. It has become clear in recent years that many pathogens have the ability to impair the immune defences of their hosts.
- Stresses working together to weaken bee colonies and allowing stress-pathogens to cause final collapse. For example stresses are encountered by bee colonies that are part of migratory operations. As a result of the migratory process, multiple stressors impact in these operations can cause significant losses of honey bee colonies.
- Environmental chemicals causing the immuno-suppression of bees and triggering CCD Amongst other, the neonicotinoids, a class of pesticides that have been extensively adopted for pest management. Although highly effective in controlling insect pests; these chemicals are known to be highly toxic to honey bees and other pollinators.

Latest findings

A comparison of healthy and unhealthy bee colonies points to a virus contributing to Colony Collapse Disorder (CCD), according to a report being published by the journal *Science*, at the *Science* Express web site, on 06 September 2007[35].

A team led by scientists from the Columbia University Mailman School of Public Health, Pennsylvania State University, the USDA Agricultural Research Service, University of Arizona, and 454 Life Sciences has found a significant connection between the *Israeli Acute Paralysis* Virus (IAPV) and colony collapse disorder (CCD) in honey bees. The findings, an important step in addressing the disorder that has been decimating bee colonies across the United States.

3. Factors contributing to the decline

3.1. Habitat fragmentation, loss and degradation

- Degradation and fragmentation as the main adverse habitat changes for pollinator populations[36].
- Hedgerows, field margins, embankments, and other "waste places" provide nesting habitat for some native bees. Removal of these often unappreciated habitats has been associated with dramatic declines in Germany's native bee fauna since the 1960s[37].
- Fragmentation and habitat destruction can add to the rate of genetic erosion by reducing gene flow between demes (locally interbreeding group within a geographic population), and increases the likelihood that populations and species will become extinct[38].
- When large habitats are fragmented into small isolated patches, it is not long before some of the animal residents decline in numbers to the point that they no longer provide effective ecological services

32 Tautz J, Maier S, Groh C, Rossler W, Brockmann A (2003) Behavioral performance in adult honey bees is infl uenced by the temperature experienced during their larval development. Proc Nat Acad Sci U S A 100: 7343–7347.

33 Jones J, Helliwell P, Beekman M, Maleszka RJ, Oldroyd BP (2005) The effects of rearing temperature on developmental stability and learning and memory in the honey bee, Apis mellifera. J Comp Physiol A 191: 1121–1129.

34 Testimony of Diana Cox-Foster at the U.S. House of Representatives Committee on Agriculture

Subcommittee on Horticulture and Organic Agriculture on Colony Collapse Disorder in Honey Bee Colonies in the United States March 29, 2007, http://www.ento.psu.edu/MAAREC/CCDPpt/CoxFosterTestimonyFinal.pdf

35 Diana L. Cox-Foster et al., "A Metagenomic Survey of Microbes in Honey Bee Colony Collapse Disorder," ScienceExpress (6 September 2007): 1-7 (10.1126/science.1146498((sub. req.)

36 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

37 Westrich, P., 1989. "Die Wildbienen Baden-Württembergs. Allgemeiner Teil: Lebensräume, Verhalten, Ökologie und Schutz". Verlag Eugen Ulmer, Stuttgart, Germany.

38 Barrett, S. C. H., and J. R. Kohn. 1991. "Genetic and evolutionary consequences of small population size in plants: implications for conservation". Pages 1-30 in D. A. Falk and K. E. Holsinger, editors. Genetics and conservation of rare plants. Oxford University Press, New York, New York, USA.

beneficial to plants[39]. Because some wild pollinators need undisturbed habitat for nesting, roosting and foraging, they are very susceptible to habitat degradation and fragmentation.

- Urbanisation not only removes habitat directly but also isolates and fragments much of the land that it does not degrade or assimilate.
- Reduction of food sources.
- Fewer sites for mating, nesting and migration.
- (over)grazing and early cutting of hay meadows results in plants not reaching the flowering stage.

However, forest clearing has opened up previously shaded, humid habitats for many sun-loving pollinators and their plants[40]. Roadsides, with their partially compacted soils, are frequently favoured nesting sites for bees and wasps.

3.2. Agriculture practices

Improper use of pesticides, herbicides and insecticides, for example coating seeds with regular or systemic insecticide (such as Imidacloprid), which is absorbed by the root and migrates through every part of the plant including pollen and nectar, poses a potential threat for pollinators such as honeybees and other insects. A study by Bonmatin *et al.*[41] revealed that pesticides, including the ones mentioned above, cause bees to lose their sense of direction. This is the goal for insects harmful to the crops, but should be avoided for useful pollinators. In fact other studies revealed the high toxicity of Imidacloprid and associated inert ingredients for cats, fish, rats, rabbits, birds and earthworms[42].

The replacement of natural plant communities by monoculture, is also a factor since most monoculture are not capable of sustaining pollinator populations: wheat and corn do not provide nectar or pollen needs for any bee species[43]. Adding to this, insecticides are applied not only on agricultural fields but also in backyards, recreational areas, forests and mosquito-ridden marshes and swamps. The broad-spectrum insecticides that are commonly used are often as toxic to beneficial insects as they are to the target species[44].

Whether managed or wild, pollinators need protection from excessive exposure to pesticides and other chemicals that can poison them or impair their reproduction. These chemicals can also eliminate nectar sources for pollinators, destroy larval host plants for moths and butterflies, and deplete nesting materials for bees[45]. On the other hand, it may be that plant losses from chronic herbicide use are, in fact, driving losses of pollinator species, and not vice versa[46]

3.3. Other factors

- Diseases. Honey bees have been affected by *Varroa mites*, which is a virus transmitter, in hives, due to appearance of resistance to acaricides.
- For genetic reasons, bees are more extinction prone than other taxa because single-locus sex determination makes them particularly sensitive to the effects of small population size through the production of sterile diploid males .

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

Bohart, G. E. 1972, Management of habitats for wild bees. Proceedings of the Tall Timbers Conference on Ecological Animal Control by Habitat Management 3: 253-266

41 Bonmatin, J.M., P.A. Marchand, R. Charvet, M.E. Colin, (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.

42 Cox, C., (2001), Imidacloprid, Insecticide factsheet, journal of Pesticide Reform, Vol. 21, N°1, http://www.pesticide.org/imidacloprid.pdf.

43 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. [online] URL: www.consecol.org/vol5/iss1/art1

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

45 Nabhan, G.P. and S.L. Buchmann, 1996 (in press), Pollination services: biodiversity's direct link to world food stability, in G. Daly, ed. Ecosystem Services, Island Press, Washington, D.C.

46 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. [online] URL: www.consecol.org/vol5/iss1/art1

47 Zayed, A. and Packer, L. (2005) Complementary sex determination substantially increases extinction proneness of haplodiploid populations. Proc. Natl. Acad. Sci. U. S. A. 102, 10742–10746

- Competition from invasive non-native species.
- Predators.
- Global and local climate change. Land-cover changes affect regional climates through changes in surface energy and water balance.
- Decrease in larval host plants.
- (Elimination of subsidies for beekeepers)

4. Consequences of decline

- Less frequent flower visitation, abrupt or gradual decrease of seed and fruit production.
- Beekeeping sector in danger in several areas in Europe.
- Self-compatible flower plants can suffer from inbreeding.
- Pistil senescence.

5. International Conventions / Relevant Policy Measures / Recommendations

5.1. Larval stage conservation

Important invertebrate pollinators have discrete larval stages whose mobility and habitat requirements are dramatically different from those of the winged adult. Conservation initiatives have sometimes been slow to consider the needs of different life-cycle stages. For example, many conservation-minded researchers advocate planting nectar plants for butterflies, but then fail to foster their larval host plants[48].

5.2. Alternative agricultural

Alternative agricultural techniques can provide non-toxic methods of weed and insect control that incorporate use of habitat set-asides for beneficial insect populations and require the use of fewer toxins. Gardeners and farmers can rely on alternative non-toxic methods to control pests and weeds. More widespread practice of such methods has the potential to reduce wildlife exposure to insecticides, herbicides and fungicides[49].

Farmers that set aside land to support wild pollinators could be rewarded for such a practice. Unploughed farmland set aside for several years can produce vegetation that supports considerable insect diversity and benefits nearby crops by providing pollinators and other beneficial insects. Large-scale protection and management of habitat networks are required to minimize habitat-related declines and to maximize the ability of species to track the distribution of suitable climate[50].

A major objective will be to identify, test and document good agricultural practices for pollinator conservation and management, through an "ecosystem approach". Farmers might be encouraged to protect "corridors" that connect natural habitats, or uncultivated areas within and around cultivated ones (see also “Pollinator Friendly Practices” from NAPPC.org).

6. Conclusions

Anthropogenic activities may be detrimental to some species but beneficial to others, with sometimes subtle and counter intuitive causal linkages[51, 52]. It is essential to recognize that pollination is not a free service, and that investment and stewardship are required to protect and sustain it. Economic assessments of agricultural productivity should account for the "cost" of sustaining wild and managed pollinator populations[53]. There is a need for Well-documented cases of specific pollinator declines notwithstanding, rapid extrapolation from our

48 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. [online] URL: www.consecol.org/vol5/iss1/art1

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

50 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.

51 Thomas, C. D., and T. M. Jones. 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.

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

53 Ingram M. , Nabhan G. and Stephen Buchmann. “Global Pesticide Campaigner”, Volume 6, Number 4, December 1996.

current knowledge to imply worldwide pollinator and crop production crises might be inappropriate and premature, much uncertainty remains regarding pollinator-pollination declines[54]. As Albert Einstein put it bluntly, "*No bees, no food for mankind. The bee is the basis for life on this earth.*"

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

7. References

1. Wilson E.O, 1999. "The Diversity of Life" (new edition). W.W. Norton & Company, Inc. New-York.
2. Wilcove, D.S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos. 1998. Quantifying threats to imperiled species in the United States. BioScience 48:607-615.
3. Food and Agriculture Organisation of the U.N. at www.fao.org.
4. 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.
5. Ingram M., Nabhan G. and Stephen Buchmann, 1996. "Global Pesticide Campaigner", Volume 6, Number 4, December 1996.
6. Free, J.B., 1993. "Insect Pollination of Crops", Academic Press
7. 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.
8. 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.
9. 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.
10. 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. [online] URL: www.consecol.org/vol5/iss1/art1
11. Oldroyd B. P., 2007. "What's Killing American Honey Bees?", PLoS Biol 5(6): e168 doi:10.1371/journal.pbio.0050168.
12. Holden C., "Report Warns of Looming Pollination Crisis in North America", Science 20 October 2006 314: 397 [DOI: 10.1126/science.314.5798.397] (in News of the Week)
13. 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)
14. Morse R.A., Calderone N.W., 2000. "The value of honey bees as pollinators of U.S. crops in 2000".
15. "Colony Collapse Disorder (CCD) Working Group: Summary of purpose and responsibility" at http://maarec.cas.psu.edu/pressReleases/CCDSummaryWG0207.pdf
16. 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)
17. Senator Barbara Boxer, a California Democrat, introduced on Friday June 29 2007 "The Pollinator Protection Act", a bill to increase funding for research on honey bees and native pollinators, whose numbers have been in decline in recent decades.
18. Status of Pollinators in North America, summary, National Academy of Sciences (June 2007), http://books.nap.edu/catalog/11761.html, p.4
19. Frazier, M., D. vanEngelsdor, and D. Caro, (2007), Edited by the CCD working group at www.agr.state.il.us/programs/bees/CCD.pdf
20. Bailey L (1983) Melissococcus pluton, the cause of European foulbrood of honey bees (Apis spp.). J Appl Bacteriol 55: 65–69.
21. Ashiralieva A, Genersch E (2006) Reclassifi cation, genotypes and virulence of Paenibacillus larvae, the etiological agent of American foulbrood in honeybees - a review. Apidologie 37: 411–420.
22. Oldroyd BP (1999) Coevolution while you wait: Varroa jacobsoni, a new parasite of western honeybees. Trends Ecol Evol 14: 312–315.
23. Van Baalen M, Beekman M (2006) The costs and benefi ts of genetic heterogeneity in resistance against parasites in social insects. Am Nat 167: 568–577.
24. Evans JD, Aronstein K, Chen YP, Hetru C, Imler JL et al. (2006) Immune Pathways and defence mechanisms in honey bees Apis mellifera. Ins Mol Biol 15: 645–656.
25. O'Callaghan M, Glare TR, Burgess EPJ, Malone LA (2005) Effects of plants genetically modifi ed for insect resistance on nontarget organisms. Ann Rev Ent 50: 271–292.
26. Malone LA, Pham-Delegue MH (2001) Effects of transgene products on honey bees (Apis mellifera) and bumblebees (Bombus sp.). Apidologie 32: 287–304.

27. Huang ZY, Hanley AV, Pett WL, Langenberger M, Duan JJ (2004) Field and semifi eld evaluation of impacts of transgenic canola pollen on survival and development of worker honey bees. J Econ Ent 97: 1517–1523.

28. Malone LA, Burgess EPJ, Stefanovic D (1999) Effects of a Bacillus thuringiensis toxin, two Bacillus thuringiensis biopesticide formulations, and a soybean trypsin inhibitor on honey bee (Apis mellifera L.) survival and food consumption. Apidologie 30: 465–473.

29. Tautz J, Maier S, Groh C, Rossler W, Brockmann A (2003) Behavioral performance in adult honey bees is infl uenced by the temperature experienced during their larval development. Proc Nat Acad Sci U S A 100: 7343–7347.

30. Jones J, Helliwell P, Beekman M, Maleszka RJ, Oldroyd BP (2005) The effects of rearing temperature on developmental stability and learning and memory in the honey bee, Apis mellifera. J Comp Physiol A 191: 1121–1129.

31. 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

32. Westrich, P., 1989. "Die Wildbienen Baden-Württembergs. Allgemeiner Teil: Lebensräume, Verhalten, Ökologie und Schutz". Verlag Eugen Ulmer, Stuttgart, Germany.

33. Barrett, S. C. H., and J. R. Kohn. 1991. "Genetic and evolutionary consequences of small population size in plants: implications for conservation". Pages 1-30 in D. A. Falk and K. E. Holsinger, editors. Genetics and conservation of rare plants. Oxford University Press, New York, New York, USA.

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

35. Diana L. Cox-Foster et al., "A Metagenomic Survey of Microbes in Honey Bee Colony Collapse Disorder," ScienceExpress (6 September 2007): 1-7 (10.1126/science.1146498((sub. req.)

36. Cane, J. H. and V. J. Tepedino. 2001. op. cit.

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

38. Nabhan, G.P. and S.L. Buchmann, 1996 (in press), Pollination services: biodiversity's direct link to world food stability, in G. Daly, ed. Ecosystem Services, Island Press, Washington, D.C.

39. 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. [online] URL: www.consecol.org/vol5/iss1/art1

40. Dively, G., P., 2007, "Summary of Research on the Non-Target Effect of BT Corn Pollen on Honeybees", http://www.ento.psu.edu/MAAREC/CCDPpt/NontargeteffectsofBt.pdf

41. Zayed, A. and Packer, L., 2005, "Complementary sex determination substantially increases extinction proneness of haplodiploid populations". Proc. Natl. Acad. Sci. U. S. A. 102, 10742–10746

42. 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. [online] URL: www.consecol.org/vol5/iss1/art1

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

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. Testimony of Diana Cox-Foster at the U.S. House of Representatives Committee on Agriculture

46. Subcommittee on Horticulture and Organic Agriculture on Colony Collapse Disorder in Honey Bee Colonies in the United States March 29, 2007, http://www.ento.psu.edu/MAAREC/CCDPpt/CoxFosterTestimonyFinal.pdf

47. Thomas, C. D., and T. M. Jones. 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.

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

URLs:

a The Sao Paulo Declaration at www.biodiv.org/doc/case-studies/agr/cs-agr-pollinator-rpt.pdf

b International Initiative for the Conservation and Sustainable Use of Pollinators at www.biodiv.org/programmes/areas/agro/pollinators.asp

c The European Pollinator Initiative at www.europeanpollinatorinitiative.org

d The North American Pollinator Protection Campaign at www.nappc.org

e The Pollinator Partnership (Sponsored by The North American Pollinator Protection Campaign and The Coevolution Institute) at www.pollinator.org

f The International Centre for Integrated Mountain Development Initiative from South Asia at www.icimod.org/index.htm)

g The Brazilian Pollinators Initiative at http://eco.ib.usp.br/beelab/bpi_ceara.pdf

h The African Pollinators Initiative at www.up.ac.za/academic/entomological-society/rostrum/apr01/page5.html

i L'Institut National de Recherche Agronomique at www.inra.fr

j Food and Agriculture Organisation of the U.N. at www.fao.org