Horizon scan report on future risks and opportunities

Deliverable 10.9

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PoshBee

Pan-european assessment, monitoring, and mitigation of stressors on the health of bees

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Emerging threats and opportunities to managed bee species in European agricultural systems - A Horizon Scan

Preface

Work Package 10 included Task 10.7, which was to establish a horizon scanning expert group. This expert group then participated in a Horizon scanning exercise leading to this deliverable D10.9 – A Horizon scan report on future risks and opportunities for managed bee health. Based on the outputs of the workshop, the report includes the current (13/02/2023) full draft version of the manuscript being prepared for publication, which presents the future risks and opportunities to managed bee health which were identified and discussed in the workshop. At the time of publishing this deliverable report, the manuscript is still in the final stages of preparation for publication and is undergoing wider review by the expert participants in the workshop. We expect several sections will likely undergo small, but important, edits or alterations. Therefore, the text that appears below represents the final deliverable report, however there will be amendments to the text and formatting that appear in the published manuscript resulting from this task.

Summary

Managed pollinators provide a wide range of benefits to society in terms of contributions to food security, farmer and beekeeper livelihoods, and social and cultural values (Potts et al., 2016). Bees are important pollinators worldwide, with ~20,000 species; however, there are fewer than 20 managed species for crop pollination services (Potts et al., 2016). In Europe, the main managed bee species are *Apis mellifera*, *Bombus terrestris* and, to a lesser extent, solitary bees such as those belonging to the genus *Osmia* (Osterman et al., 2021). Bees, along with other pollinators, face serious threats from disturbances including landscape modification, climate change, pests, pathogens, and agrochemicals (Dicks et al., 2021); while these issues are common across both wild and managed species, there may be other risks or opportunities that are specific to managed bees in a European agricultural context. For example, as managed bees are specifically managed to pollinate crops, they may be at a greater risk of disease transmission due to their higher densities (Bartlett et al., 2019). Identifying these in a timely and effective manner can enable the development of effective policies and mitigation strategies across Europe (EU and national equivalents) to sustain healthy populations of managed bees.

Furthermore, safeguarding European food security and promoting agricultural sustainability remains a prominent political ambition, driving the implementation of the European Green Deal and the Farm to Fork strategy (EC, 2020; EC, 2021). Yet, current geopolitical instabilities and recovery from the worldwide COVID-19 pandemic potentially threaten to undermine many of the identified pathways to achieving these goals (Morales et al., 2022). In hindsight, these issues may or may not have been foreseeable, highlighting the importance of a forward scanning process to ensure policies are preemptive rather than reactive. To make informed decisions, policymakers and practitioners need to anticipate the likely developments and their impacts to understand and proactively develop preventative action plans. A systematic approach, such as routine horizon scanning, can provide the necessary insights to do this (Sutherland et al., 2018; Brown et al., 2016), helping guide research priorities to generate actionable knowledge for policy and practice.

To this end, we used a core expert group to horizon scan for potential threats and opportunities to managed bees in European agricultural systems over the next five to ten years.

1. Methods

We followed a horizon scanning approach based on a modified Delphi technique and previous horizon scans (e.g., Sutherland et al 2018; Brown et al. 2016). A core group of 20 experts from nine European countries undertook the scanning exercise. Participants were members of a wider consortium collaborating on the EU-funded project, PoshBee – Pan-European Assessment, Monitoring and Mitigation of Stressors on the Health of Bees (www.poshbee.eu). Experts were affiliated with research institutes, universities, government and non-government organisations and industry. In this scan, we considered both policy and practice contexts, and issues from within the EU and national equivalents in countries including the UK, Switzerland, and Norway.

Each expert was encouraged to consult with their networks to collect up to 5 potential horizon issues. The aim was to identify poorly known issues that could have a substantial positive or negative impact on managed bees (e.g., *Apis mellifera*, *Bombus* spp., *Osmia* spp.) in European agricultural systems over the next 10 years.

Initial submissions that dealt with similar issues were grouped together by topic area and direction of impact (threat or opportunity), to be scored collectively. A list of 63 issues, including references, was compiled, and sent out to the core expert group to complete a first round of anonymous scoring (Table 1). Issues were scored from 1 (well known, unlikely to have a substantial impact on pollinators) to 100 (poorly known, likely to have a substantial impact on pollinators) following the methods adopted by Brown et al. (2016). From this first round of scoring, we produced a ranked list of issues for each participant and then calculated the median rank for each horizon issue (Table 1). The 20 issues with the highest median scores, along with comments and references, were kept and used for the next stages of the process (Figure 1; highlighted in Table 1). In this horizon scan, with the number of experts we had involved, 20 issues going forward was decided as a reasonable number which could be assessed in depth in the next stages of the process. After this initial scoring, participants were given the opportunity to retain any issues they felt strongly should have been included; one issue was retained by this process.

Based on their established domain knowledge two experts were assigned to each of the 21 issues to play the role of cynic and to further investigate their novelty, likelihood of emergence, and whether the impact on managed pollinators would be a threat, opportunity, or potentially both. Experts were not assigned to issues they had originally proposed. Experts wrote a short report on their assigned issues that included a summary of the current knowledge and evidence for why it was likely to be a significant threat or opportunity over the next decade. These reports were then compiled and shared with the group (authorship of individual reports was not revealed to the group) prior to the workshop discussion. To reduce biases due to reader fatigue, the order of these short reports in the compiled document was reversed for half the participants.

An online workshop, with 16 experts in attendance, was held in July 2022. Each of the 21 issues was discussed, and following each discussion, experts privately re-scored the issue between 1-100, as previously described. The four experts unable to attend the workshop were sent detailed accounts of the discussions that took place and were asked to re-score each issue after reading these accounts.

Table 1: The full list of issues initially identified and ranked as a part of our 2022 Horizon Scan process. Highlighted, bold rows indicate the final shortlisted issues. Column 'Type' refers to whether shortlisted issues were determined to be a threat (T), opportunity (O) or both (B).

			Median Rank	
Issue	**Type**	**Topic**	**1st round scoring**	**2nd round scoring**
1	NA	Densely populated areas - concentrating large number of honeybee colonies in certain areas will be a good breeding ground for the spread of diseases and parasites	25.5	NA
2	NA	The effect of protective covers on managed pollinators	27.5	NA
3	**T**	**Increasing threat of emerging pathogens and predators**	**10**	**2**
4	**O**	**Increase of varroa-resistant stocks of *Apis mellifera***	**17.5**	**7.5**
5	NA	Impact of broad-spectrum insecticides (such as pyrethroids, organophosphates and carbamates) being used more widely in the wake of the ban on neonicotinoids	35.5	NA
6	**B**	**Prime editing and genetically modified crops in Europe**	**23**	**13**
7	NA	Use the eco-exposome concept to protect pollinators	38	NA
8	**T**	**Exposure to micro or nano plastics either alone or in combination with other stressors and transgenerational impacts on bees and bee health**	**20.5**	**8**
9	NA	Develop monitoring and analytical tools to identify and monitor microplastic pollution in the environment	33	NA
10	**T**	**Cutting pollinators out of food production**	**12.5**	**12.5**
11	NA	The replacement of bees with drones, robotic bees, AI	38	NA
12	**T**	**Direct or indirect effects of biopesticides on bees**	**20.5**	**11.5**
13	**T**	**Increase of migratory beekeeping**	**11.5**	**12.5**
14	**T**	**Increase of inexperienced beekeepers**	**22.5**	**7.5**
15	**T**	**Extreme weather events**	**10.5**	**5**
16	**B**	**Impact of Ukraine Invasion on the EU Common Agricultural Policy (Rapid policy changes or delay of the green-deal due to Russian attack on Ukraine), food prices and agroecological transitions**	**20.5**	**12**
17	NA	Increased environmental pollution/ pollinators health and human health (heavy metals & nanomaterials)	24	NA
18	NA	Wild bees as managed pollinators	40	NA
19	NA	Emerging technologies: telecommunication networks 5G (6, 7G) and the impact of electromagnetic fields / high-frequency radiation on bee health	40	NA
20	NA	Impact of covid and resulting quarantine and cross border restrictions on commercial beekeeping and health of managed pollinators	53	NA
21	**B**	**Strengthening trade and biosecurity measures in the EU to better protect local managed bee populations, managed bee breeding and trade.**	**16.5**	**11**
22	NA	Companion cropping and oilseed rape	34	NA
23	NA	What are the impacts of increased technology use in monitoring bee colonies remotely? (e.g., energy consumption concerns, loss of field expertise)	37	NA
24	**O**	**Greater availability of technology and automation to remotely monitor bee colony health.**	**21**	**6.5**

25	NA	Exposure assessment for precision application methods	30	NA
26	NA	New, increasingly user-friendly bee models allow us to generalise ecological patterns and ask questions beyond our empirical abilities	26	NA
27	NA	How do poor regulations surrounding bee hotels and their design, impact on bee health?	49	NA
28	NA	Landscape simplification and the profitability of unifloral honeys, influencing the beekeeper's managing strategies	24	NA
29	**O**	**Artificial intelligence for disease, weed and pest control to reduce pesticide use in agroecosystems**	**23**	**13**
30	NA	Africanized bees and the negative behavioural traits associated with them	48	NA
31	NA	Land abandonment of extensive farmlands and agroforestry systems leading to landscape and vegetation homogenisation which are known to have negative consequences for biodiversity conservation	39.5	NA
32	NA	Strengthen the environmental responsibility: protect the pollinators by law using the crime of ecocide	39	NA
33	NA	Producing bumblebee colonies on demand. Will Biobest, Koppert, and other companies be able to respond to changing crop phenology from climate change. Potentially leading to the over-production of bumblebee colonies and, thus, ethical issues	40	NA
34	NA	Declining air quality (pollution) and the interaction with climate change	24.5	NA
35	**O**	**Thermic vehicles and the hazardous pollutants they release will decrease in the coming years, does switching to electric vehicles represent an opportunity for managed bees?**	**22.5**	**18.5**
36	NA	How do we address the lack of effective and affordable anti-parasitic and veterinary treatments for managed bees?	29	NA
37	NA	Pesticides: Risk of exposure from greenhouses	31	NA
38	**O**	**Co-formulants in agrochemical formulations and managed bee health.**	**9.5**	**7**
39	**O**	**Optimising diets of managed bees to develop better artificial diets and inform agri-environment schemes**	**16**	**10.5**
40	**O**	**Agricultural policy to encourage biodiversity-promoting floral resources on arable land**	**20.5**	**8**
41	**B**	**Accessibility of European pesticide exposure datasets**	**27**	**12**
42	NA	Include testing pesticide side-effects on pollinators in target crops as a requirement in the EU guidelines	27.5	NA
43	NA	Non-destructive DNA sampling for conservation using non-lethal sampling methods like tarsal clips, swabbing or airborne eDNA	36.5	NA
44	**B**	**Changing farm practice and timing of the demand for managed bees**	**21**	**9.5**
45	NA	Development of undetectable methods of adulteration of bee products and production of synthetic products (vegan products)	38	NA
46	NA	Farm-to-Fork strategy and food industry: food industry and retailers as a driver towards pesticide reduction	25	NA
47	NA	Disagreements between beekeeping and wild pollinator conservation groups have potential to spill over into public sphere – through media – might lead to erosion of public trust	35	NA
48	NA	Apis mellifera: spread of unmanaged colonies as an opportunity	29	NA

49	NA	Opportunities to utilise manage pollinators (bumbles and solitaries) in allotments to improve food security and self-sufficiency of urban agriculture	39.5	NA
50	NA	Using plant secondary chemicals to optimise managed bumble bee health	24	NA
51	**B**	**Nanotechnology-based pesticides (NBPs)**	**16**	**3.5**
52	NA	Issue of bee bycatch in pheromone traps	48	NA
53	NA	New spaces for honeybees – solar parks	24	NA
54	NA	Decrease of bee fitness from impacts of multiple stressors (chemical/biological/nutritional) on bee microbiome	31	NA
55	NA	Competition for resources and impacts on health of managed bees	39	NA
56	NA	Silage Crops: A future increase of the cultivation of silage crops could further reduce the availability of forage for managed pollinators in the agricultural landscape	41	NA
57	NA	Tendency to destroy old building that may be suitable habitats for Osmia and other managed cavity-nesting bees	53	NA
58	**O**	**Development of field instruments for evaluation of genetic markers to be used in breeding for resilience.**	**21**	**17.5**
59	NA	Educating younger generation about preserving managed pollinators	27.5	NA
60	NA	Could managed solitary bees be invasive?	38	NA
61	NA	Carbon farming	36	NA
62	NA	Increasing prevalence of artificial grass in urban areas	41	NA
63	NA	Opportunities for Certification for pollinator friendly products and good practices	31.5	NA

2. Results

A summary for each of the 21 shortlisted issues follows (Figure 1; also highlighted in Table 1). Issues are listed by type, i.e., whether they are identified as an opportunity, threat, or both.

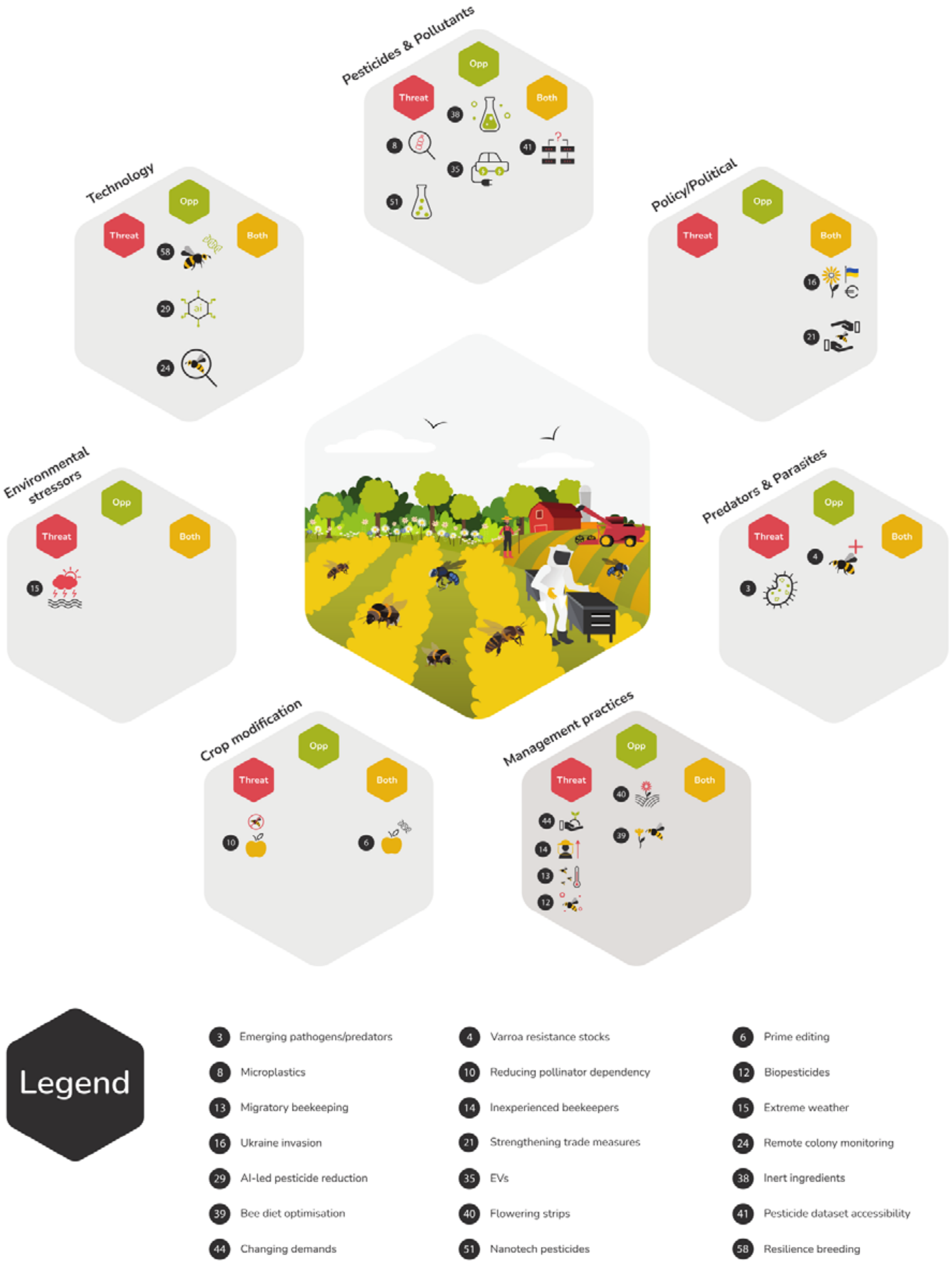

Figure 1: Shortlisted issues were categorised under seven broader themes and by the type of issue (threat, opportunity, or both) they represent.

OPPORTUNITY

Issue #24: Greater availability of technology and automation to remotely monitor bee colony health.
Using technology to monitor and improve bee colony health status is not new; however, the development of new techniques based on artificial intelligence and deep learning has provided enormous recent advances in the field (Odemer, 2021). Advances include systems that track honey bees over hundreds of meters with high precision (Vo-Doan and Straw, 2020), and recent investigations have developed new tools to monitor parameters such as duration and number of foraging trips (i.e., potential proxy for food flow) of individual solitary bees (Knauer et al., 2022). Furthermore, integration of disease and parasite prevalence and levels with meteorological predictions and nectar flow information can provide the basis for important decision support tools for beekeepers. Current data collection is highly unaggregated and diverse. A recent project attempts to integrate these different types of data originating from diverse sources (Simón Delso et al, 2021), but further effort is required in this direction.

If current difficulties are overcome, there is an opportunity for these technological advances to become mainstream tools within 10 years. The development of sensor technology, the spread of wireless infrastructures, the increased ability to manage and model big data and provide predictions, could all together represent an opportunity to interconnect all apiaries across Europe and produce real-time predictions that could support decisions in the field.

Issue #38: Co-formulants in agrochemical formulations and managed bee health.
While co-formulants (ingredients included in formulations that are not expected to have insecticidal impacts) were already shown to have lethal effects on honey bees in the early 1970s (Moffet et al. 1972, Moffet & Morton 1975), it is only recently that concerns about the broader potential impact of these constituents of agrochemical formulations on managed bees has been raised (Straw et al. 2022). This is a potential opportunity to improve managed bee health. For example, a recent study showed that different formulations of a herbicide varied in their toxicity to bumble bees, presumably because of differences in co-formulants rather than the active ingredient (Straw et al. 2021). If future research shows that specific co-formulants have potential toxicity to bees, and these can be removed from formulations and replaced by less toxic ingredients, it could remove a potential threat to bee health from the environment. In addition, if co-formulants are shown to be a risk to managed bees, this could lead to modification of labelling and training for use that reduces exposure.

Issue #4: Increase of varroa-resistant stocks of *Apis mellifera.*
The significant negative impact of varroa mites on honey bees is well-established and widely recognised (Le Conte et al. 2010; van Dooremalen et al. 2012). Most beekeeping operations, from commercial to hobbyist scale, rely heavily on chemical treatments to control mite populations. These, however, can cause negative side effects and may become ineffective due to mites developing resistance (Millan-Leiva et al. 2021). An alternative approach is to selectively enhance heritable honey bee traits of resistance or tolerance to the mite through breeding programs or select for naturally surviving untreated colonies. A recent review (Mondet et al., 2020) of studies on populations resistant or tolerant to varroa showed that in most cases, survival of both naturally and artificially selected populations is due to the expression of several traits that appear to collectively confer resilience to varroa infestation. Currently, a certain number of features are recognised as regulatory traits and can be assessed in the field or in the lab. However, a Europe-wide survey showed that despite huge demand, there is no well-established market for resistant stock in Europe (Buechler et al. 2022). Thus, the next ten tears could represent a turning point for breeding strategies and beekeeping management to be directed towards the development of varroa-resistant stocks.

Issue #40: Agricultural policy to encourage biodiversity-promoting floral resources on arable land.
Incentives to reinstate greater diversity in European farmlands have been introduced for over a decade in the Common Agricultural Policy and led to the implementation of Agri Environmental Schemes (AES), encouraging the reintroduction and widening of vegetated field margins, connectivity corridors and ecological recovery areas (EC, 2012). The benefits of these AES to biodiversity, and in particular pollinators, have been widely studied across Europe (Batary et al. 2015; Dicks et al. 2013) and have led to recommendations on the crucial role of scale and purpose in their effectiveness (Alix et al. 2017, Dicks et al. 2018). The European Green Deal and the associated strategic policies such as the Biodiversity Strategy (EC, 2020), and the Nature Restoration Law (EC, 2022), provide additional insight on the means to regain biodiversity to a reference level by 2050, and include indices to measure the results obtained. Measures to achieve areas of high biodiversity include implementing pollinator-friendly actions, such as the promotion of wild and cultivated flowers on large amounts of arable land (Scheper et al. 2013). These planted flowers directly benefit bees (Jachula et al. 2022) and may reduce the impact of pesticides (Rundlöf et al. 2022, Klaus et al. 2020, Wintermantel et al. 2022). The conversion of significant parts of specific ecosystems to these highly biodiverse areas offers a significant opportunity in sustaining healthy managed bee populations in Europe.

Issue #39: Optimising diets of managed bees to develop better artificial diets and inform agri-environment schemes.
The nutritional requirements of bees may not be sufficiently met due to landscapes being increasingly characterized by agriculturally intensive monocultures and managed bee pollination services frequently occurring within a human-defined ecosystem (Naug, 2009). "Food resource deficiency" in this context refers both to a lack of food and the lower nutritional quality of food sources that are accessible in occupied habitats. The differences between what bees require and what their environment can provide as a result contributes to the decline in bee populations (Hemberger et al. 2021). Consequently, the question arises of whether and how bees should be provided with supplemental food when nutritional deficits occur. This knowledge could be used to improve artificial diets and to inform agri-environment schemes by selecting the appropriate array of floral provision to support pollinators. A recent study, for example, revealed that crushing corn pollen grains, a poor protein source for bees, increased diet digestibility and hemolymph protein content while decreasing honey bee consumption (Omar et al. 2022). These findings could be beneficial to beekeepers in areas where corn monoculture is prevalent.

Issue #29: Artificial intelligence for disease, weed and pest control to reduce pesticide use in agroecosystems.
Artificial Intelligence (AI) is the use of digital data and AI technology to fulfill specific operations such as weeding (using robots that can recognize weeds and remove them), or sensors equipping pesticide sprayers and enabling direct spray of a herbicide only on the weeds. It is estimated that one-third of global crop production is lost due to weed competition and another third due to pest and disease damage, with pesticides effective in combating these (Zhang et al., 2021). The use of sensor-equipped sprayers can reduce the volume of products sprayed by more than 50% (up to 90% for ultra-precision sprayers) (Dorr and Natchtmann, 2022). As early as the mid-1980s, AI for disease, weed and pest control was discussed (Jha et al., 2019; McKinion and Lemmon, 1985), and the first AI applications for crop production were developed (Jha et al., 2019). The use of AI for crop disease and weed control is certainly expected to increase; however, even though AI solutions have already been used for over three decades in agriculture, their use to reduce the risk to bees associated with pesticides is limited (Zhang, 2018). If this trend reverses in the next 10 years due to AI solutions aimed at reducing agrochemical input, it presents a clear opportunity for enhanced managed bee health.

Issue #58: Development of field instruments for evaluation of genetic markers to be used in breeding for resilience.

The identification of molecular markers to indicate the presence of certain resilience traits offers an opportunity to facilitate selective, targeted breeding and enhance the efficiency of bee breeding efforts. There are many honey bee breeding programs and projects in which phenotypic data on honey bee behaviour and development is collected, and increasingly, phenotypic observations are coupled to molecular studies which are paving the way to understanding the molecular pathways underlying specific traits (Mondet et al., 2020). Biotechnology is advancing at a fast pace (Cornelissen, 2021) and recent advances could help to facilitate selection efforts. For instance, causative genes and proteins associated with resistance or tolerance could be developed as marker-assisted selection (MAS) tools for improving breeding stock at a large scale (Guarna et al., 2017; Grozinger and Robinson, 2015). In addition, DNA-based technologies have become more affordable over the last decades, so the financial aspects may not necessarily be prohibitive. Relatively cheap SNP-based assays have already been developed for some traits linked to resilience (Jones et al., 2020). Portable PCR tools are already in use, and it is feasible to foresee portable genetic marker kits that could be used directly in the field and assist beekeepers in selecting colonies with traits linked to resilience (to parasites, to drought, to higher temperatures). However, this potential is offset by various issues including the differing suites of genes underlying resilience and sensitivity to stressors identified in different honey bee populations (Mondet et al., 2020).

Issue #35: Thermic vehicles and the hazardous pollutants they release will decrease in the coming years. Does switching to electric vehicles represent an opportunity for managed bees?

The threat of air pollutants is not particularly novel in itself, but the opportunity arising from a shift from thermic to electric vehicles could be considered a relatively new issue. The global trend in electric vehicles suggests they will move from around a 5-10% market share in 2022 to a 25-50% share (depending upon region) by 2030 (e.g., Deloitte 2020). The expectation is that the pressures on managed pollinators from pollutants from vehicles, in general, will be reduced, although it does not prevent all risks associated with road pollution (e.g., Phillips et al. 2021). The situation is complex and hard to quantify, though qualitatively, the switch to electric vehicles is an improvement from a historical perspective.

THREAT

Issue #3: Increasing threat of emerging predators and pathogens.

The spread of non-native and invasive species and the emergence of novel pathogens or variants of existing ones are a continuing threat to managed bee populations (Proesmans et al. 2021; Requier et al. 2019). For example, climate and human activity-based modelling have shown that Europe may be a suitable niche for the giant hornet *Vespa mandarinia* in the coming years (Zhu et al. 2020), thus becoming a threat to European apiaries and adding to the pressure from *Vespa velutina* (Monceau et al 2014) and *Vespa orientalis*. Furthermore, pathogen transfers such as virus spillover between honey bees and hornets have been found, underlining that hornets may directly (i.e., predation) and indirectly (i.e., pathogen dynamic) impact honey bee populations (Mazzei et al. 2019).

Issue #15: Extreme weather events

The impact of some extreme weather and climatic events on pollinator communities is well-characterised in the literature (Erenler, Gillman, and Ollerton 2020; Nicholson and Egan 2020; Kükrer et al. 2021). However, the novelty and significance of these threats, including those that are less well-characterised (e.g., extreme frost events) remain unknown. In particular, open questions remain over how extreme events might interact with other drivers of decline and potentially exacerbate negative impacts on managed bee populations across Europe. The impacts of extreme temperatures and heatwaves (Martinet et al. 2021; Sutton et al. 2018) are already apparent; for example, there is emerging anecdotal evidence the summer heatwaves of 2022 in France affected egg-laying in honey bees during the *Robinia pseudoacacia* nectar flow and severe Spring rainfall in Spain led to colony collapse due to lack of foraging resources. Any additional interactions between extreme climatic events and other drivers of decline remain a significant threat in the foreseeable future.

Issue #14: Increase of inexperienced beekeepers.
Beekeeper experience is a key factor in determining their response to bee health issues (Morawetz et al. 2019), and an increase in the number of inexperienced beekeepers has been identified as an emerging threat to bee health. Several studies at a pan-European level have found that beekeeper background and apicultural practices are major drivers of honey bee colony losses, with inexperienced beekeepers with small apiaries experiencing double the rate of winter mortality compared to experienced beekeepers due to improper disease control (Jacques et al. 2017; Brodschneider et al., 2018). Sick colonies can also favour the spread of pathogens within *Apis mellifera* due to robbing, and swarming, typical honey bee behaviours, and possibly also across other bee species (Nanetti et al., 2020).

Issue #8: Exposure to micro- or nano-plastics either alone or in combination with other stressors and transgenerational impacts on bees and bee health.
The use, consumption, and disposal of plastics, coupled with their effects on human and the health of other species, has identified microplastics (MPs) (plastics <5 mm, including nano plastics <0.1 µm) as an emerging threat in terrestrial systems (e.g., de Souza Machado et al., 2018). MPs transfer through the food web, are readily absorbed into plants from the soil (Yu et al., 2021) and by bee bodies through contaminated food under laboratory conditions (Buteler et al., 2022). Evidence suggests that MPs can increase honey bee mortality (albeit only at high concentrations: Balzani et al., 2022) and change the diversity of gut biota, gene expression related to oxidative damage, detoxification, and immunity and increase worker susceptibility to antibiotics (Wang et al., 2020). Mixture effects are also likely between MPs and other environmental stressors, and co-occurrences are highly likely in agricultural landscapes; for example, honey bees showed higher mortality to viral infection when exposed to MPs (Deng et al., 2021). MPs can also absorb pollutants such as pesticides, acting as a source and sink of environmental contaminants (Wang et al., 2020). More research is needed to monitor MPs, such as being undertaken in the INSIGNIA project (www.insignia-bee.eu), to generalise exposure patterns, i.e., across food webs (nectar and pollen), between bee species and in different landscape contexts, to provide essential information for their monitoring and management (de Souza Machado et al., 2018; Oliveira et al., 2019). MPs are ubiquitous in the environment and already a major environmental issue for biodiversity (Anbumani & Kakkar, 2018), yet poorly understood in the context of managed bees (Al Naggar et al. 2021). MPs are likely to remain a significant environmental threat.

Issue #12: Direct and indirect effects of biopesticides on bees.
Biopesticides regroup a broad range of products, including natural (or nature identical) chemical substances, plant or animal extracts, pheromones or semiochemicals, untransformed inorganic pesticides and microorganisms (bacteria, viruses, or fungi), and a recent EU regulation update has provided a faster authorisation pathway for their use (EC, 2022). Their activity is highly variable, from broad spectrum (e.g., microorganisms, plant extracts, fermentation products, inorganics) to species specific (e.g., neuropeptides, antibodies). Yet, while their risk assessment is well covered in the case of semiochemicals, inorganics and nature-identical chemicals that are usually the sole active component in a formulation, for complex mixtures, or microorganisms that typically exert activity as an organism plus secondary active metabolites, testing methods are at their infancy or not totally adapted to a clear interpretation of the results. New standardized testing methods are needed to address potential non-intentional effects on bees, if any, of the active substances and their formulations. Testing requirements can then be tailored to needs e.g., broad versus specific mode of action.

Issue #13: Increase of migratory beekeeping.
Increases in drought and severe heat waves will likely contribute to an increase in migratory beekeeping, with increases expected in terms of the proportion of hives relocated and the distance travelled. Recent studies suggest that migratory beekeeping leads to increased disease risk (Jara et al. 2021; Martinez-Lopez et al. 2022), genetic introgression (Jara et al. 2021; Ellis et al. 2018) and may decrease biodiversity among local pollinators (Kukrer et al., 2021). Given the importance of locally adapted genotypes in Europe (Büchler et al. 2014) and the threats posed by disease, increases in migratory beekeeping could have a high negative impact on European honey bee health.

Issue #10: Cutting pollinators out of food production.
Excluding pollinators from food production has been previously highlighted as a horizon scan issue (Brown et al., 2016) and continues to be a significant threat to the sustainability of managed bee populations through breeding and cultivation practices. For example, methods to promote parthenocarpy (fruit set in the absence of fertilisation), such as genetic modification, hormone application and selective breeding, may reduce the need for pollinators in many horticultural crops (Knapp et al. 2016). Whilst reducing our dependence on pollinators may allow growers to extend their growing seasons, it could remove our imperative to utilise bees (Brown et al. 2016), ultimately affecting pollination of non-parthenocarpic pollinator-dependent crops that include seed and nut crops and wild plants. Furthermore, the trend in agriculture to increasingly incorporate crops under permanent cover into rotations also poses an issue. Crops under protective cover have been found to negatively impact on honey bee health and foraging (Evans et al., 2019). Data on crop cultivation under permanent cover protection is barely available, making it hard to estimate the extent of the issue.

BOTH

Issue #51: Nanotechnology-based pesticides (NBPs).
Nanotechnology can modify a pesticide's solubility, stability, and efficacy to improve crop protection. However, this process changes NBPs' environmental fate and behaviour, i.e., what they break down into, how quickly, and their behaviour in the air, soil, water, and plant materials, compared to conventional pesticides. NBPs may be an opportunity for managed bees as their stability and controlled-release mechanisms increase efficiency and thereby reduce the quantity of chemical required on crops (Meyer et al., 2015). But this emerging technology has outpaced our understanding of how NBPs may affect pollinators (Hooven et al., 2019; Chaud et al., 2021); only one study has explored the effect of NBPs on pollinators, showing that pyrethrum extract in a nanocarrier was safer than traditional pyrethrum extract (Oliveira et al., 2019). However, similar to traditional pesticides, NBPs may threaten managed bees and other non-target organisms through toxicity, yet virtually no data exist to test this (Sun et al., 2019). Indeed, the structure of NBPs, similar to pollen, means that bees are adapted to collect and move NBPs, resulting in their exposure (Hooven et al., 2019). NBP technology and design are rapidly developing, poorly understood, and likely to substantially impact managed bees in agricultural landscapes; thus, NBPs are likely to be a significant environmental threat as well as opportunity to managed bees.

Issue #44: Changing farm practice and timing of the demand for managed bees.
Among the Green Deal strategic policies, the development of Sustainable Food Systems (UNEP, 2021) foresees a significant change in food production schemes and practices, which may either pose an opportunity or a threat depending on the context and the practices recommended or adopted. For example, opportunities may exist through fulfilling global strategic orientations towards more diverse crop productions, less dependence on global markets and increased connection to local production sources, and more sustainable approaches taken with respect to the use of water and energy

resources. This will operate alongside changes triggered by adaptations to climate change, which the policies are trying to tackle. In this context, modifications will be observed in crop availability, growing and flowering seasons, with concomitant impacts on the need for managed pollinators in space and time to meet crop pollination demands and honey production.

Issue #21: Strengthening trade and biosecurity measures in Europe to better protect local managed bee populations, managed bee breeding and trade.

The lack of limitations on the trade and movement of managed bees, other than for health reasons, has caused genetic erosion of local bee populations (Péntek-Zakar et al., 2015; Tanasković et al., 2022; Ilyasov et al, 2020; Ellis et al, 2018; Muñoz et al., 2016), ultimately resulting in the loss of traits involved in bee resilience. Currently, bees fall under several regulations governing importation at European borders (regulation 2021/632, (EU) 2017/625, 2021/403). However, these official texts do not mention subspecies of bees. Moreover, only honey bee queens and bumble bees are permitted to enter the EU, subject to good health status. Typically, imported bees are checked for signs of small hive beetle (*Aethina tumida*), mites (*Tropilaelaps* spp. and *Varroa* spp.) and bacterial (*Paenibacillus larvae*) infestations. But there are no regulations regarding other pathogens or the magnitude of the trade (Commission Delegated Regulation (EU) 2020/692). Furthermore, there is also a need for subspecies of bees to be included in the regulation, with genotype-environment interactions described as underlying the complex relationships between local populations of honey bees, landscape, infection, and parasites (particularly *Varroa* spp., viruses and *Nosema* spp.), and for regulations on solitary bee trade to be introduced. If regulations do not change, they will continue to pose a threat to managed bee populations. There is thereby an opportunity for EU legislators to include biodiversity protection of managed bees in the CAP strategy and more specifically in National Apiculture Programmes. In this way, trade and biosecurity measures can contribute to the protection of local managed bee populations from genetic introgression as well as from the spread of diseases.

Issue #16: Impact of Ukraine Invasion on the EU Common Agricultural Policy (Rapid policy changes or delay of the green-deal due to Russian attack on Ukraine), food prices and agroecological transitions.

The Russian invasion of Ukraine has significantly affected the import and export of grains and other crops that impact food security. In response, the European Commission (EU Commission 2022) has presented a range of short-term and medium-term actions to enhance global food security and to support farmers. Impacts of this conflict on the agricultural policy of Europe may be both a threat and an opportunity for managed bees. For example, the recent decision to allow the tillage of fallow lands to ameliorate food shortages due to the conflict may lead to a reduction in the uptake of AES measures (agriculture environment schemes e.g., wildflower strips) that benefit bees. However, if alternative crops which are mass flowering, such as clover or sunflower are planted then the result could be beneficial for bees (Harris & Ratnieks, 2022).

Issue #41: Accessibility of European pesticide exposure datasets.

Researchers, particularly ecotoxicologists, need precise information on pesticide use in the landscape. Through the EU Pesticides Database (https://food.ec.europa.eu/plants/pesticides/eu-pesticides-database_en), users can access information on active substances used in plant protection products, Maximum Residue Levels (MRLs) in food products, and emergency authorisations of plant protection products in Member States However, the database does not provide information on spatial and temporal patterns of use of commercial products across Europe. There are two main sources of information for pesticide use at the European level: the Common Agriculture Policy (CAP) dataset and data produced to comply with the regulation (EC) No 1185/2009 - statistics on pesticides (EC, 2009)). However, currently these datasets are not open to the public. Although there are attempts to address these issues in the regulatory framework, for example, through the specification for records of pesticide use to be kept by farmers (EC, 2009), data from the different European countries are not aggregated in a single database and efforts remain to be made to standardise data collection and collation across Member States.

Issue #6: Prime editing and genetically modified crops in Europe.
The EU currently has extensive limits on the use and development of GM crops (i.e., only GM maize crops (MON810) can be found for now in Spain and Portugal); however, Member States are seeking new regulatory frameworks to make EU research institutions competitive at an international level (European Parliament 2021). This presents an opportunity as the first prime edited plant species could be commercially available next year (Eisenstein 2022), joining a number a genetically modified (GM) crops already utilised worldwide (Kumar et al. 2020). Along with base editing, prime editing is a relatively new genomic technique based on the CRISPR–Cas9 system (Jinek et al. 2012). As far as managed bees are concerned, impacts likely differ among crop resistance properties. While insect-resistant crops paradoxically have little impact on bees (Malone and Burgess 2009) and benefit non-target organisms due to reductions in insecticide use (Brookes & Barfoot 2018), herbicide-resistant crops favour the use of herbicides around valuable crops. This extensive use of herbicides eliminates non-cultivated plants and weeds around crop fields that are known to be beneficial to pollinators (Roy et al. 2003, Balfour & Ratnieks 2022). There are also potential risks for managed bees of other GM crop types, such as abiotic stress-resistant, disease-tolerant, and nutritionally improved crops, which have never been assessed.

3. Concluding remarks

In this horizon scan we identified a series of 63 issues (threat, opportunity, or both) with the potential to impact on managed bees in European agricultural systems. Through the horizon scanning process, 21 issues were prioritised and these fell under seven broader themes (Figure 1): *Pesticides & pollutants, Technology, Management practices, Predators & parasites, Environmental stressors, Crop modification and Political influences.*

A consistent point raised across multiple issues under the theme of *Pesticides & pollutants* was a current dearth of knowledge on the impact on managed bee populations, for example, around the threat posed by microplastic accumulation and its movement through the food chain (Issue #8), the fast-paced emergence of NBPs (Issue #51), or the transition from thermic to electric vehicles (Issue #35). For microplastics, current projects (e.g., Insignia and IPol-ERA) are beginning to quantify their impact on various aspects of managed bee health and, with EU policies set in place to ban plastics, results from these projects will be best placed to inform future monitoring activities and regulatory practices. There was also a recognition of the need to strengthen current EU pesticide reduction policies through measures such as stipulating requirements on the use of effective co-formulants (Issue #38) and providing standardised data on the spatial and temporal use of commercial pesticide products across Member States (Issue #41).

Three opportunities prioritised in this scan fell under the theme of *Technology*. These ranged from remotely monitoring bee health (Issue #24) and evaluating genetic markers in the field (Issue #58) to the use of artificial intelligence in reducing pesticide use in agriculture (Issue #29). Rapid advancements in biotechnology and tools are facilitating in-field monitoring and evaluation capabilities that, if widely adopted, are expected to be beneficial to managed bee health status and breeding stocks.

The threat to managed bees from extreme weather events (Issue #15) was the only issue to fall under the theme of *Environmental stressors*. The impact of well-characterised events, such as heat waves and drought, are already impacting bees and beekeeping practices (Erenler, Gillman, and Ollerton 2020; Nicholson and Egan 2020; Kükrer et al. 2021). However, the potential threat to managed bees from interactions between extreme events (including less well characterised events such as frosts) and other stressors (e.g., pesticides and parasites) was recognised as a high priority area for research and will need to be considered in future policy outlooks.

Extreme weather events and their impact are also strongly tied to several issues raised under the theme of *Management practices*. The continuing threat to managed bee health posed by increased migratory beekeeping (Issue #13) is in direct response to heatwave and drought events and is also linked to changing farm practices (Issue #44) which are imminent with the transition to sustainable food systems and with adaptations to deal with climate change issues.

Finally, two issues were raised that fell under the theme of *Political and trade influence*. The European Commission response to recent geopolitical developments, such as the war on Ukraine (Issue #16), was raised here Particularly noteworthy was the uncertainty around the impact on managed bees of short and medium-term actions aimed at supporting farmers and food security which may negate bee beneficial practices. Alongside the uncertainty of rapid policy changes in response to ongoing geopolitical issues was the need to strengthen trade regulations to better protect managed bee populations (Issue #21).

Given the accelerating pace of technology, the trajectory for current policy development and geopolitical crises, we highlight the need to repeat this exercise in 5 years.

4. References

Alix A, Brown C, Capri E, et al. (2017) Mitigating the Risks of Plant Protection Products in the Environment: MAgPIE workshop. SETAC editions. ISBN: 978-1-880611-99-9 Publication Date: May 2017. Publisher: SETAC.

Al Naggar, Y., Brinkmann, M., Sayes, C. M., Al-Kahtani, S. N., Dar, S. A., El-Seedi, H. R., ... & Giesy, J. P. (2021). Are honey bees at risk from microplastics? Toxics, 9(5), 109.

Anbumani, S., & Kakkar, P. (2018). Ecotoxicological effects of microplastics on biota: a review. Environmental Science and Pollution Research, 25, 14373-14396.

Balfour, N. and Ratnieks, F. The disproportionate value of 'weeds' to pollinators and biodiversity. J. Appl. Ecol. 59, 1209–1218 (2022).

Balzani, P., Galeotti, G., Scheggi, S., Masoni, A., Santini, G., & Baracchi, D. (2022). Acute and chronic ingestion of polyethylene (PE) microplastics has mild effects on honey bee health and cognition. Environmental Pollution, 305, 119318.

Batáry P, Dicks LV, Kleijn D and Sutherland WJ (2015) The role of Agri-environment schemes in conservation and environmental management. Conservation Biology 29: 1006–1016. https://doi.org/10.1111/cobi.12536.

Brodschneider et al. (2018). Multi-country loss rates of honey bee colonies during winter 2016/2017 from the COLOSS survey, Journal of Apicultural Research, 57:3, 452-457

Brookes, G. and Barfoot, P. Environmental impacts of genetically modified (GM) crop use 1996–2016: impacts on pesticide use and carbon emissions. GM Crops Food. 9:109–139 (2018).

Brown, M. J., Dicks, L. V., Paxton, R. J., Baldock, K. C., Barron, A. B., Chauzat, M. P., ... & Stout, J. C. (2016). A horizon scan of future threats and opportunities for pollinators and pollination. PeerJ, 4, e2249.

Buechler, R., Uzunov, A., Costa, C., Meixner, M., Le Conte, Y., Mondet, F., Kovacic, M., Andonov, S., Carreck, N.L., Dimitrov, L., Basso, B., Bienkowska, M., Dall'Olio, R., Hatjina, F., Wirtz, U. EurBeST – a pilot study testing varroa resistant bees under commercial beekeeping conditions. January 2022 American Bee Journal 162(2):213. DOI:10.2762/470707

Buteler, M., Alma, A. M., Stadler, T., Gingold, A. C., Manattini, M. C., & Lozada, M. (2022). Acute toxicity of microplastic fibers to honeybees and effects on foraging behavior. Science of The Total Environment, 822, 153320.

Casanelles-Abella, J., Moretti, M. Challenging the sustainability of urban beekeeping using evidence from Swiss cities. npj Urban Sustain 2, 3 (2022).

Chaud, M., Souto, E. B., Zielinska, A., Severino, P., Batain, F., Oliveira-Junior, J., & Alves, T. (2021). Nanopesticides in agriculture: Benefits and challenge in agricultural productivity, toxicological risks to human health and environment. Toxics, 9(6), 131.

Cornelissen Marc, Małyska Aleksandra, Nanda Amrit Kaur, Klein Lankhorst René, Parry Martin A.J., Rodrigues Saltenis Vandasue, Pribil Mathias, Nacry Philippe, Inzé Dirk, Baekelandt Alexandra, Biotechnology for Tomorrow's World: Scenarios to Guide Directions for Future Innovation, Trends in Biotechnology, Volume 39, Issue 5, 2021, Pages 438-444, ISSN 0167-7799

De La Rúa, P; Jaffé, R; Dall'olio, R; Muñoz, I; Serrano, J (2009) Biodiversity, conservation and current threats to European honey bees. Apidologie 40: 263-284

de Souza Machado, A. A., Kloas, W., Zarfl, C., Hempel, S., & Rillig, M. C. (2018). Microplastics as an emerging threat to terrestrial ecosystems. Global change biology, 24(4), 1405-1416.

Deloitte (2020) https://www2.deloitte.com/uk/en/insights/focus/future-of-mobility/electric-vehicle-trends-2030.html

Deng, Y., Jiang, X., Zhao, H., Yang, S., Gao, J., Wu, Y., ... & Hou, C. (2021). Microplastic polystyrene ingestion promotes the susceptibility of honeybee to viral infection. Environmental science & technology, 55(17), 11680-11692.

Dicks, L.V., Abrahams, A., Atkinson, J., Biesmeijer, J., Bourn, N., Brown, C., Brown, M.J., Carvell, C., Connolly, C., Cresswell, J.E. and Croft, P. (2013). Identifying key knowledge needs for evidence ‐ based conservation of wild insect pollinators: a collaborative cross ‐ sectoral exercise. Insect Conservation and Diversity, 6(3), pp.435-446.

Dicks, L. (2018). Enabling ecological intensification of agriculture through policy. In ECCB2018: 5th European Congress of Conservation Biology. 12th-15th of June 2018, Jyväskylä, Finland. Open Science Centre, University of Jyväskylä.

Dicks, L. V., Breeze, T. D., Ngo, H. T., Senapathi, D., An, J., Aizen, M. A., ... & Potts, S. G. (2021). A global-scale expert assessment of drivers and risks associated with pollinator decline. Nature Ecology & Evolution, 5(10), 1453-1461.

Dörr, J. & Nachtmann, M. 2022. Handbook Digital Farming. Digital Transformation for Sustainable Agriculture, Springer Berlin, 403 pp.

Eisenstein, M. Base edit your way to better crops. Nature. 604, 790–792 (2022).

Ellis, J.S., Soland-Reckeweg, G., Buswell, V.G. et al. Introgression in native populations of Apis mellifera mellifera L: implications for conservation. J Insect Conserv 22, 377–390 (2018).

Erenler, H. E., Gillman, M. P., & Ollerton, J. (2020). Impact of extreme events on pollinator assemblages. Current Opinion in Insect Science, 38, 34-39.

European Commission (2009) REGULATION (EC) No 1185/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 November 2009 concerning statistics on pesticides.

European Commission (2012) Innovating for Sustainable Growth: A Bioeconomy for Europe. Brussels, 13.2.2012, COM (2012) 60 final.

European Commission (2020). Communication on the Biodiversity strategy. EUR-Lex - 52020DC0380 - EN - EUR-Lex (europa.eu)

European Commission (2020). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, EU biodiversity strategy for 2030: Bringing nature back into our lives. EU Commission.

European Commission (2021). Proposal for a regulation of the European Parliament and the Council establishing rules on support for strategic plans to be drawn up by Member States under the Common agricultural policy (CAP Strategic Plans) (Consolidated version of 28 July 2021). EU Commission.

European Commission (2021): Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee of the Regions: Progress in the implementation of the EU Pollinators Initiative.

European Commission (2022a) COMMISSION REGULATION (EU) 2022/1438 of 31 August 2022 amending Annex II to Regulation (EC) No 1107/2009 of the European Parliament and of the Council as regards specific criteria for the approval of active substances that are micro-organisms

European Commission (2022): Honey Bees: Movements between Member States and entry into the Union.https://ec.europa.eu/food/animals/live-animal-movements/honey-bees/movements-between-member-states-and-entry-union_en

European Parliament - Prospects and challenges for the EU apiculture sector - European Parliament resolution of 1 March 2018 on prospects and challenges for the EU apiculture sector, P8_TA(2018)0057, (2017/2115(INI)), (2019/C 129/05)

European Parliament. New genomic techniques: European Commission study and first reactions (10/2021). . Accessed on 27/05/2022.

Evans, L. J., Cutting, B. T., Jochym, M., Janke, M. A., Felman, C., Cross, S., ... & Goodwin, M. (2019). Netted crop covers reduce honeybee foraging activity and colony strength in a mass flowering crop. Ecology and evolution, 9(10), 5708-5719.

Fontana P. et al. (2018) - Appeal for biodiversity protection of native honey bee subspecies of Apis mellifera in Italy (San Michele all'Adige declaration). Bulletin of Insectology 71: 257-271.

Gérard M, Vanderplanck M, Wood T, Michez D. Global warming and plant-pollinator mismatches. Emerg Top Life Sci. 2020 Jul 2;4(1):77-86.

Grozinger CM, Robinson GE. The power and promise of applying genomics to honey bee health. Curr Opin Insect Sci. 2015 Aug 1;10:124-132.

Guarna, M. M., Hoover, S. E., Huxter, E., Higo, H., Moon, K. M., Domanski, D., ... & Foster, L. J. (2017). Peptide biomarkers used for the selective breeding of a complex polygenic trait in honey bees. Scientific reports, 7(1), 8381.

Hadjur, H., Ammar, D., Lefèvre, L. Toward an intelligent and efficient beehive: A survey of precision beekeeping systems and services. Computers and Electronics in Agriculture, 2022, 192, pp.1-16.

Harris C., Ratnieks F.L.W. Clover in agriculture: combined benefits for bees, environment, and farmer. J Insect Conserv. 26, 339–357 (2022)

Hemberger, J., Crossley, M. S., & Gratton, C. (2021). Historical decrease in agricultural landscape diversity is associated with shifts in bumble bee species occurrence. Ecology Letters, 24(9), 1800-1813

Hooven, L. A., Chakrabarti, P., Harper, B. J., Sagili, R. R., & Harper, S. L. (2019). Potential risk to pollinators from nanotechnology-based pesticides. In Molecules (Vol. 24, Issue 24). MDPI AG.

Ilyasov, R, Myeong-Lyeol Lee, Ural Yunusbaev, Alexey Nikolenko, Hyung-Wook Kwon, Estimation of C-derived introgression into A. m. mellifera colonies in the Russian Urals using microsatellite genotyping, Genes & Genomics, 10.1007/s13258-020-00966-0, 42, 9, (987-996), (2020).

Jachuła, J., Denisow, B., Wrzesień, M., & Ziółkowska, E. (2022). The need for weeds: Man-made, non-cropped habitats complement crops and natural habitats in providing honey bees and bumble bees with pollen resources. Science of The Total Environment, 156551.

Jacques A, Laurent M, Ribiere-Chabert M, Saussac M, Bougeard S, Budge GE, Hendrikx P, Chauzat M-P. A pan-European epidemiological study reveals honey bee colony survival depends on beekeeper education and disease control. PLoS ONE 2017, 12(3)

Jara, L.; Ruiz, C.; Martín- Hernández, R.; Muñoz, I.; Higes, M.; Serrano, J.; De la Rúa, P. The Effect of Migratory Beekeeping on the Infesta- tion Rate of Parasites in Honey Bee (Apis mellifera) Colonies and on Their Genetic Variability. Microorganisms 2021, 9, 22.

Jha, K., Doshi, A., Patel, P., Shah, M. (2019). A comprehensive review on automation in agriculture using artificial intelligence. Artif. Intell. Agric. 2, 1–12.

Jinek, M.; Chylinski, K.; Fonfara, I.; Hauer, M.; Doudna, J.A. and Charpentier, E. A programmable dual-RNA-guided DNA endonuclease in adaptive bacterial immunity. Science. 337, 816–821 (2012).

Jones, JC, Du, ZG, Bernstein, R, et al. Tool for genomic selection and breeding to evolutionary adaptation: Development of a 100K single nucleotide polymorphism array for the honey bee. Ecol Evol. 2020; 10: 6246– 6256.

Klaus, F., Tscharntke, T., Bischoff, G., & Grass, I. (2021). Floral resource diversification promotes solitary bee reproduction and may offset insecticide effects‐evidence from a semi‐field experiment. Ecology Letters, 24(4), 668-675.

Knapp, J. L., Bartlett, L. J., & Osborne, J. L. (2017). Re‐evaluating strategies for pollinator‐dependent crops: How useful is parthenocarpy? Journal of Applied Ecology, 54(4), 1171-1179.

Knauer, A. C., Gallmann, J., & Albrecht, M. (2022). Bee Tracker–an open‐source machine learning‐based video analysis software for the assessment of nesting and foraging performance of cavity‐nesting solitary bees. Ecology and Evolution, 12(3), e8575.

Kükrer M, Kence M and Kence A (2021) Honey Bee Diversity Is Swayed by Migratory Beekeeping and Trade Despite Conservation Practices: Genetic Evidence for the Impact of Anthropogenic Factors on Population Structure. Front. Ecol. Evol. 9:556816

Kumar, K.; Gambhir, G.; Dass, A.; Tripathi, A.K.; Singh, A.; Jha, A.K.; Yadava, P.; Choudhary, M. and Rakshit, S. Genetically modified crops: current status and future prospects. Planta. 251, 91 (2020).

Le Conte, Y., Meixner, M. D., Brandt, A., Carreck, N. L., Costa, C., Mondet, F., & Büchler, R. (2020). Geographical distribution and selection of European honey bees resistant to Varroa destructor. Insects, 11(12), 873.

Le Conte, Y., Ellis, M., & Ritter, W. (2010). Varroa mites and honey bee health: can Varroa explain part of the colony losses?. Apidologie, 41(3), 353-363.

Malone LA and Burgess EPJ, Impact of genetically modified crops on pollinators, in Environmental Impact of Genetically Modified Crops, ed. by Fery N and AMR G. CAB International, Wallingford, pp. 199–222 (2009).

Martinet, B., Zambra, E., Przybyla, K., Lecocq, T., Anselmo, A., Nonclercq, D., ... & Hennebert, E. (2021). Mating under climate change: Impact of simulated heatwaves on the reproduction of model pollinators. Functional Ecology, 35(3), 739-752.

Martínez-López, V., Ruiz, C., & De la Rúa, P. (2022). Migratory beekeeping and its influence on the prevalence and dispersal of pathogens to managed and wild bees. International Journal for Parasitology: Parasites and Wildlife.

Mazzei, M., Cilia, G., Forzan, M. et al. Detection of replicative Kashmir Bee Virus and Black Queen Cell Virus in Asian hornet Vespa velutina (Lepelieter 1836) in Italy. Sci Rep 9, 10091 (2019).

McKinion, J.M., Lemmon, H.E., 1985. Expert systems for agriculture. Comput. Electron. Agric. 1, 31–40.

Meixner D.M., Costa C., Kryger P., Hatjina F., Bouga M., Ivanova E., Büchler R. (2010) - Conserving diversity and vitality for honey bee breeding. Journal of Apicultural Research 49 (1): 85-92.

Meyer, W. L., Gurman, P., Stelinski, L. L., & Elman, N. M. (2015). Functional nano-dispensers (FNDs) for delivery of insecticides against phytopathogen vectors. Green Chemistry, 17(8), 4173-4177.

Millán-Leiva, A., Marín, Ó., De la Rúa, P. et al. Mutations associated with pyrethroid resistance in the honey bee parasite Varroa destructor evolved as a series of parallel and sequential events. J Pest Sci 94, 1505–1517 (2021).

Moffet JO, Morton HL, MacDonald RH. (1972) Toxicity of some herbicidal sprays to honey bees. J. Econ. Entomol. 65, 32–36. (doi:10.1093/jee/65.1.32)

Moffett JO, Morton HL. (1975) Repellency of surfactants to honey bees. Environ. Entomol. 4, 780–782. (doi:10.1093/ee/4.5.780)

Monceau K, Bonnard O and Thiéry D, 2014. Vespa velutina: a new invasive predator of honeybees in Europe. Journal of Pest Science volume 87, pages 1–16 (2014).

Mondet, F.; Beaurepaire, A.; McAfee, A.; Locke, B.; Alaux, C.; Blanchard, S.; Danka, B.; Le Conte, Y. Honey bee survival mechanisms against the parasite Varroa destructor: A systematic review of phenotypic and genomic research efforts. Int. J. Parasitol. 2020, 50, 433–447

Mondet, F., Parejo, M., Meixner, M. D., Costa, C., Kryger, P., Andonov, S., ... & Büchler, R. (2020). Evaluation of suppressed mite reproduction (SMR) reveals potential for Varroa resistance in European Honey Bees (Apis mellifera L.). Insects, 11(9), 595.

Morales, M. B., Díaz, M., Giralt, D., Sardà-Palomera, F., Traba, J., Mougeot, F., ... & Bota, G. (2022). Protect European green agricultural policies for future food security. Communications Earth & Environment, 3(1), 1-3.

Morawetz L, Köglberger H, Griesbacher A, Derakhshifar I, Crailsheim K, Brodschneider R, et al. (2019) Health status of honey bee colonies (Apis mellifera) and disease-related risk factors for colony losses in Austria. PLoS ONE 14(7): e0219293.

Muñoz, I, Dora Henriques, Laura Jara, J. Spencer Johnston, Julio Chávez ‐ Galarza, Pilar De La Rúa, M. Alice Pinto, SNPs selected by information content outperform randomly selected microsatellite loci for delineating genetic identification and introgression in the endangered dark European honeybee (Apis mellifera mellifera), Molecular Ecology Resources, 10.1111/1755-0998.12637, 17, 4, (783-795), (2016).

Nanetti A, Bortolotti L, Cilia G. Pathogens Spillover from Honey Bees to Other Arthropods. Pathogens. 2021; 10(8):1044.

Naug, D. (2009). Nutritional stress due to habitat loss may explain recent honeybee colony collapses. Biological Conservation, 142(10), 2369-2372

Nicholson, C. C., & Egan, P. A. (2020). Natural hazard threats to pollinators and pollination. Global Change Biology, 26(2), 380-391.

Odemer, R. (2022). Approaches, challenges and recent advances in automated bee counting devices: A review. Annals of Applied Biology, 180(1), 73-89.

Oliveira, M., Ameixa, O. M., & Soares, A. M. (2019). Are ecosystem services provided by insects "bugged" by micro (nano) plastics? TrAC Trends in Analytical Chemistry, 113, 317-320.

Omar, E. M., Darwish, H. Y., Othman, A. A., El-Seedi, H. R., & Al Naggar, Y. (2022). Crushing corn pollen grains increased diet digestibility and hemolymph protein content while decreasing honey bee consumption. Apidologie, 53(5), 1-12.

Osterman, J. et al., (2021): Global trends in the number and diversity of managed pollinator species. – Agriculture, Ecosystems & Environment,

Péntek-Zakar, E., Oleksa, A., Borowik, T. and Kusza, S. (2015), Population structure of honey bees in the Carpathian Basin (Hungary) confirms introgression from surrounding subspecies. Ecol Evol, 5: 5456-5467.

Phillips, BB, Bullock, JM, Gaston, KJ, et al. (2021). Impacts of multiple pollutants on pollinator activity in road verges. J Appl Ecol, 58: 1017– 1029.

Potts, S. G., Imperatriz-Fonseca, V., Ngo, H. T., Biesmeijer, J. C., Breeze, T. D., Dicks, L. V., ... & Vanbergen, A. J. (2016). The assessment report on pollinators, pollination and food production: summary for policymakers. Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

Proesmans W, Albrecht M, Gajda A, Neumann P, Paxton RJ, Pioz M, Polzin C, Schweiger O, Settele J, Szentgyörgyi H, Thulke HH, Vanbergen AJ. Pathways for Novel Epidemiology: Plant-Pollinator-Pathogen Networks and Global Change. Trends Ecol Evol. 2021

Requier, F., Rome, Q., Chiron, G. et al. Predation of the invasive Asian hornet affects foraging activity and survival probability of honey bees in Western Europe. J Pest Sci 92, 567–578 (2019).

Roy, D. B.; Bohan D.A.; Haughton A.J.; Hill M.O.; Osborne J.L.; Clark S.J.; Perry J.N.; Rothery P.; Scott R.J.; Brooks D.R.; Champion G.T.; Hawes C.; Heard M.S. and Firbank L.G. Invertebrates and vegetation of field margins adjacent to crops subject to contrasting herbicide regimes in the Farm Scale Evaluations of genetically modified herbicide–tolerant crops. Phil. Trans. R. Soc. Lond. B. 358, 1879–1898 (2003).

Rundlöf, M., Stuligross, C., Lindh, A., Malfi, R. L., Burns, K., Mola, J. M., ... & Williams, N. M. (2022). Flower plantings support wild bee reproduction and may also mitigate pesticide exposure effects. Journal of Applied Ecology, 59(8), 2117-2127.

Scheper, J., Holzschuh, A., Kuussaari, M., Potts, S. G., Rundlöf, M., Smith, H. G., & Kleijn, D. (2013). Environmental factors driving the effectiveness of European agri‐environmental measures in mitigating pollinator loss‐a meta‐analysis. Ecology letters, 16(7), 912-920.

Simón Delso N, Sušanj G and Salazar Abello A, 2021. The EUBP Prototype Platform: data model description. EFSA supporting publication 2021:EN-6694. 118 pp.

Straw EA, Carpentier EN, Brown MJF. 2021 Roundup causes high levels of mortality following contact exposure in bumble bees. J. Appl. Ecol. 58, 1167–1176.

Straw EA, Thompson LJ, Leadbeater E, Brown MJF. 2022 'Inert' ingredients are understudied, potentially dangerous to bees and deserve more research attention. Proc. R. Soc. B 289: 20212353.

Sun, H. (2019). Grand challenges in environmental nanotechnology. Frontiers in Nanotechnology, 1, 2.

Sutherland, W. J., Butchart, S. H., Connor, B., Culshaw, C., Dicks, L. V., Dinsdale, J., ... & Gleave, R. A. (2018). A 2018 horizon scan of emerging issues for global conservation and biological diversity. Trends in Ecology & Evolution, 33(1), 47-58.

Sutton, T. L., DeGabriel, J. L., Riegler, M., & Cook, J. M. (2018). A temperate pollinator with high thermal tolerance is still susceptible to heat events predicted under future climate change. Ecological Entomology, 43(4), 506-512.

Tanasković, M.; Erić, P.; Patenković, A.; Erić, K.; Mihajlović, M.; Tanasić, V.; Kusza, S.; Oleksa, A.; Stanisavljević, L.; Davidović, S. Further Evidence of Population Admixture in the Serbian Honey Bee Population. Insects 2022, 13, 180.

UNEP, D. (2021). Partnership and United Nations Environment Programme (2021). Reducing consumer food waste using green and digital technologies.

van Dooremalen C, Gerritsen L, Cornelissen B, van der Steen JJ, van Langevelde F, Blacquière T. (2012) Winter survival of individual honey bees and honey bee colonies depends on level of Varroa destructor infestation. PLoS One, 7(4):e36285.

Vo-Doan, T. T., & Straw, A. D. (2020). Millisecond insect tracking system. arXiv preprint arXiv:2002.12100.

Wang, F., Zhang, X., Zhang, S., Zhang, S., & Sun, Y. (2020). Interactions of microplastics and cadmium on plant growth and arbuscular mycorrhizal fungal communities in an agricultural soil. Chemosphere, 254, 126791.

Wintermantel, D., Pereira-Peixoto, M. H., Warth, N., Melcher, K., Faller, M., Feurer, J., ... & Klein, A. M. (2022). Flowering resources modulate the sensitivity of bumblebees to a common fungicide. Science of The Total Environment, 829, 154450.

Yu, L., Zhang, J., Liu, Y., Chen, L., Tao, S., & Liu, W. (2021). Distribution characteristics of microplastics in agricultural soils from the largest vegetable production base in China. Science of the Total Environment, 756, 143860.

Zhang, P., Guo, Z., Ullah, S., Melagraki, G., Afantitis, A., Lynch, I., 2021. Nanotechnology and artificial intelligence to enable sustainable and precision agriculture. Nat. Plants 7, 864–876.

Zhang, W., 2018. Global pesticide use: Profile, trend, cost / benefit and more. Proc. Int. Acad. Ecol. Environ. Sci. 8, 1–27.

Zhu G, Gutierrez-Illan J, Looney C, Crowder DW (2020) Assessing the ecological niche and invasion potential of the Asian giant hornet. PNAS.