STEP

Status and Trends of European Pollinators

M.7.6. Stand alone power point presentation of STEP

Prepared by READING and PENSOFT

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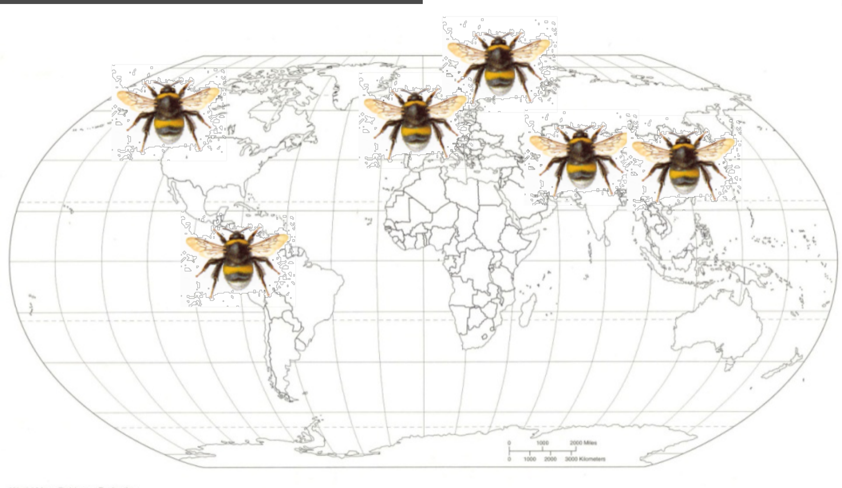
Collaborative organisations:

International Union for Conservation of Nature (IUCN)

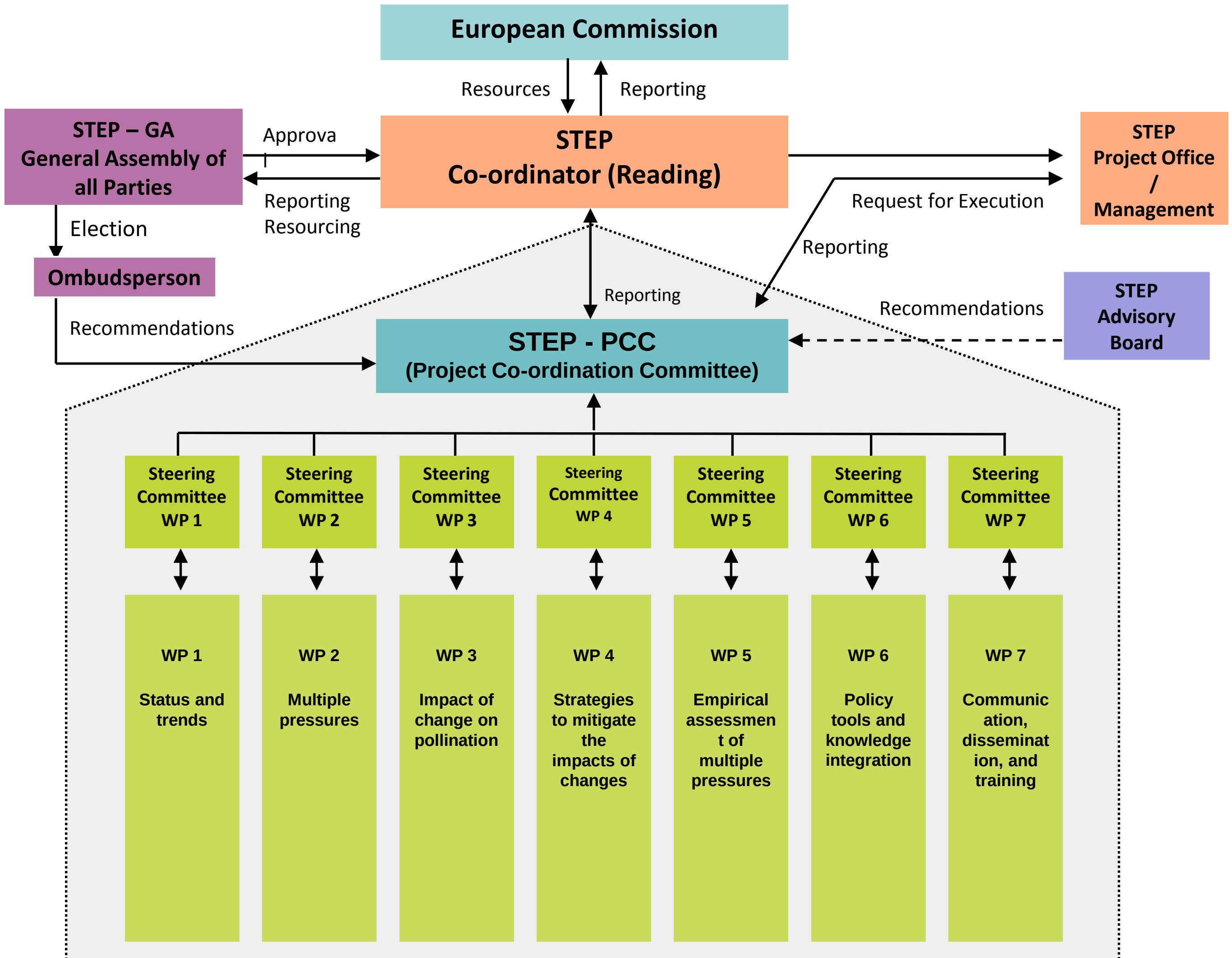
The Food and Agriculture Organization of the United Nations (FAO)

Partners

The STEP project ran from 2010-2015, combining the expertise of 22 research institutions from 17 European countries with more than 120 researchers.



Management


European Commission
Resources
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STEP – GA
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Steering Committee WP 1
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Steering Committee WP 3
Steering Committee WP 4
Steering Committee WP 5
Steering Committee WP 6
Steering Committee WP 7
WP 1
Status and trends
WP 2
Multiple pressures
WP 3
Impact of change on pollination
WP 4
Strategies to mitigate the impacts of changes
WP 5
Empirical assessmen t of multiple pressures
WP 6
Policy tools and knowledge integration
WP 7
Communic ation, disseminat ion, and training

Why study pollinators?

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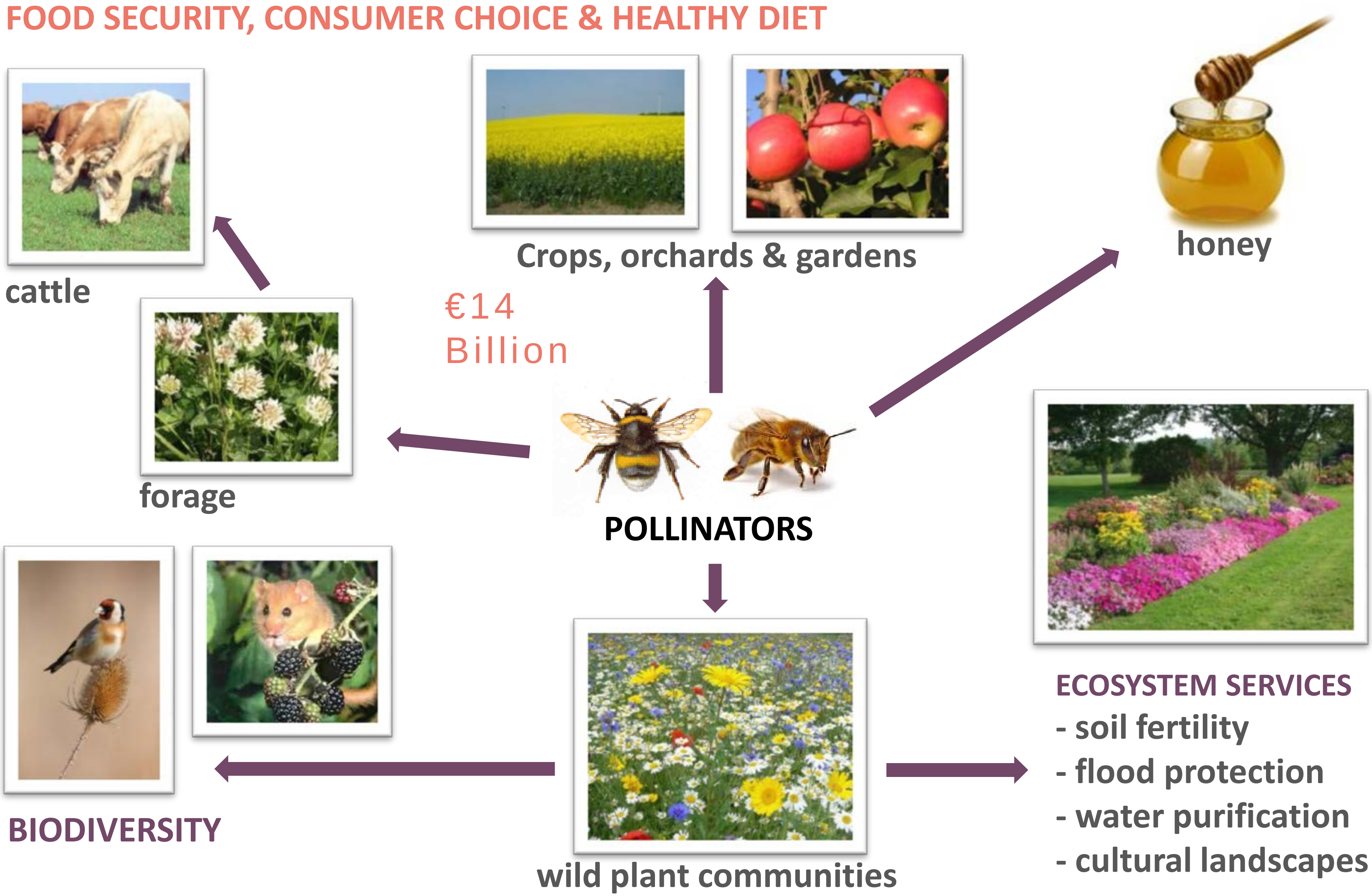
- Wide range of values to society
- In decline
- Multiple threats but poorly understood
- Need to manage pollination services for livelihoods
- Opportunity to use high quality science to underpin policy and practice

Value of pollinators

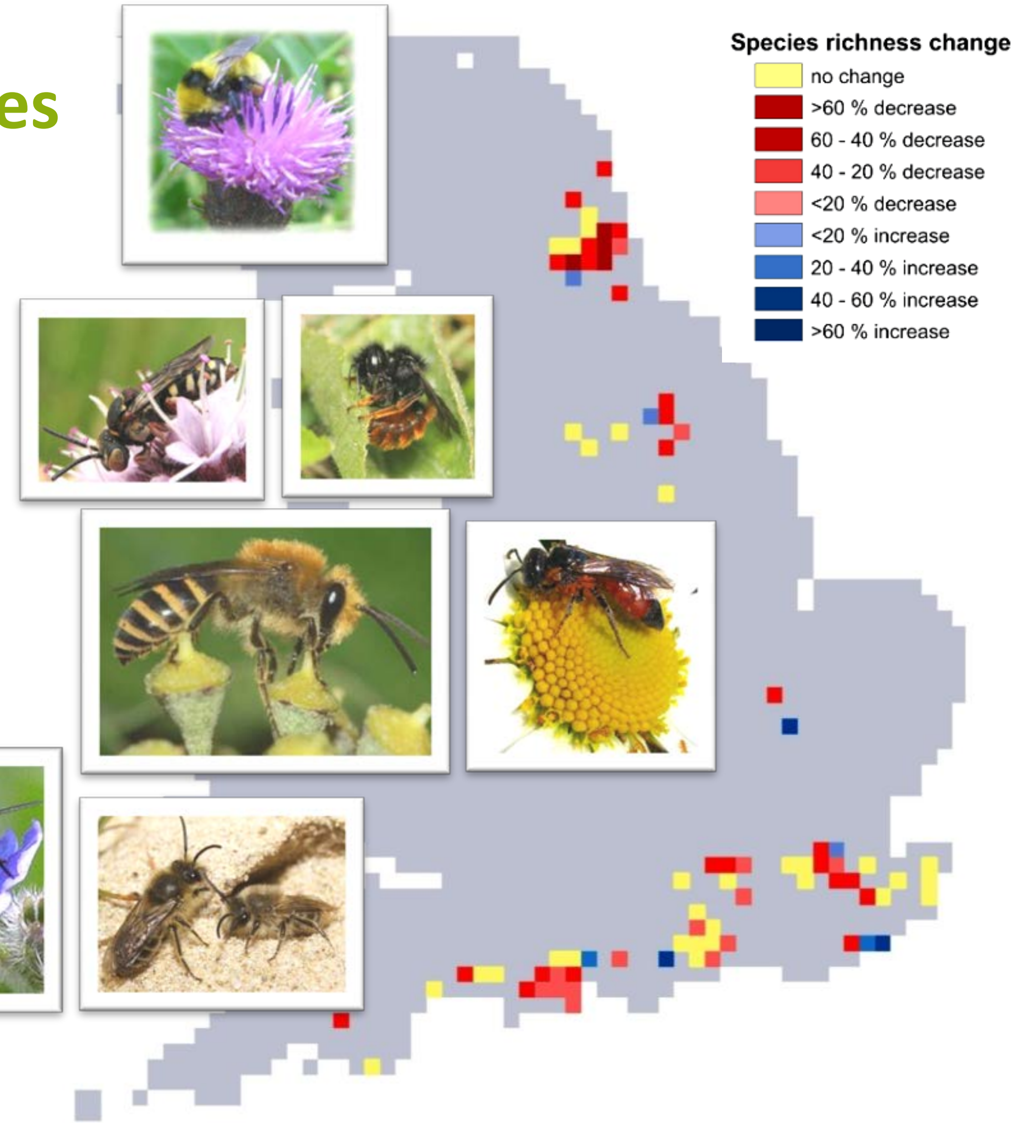
- <u>84% </u>of European crops benefit from insect pollination
- Worth <u>€14.2</u> billion p.a. to agriculture (EU25)
- <u>78% </u>temperate wild flowers require biotic pollination

Wider value


FOOD SECURITY, CONSUMER CHOICE & HEALTHY DIET
cattle
Crops, orchards & gardens
honey
€14
Billion
forage
POLLINATORS
ECOSYSTEM SERVICES
- soil fertility
- flood protection
- water purification
- cultural landscapes
BIODIVERSITY
wild plant communities

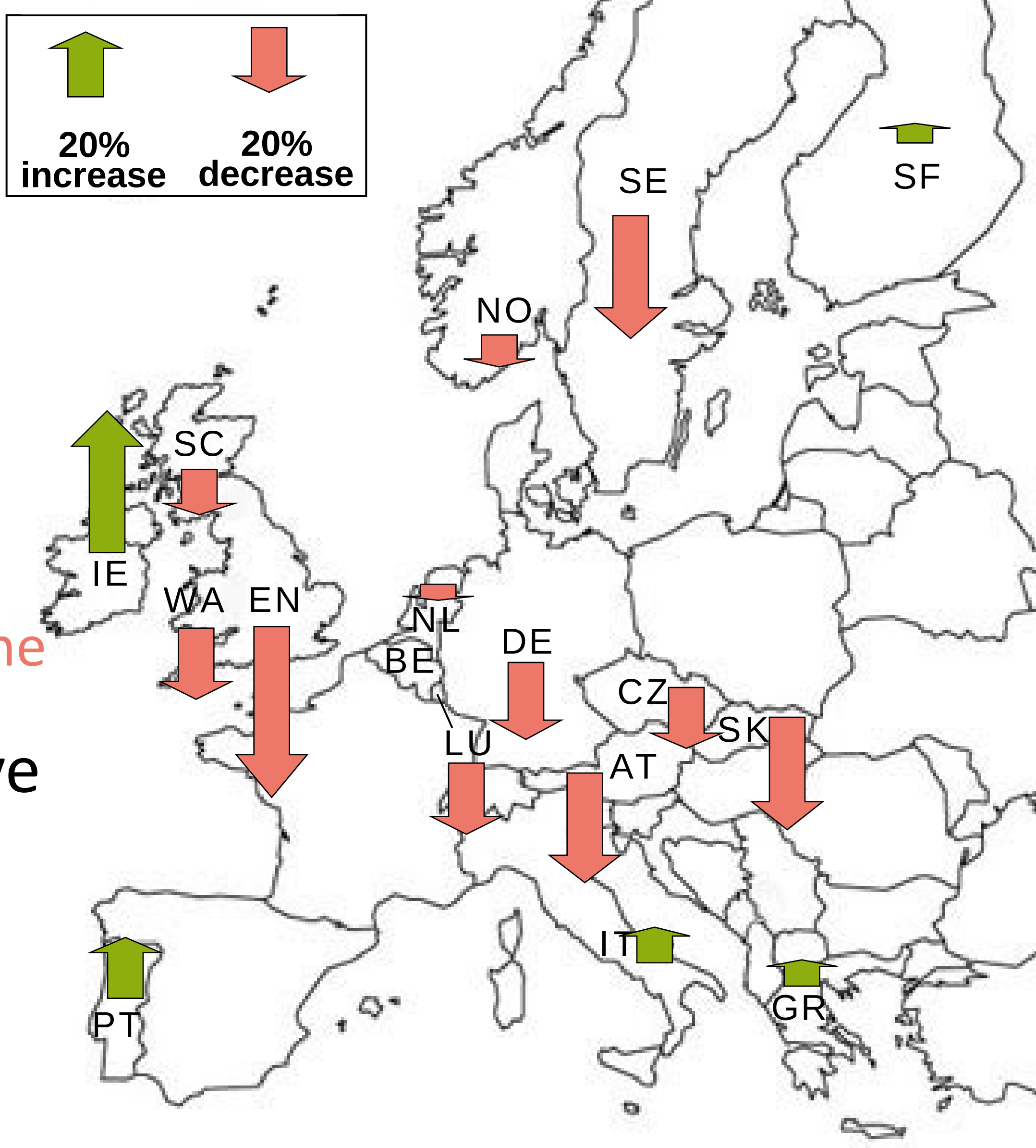
Wild bees and hoverflies

- Europe has **>2,500 species** of bee
- Bee diversity in UK has decreased in 52% of UK landscapes since 1980
- Biesmeijer et al. 2006 ***Science***



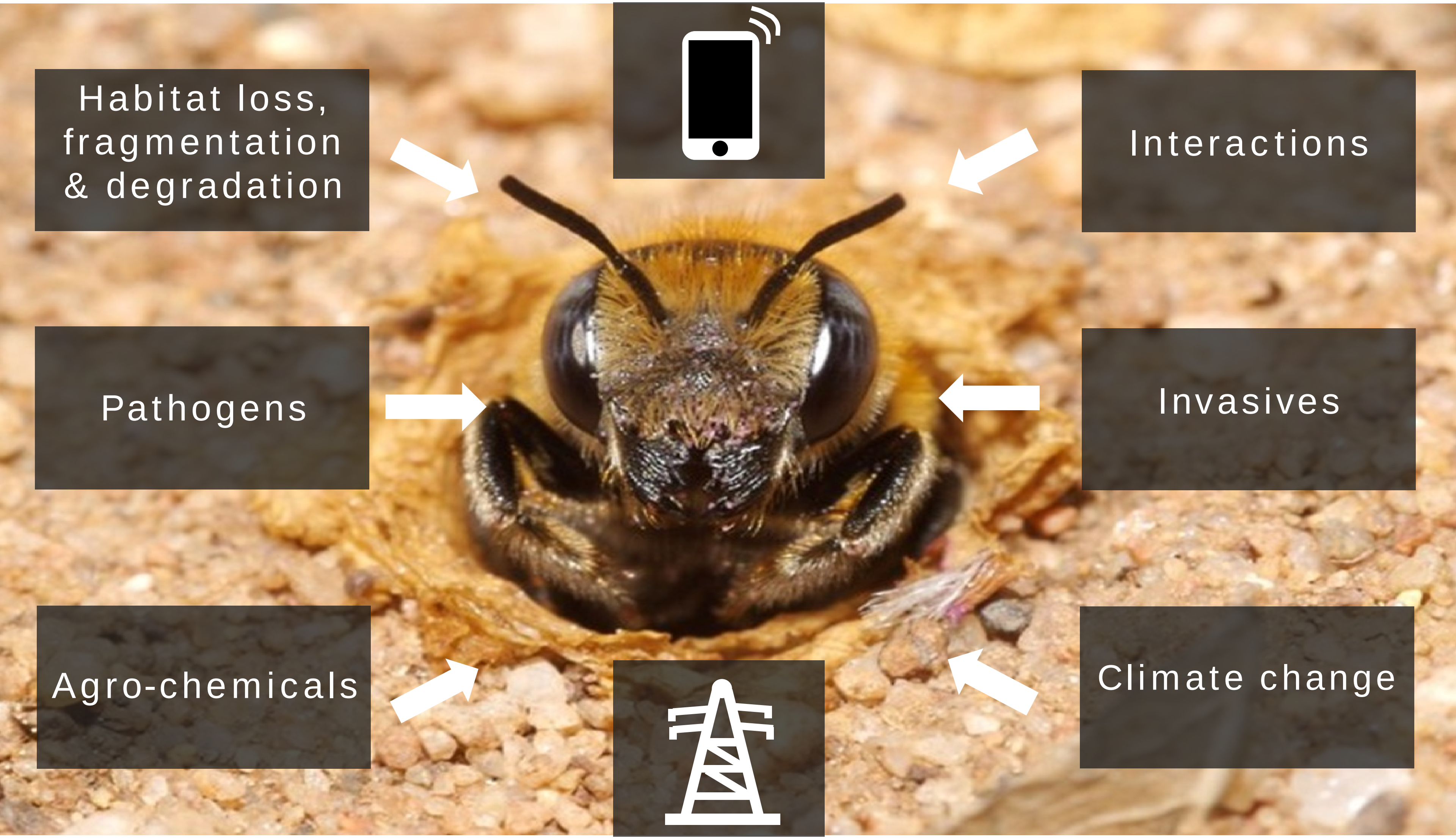
Honeybees

- Changes in colony numbers (1985-2005):
  - Mediterranean – 13% increase
  - Europe – 16% decline
  - Central – 25% decline
  - Scandinavia – 14% decline



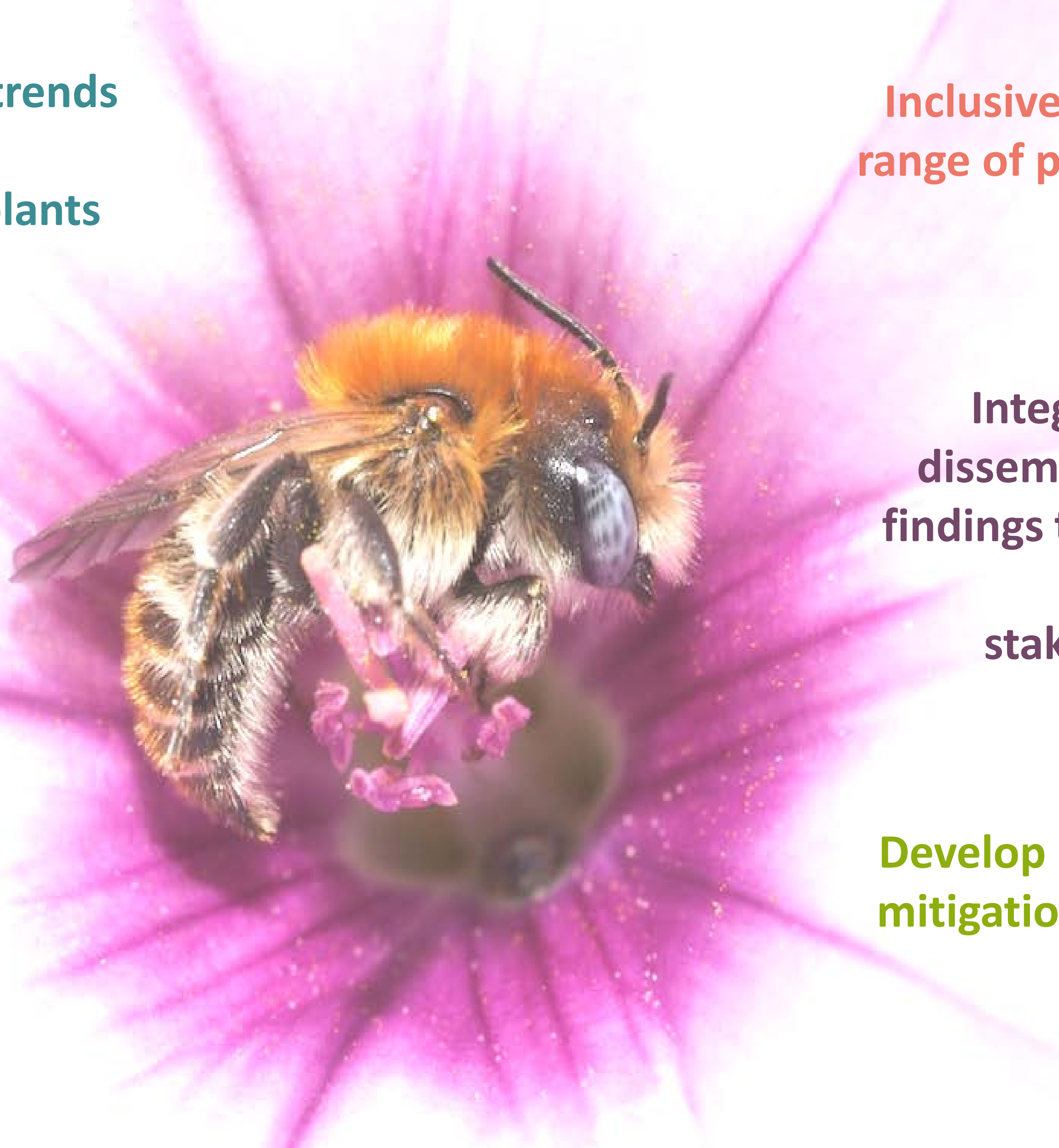
- Beekeeper numbers have also declined
- Potts et al. 2010 ***Journal of Apicultural Research***

Drivers of change



Potts et al. 2010 ***TREE***

General Aims



Document recent trends in pollinators and insect-pollinated plants

Inclusive - widest range of pollinator taxa

Assess the role of different drivers in causing such trends

Integrate and disseminate our findings to a wide range of stakeholders

Assess the ecological and economic impacts of changes

Develop potential mitigation actions

STEP: Key objectives

- 1st European Red Data Book for bees
- European monitoring scheme
- Quantify the relative of pressures affecting pollinators and plants
- Understand the ecological and economic impacts of pollinator loss
- Toolkit of interventions to conserve and mange pollinators
- Build a strong science-policy dialogue

STEP: Position paper

April or June 2011 Issue

Open Access

REVIEW ARTICLE

Developing European conservation and mitigation tools for pollination services: approaches of the STEP (Status and Trends of European Pollinators) project

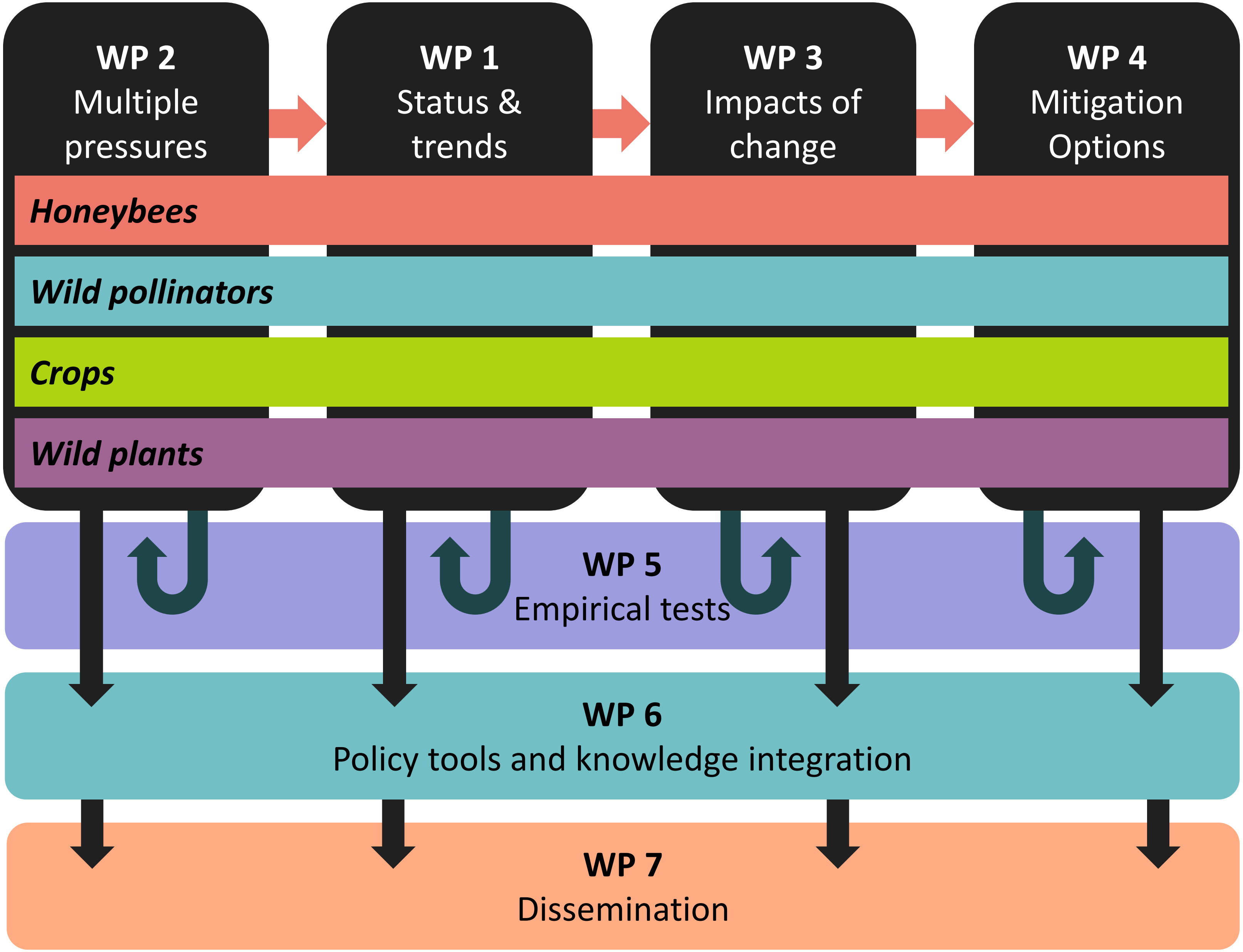
Simon G Potts[1*], Koos Biesmeijer[2,3], Riccardo Bommarco[4], Antonio Felicioli[5], Markus Fischer[6], Pekka Jokinen[7], David Kleijn[8], Alexandra-Maria Klein[9], William Kunin[2], Peter Neumann[10], Lyubomir Penev[11], Theodora Petanidou[12], Pierre Rasmont[13], Stuart Roberts[1], Henrik Smith[14], Peter Sorensen[15], Ingolf Steffan-Dewenter[16], Bernard Vaissière[17], Montserrat Vilà[18], Ante Vujić[19], Michal Woyciechowski[20], Martin Zobel[21], Josef Settele[22], Oliver Schweiger[22]

Conservation & management

How can we:

- Manage managed pollinators?
- Conserve species and communities?
- Protect and restore habitats?
- Create new habitats?
- Reduce impacts of pests, diseases, invasive competitors and pollutants?
- Develop policies?

WP Links and interdependence



STEP: Case Studies

The STEP project has helped science and policy move forward on many of the above challenges which are illustrated in the following slides. **Specifically STEP has:**

- Documented the **status and trends of pollinators** (managed honeybees, wild bees and hoverflies) and animal-pollinated plants.
- Assessed the importance of **multiple pressures** that are driving changes in pollinators and animal-pollinated plants at scales ranging from single fields to landscapes to the whole of Europe.
- Quantified **the impact of changes** in pollinator populations and communities on wild plants and crops.
- Evaluated the effectiveness of **strategies to mitigate the impacts** of changes in pollinators and animal-pollinated plants.
- Developed ways to **improve the interface between the scientific knowledge-base on pollinator shifts and policy instruments**.
- Developed **communication and educational links with a wide range of stakeholders** and the general public on the importance of recent shifts in pollinators, the main drivers and impacts of pollinator shifts and mitigation strategies through dissemination and training.

Case study 1.1 Biodiversity loss among bees and wild flowers slows in NW-Europe

STEP

A study published *Ecology Letters* in 2013 found evidence of dramatic reductions in the diversity of species of bees, hoverflies, butterflies and wild flowers in Britain, Belgium and the Netherlands in the post war period. But the picture brightened markedly after 1990, with a slowdown in local and national biodiversity losses among bees, hoverflies and wild plants.

Figure 1. The pollen specialist bee *Andrena hattorfiana* (Fabricius) (Hymenoptera: Andrenidae) is rare in the study region and foraging on Dipsacaceae. Photo: Nicolas J. Vereecken

Case study 1.1 Biodiversity loss among bees and wild flowers slows in NW-Europe

For example, the study found a 30 per cent fall in local bumblebee diversity in all three countries between the 1950s and the 1980s. However, by 2010 that decline slowed to an estimated 10 per cent in Britain, whilst in Belgium and the Netherlands bumblebee diversity had stabilised.

Reference: Carvalheiro L.G., Kunin W.E., Keil P., Aguirre-Gutiérrez J., Ellis W.N., Fox R., Groom Q., Hennekens S., Van Landuyt W., Maes D., Van de Meutter F., **Michez D.**, **Rasmont P.**, Ode B., **Potts S.G.**, Reemer M., **Roberts S.P.M.**, Schaminée J., WallisDeVries M.F. and **Biesmeijer J.C.** (2013) Species richness declines and biotic homogenization have slowed down for NW-European pollinators and plants. ***Ecology Letters*** 16: 870-878

Case study 1.2 First ever Red List of European bees

One of the main challenges of the STEP project was to assess how each bee species among the approximately 2,000 species native in Europe is potentially experiencing a risk of extinction. The STEP project used the internationally recognized IUCN (International Union for Conservation of Nature) Red List procedures (*www.iucnredlist.org*) to guide the development of a Red Data Book for European bees.

- The first outcome was an updated checklist of European bees, which now includes **1,951 species**.
- The team gathered all the available observations to produce detailed maps of **1,585 species** including **2.5 million data points**
- Of all the European native bees, **661** species were assessed as Least Concern, **101** as Near Threatened, **22** as Vulnerable, **46** as Endangered, **7** as Critically Endangered, **23** as Not Applicable and **1,091** as Data Deficient (Figure 2).

Case study 1.2 First ever Red List of European bees

Figure 1. Left, *Bombus confusus* (Apidae), Endangered generalist social species (Picture P. Rasmont). Right, *Dasypoda hirtipes* (Melittidae), Least Concern specialist solitary species (Photos: N. Vereecken).

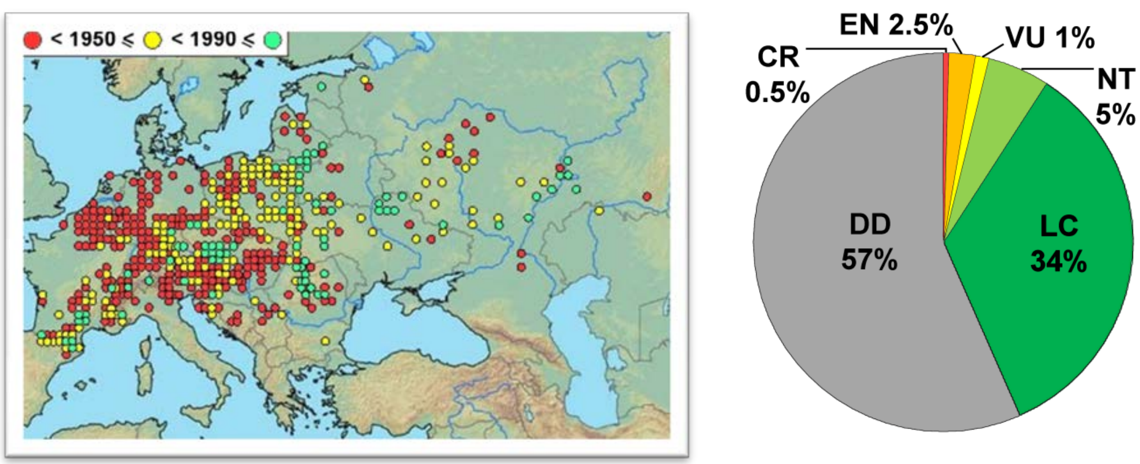


Figure 2. Left, map of *Bombus confusus* including 2712 specimens (http://zoologie.umh.ac.be/ hymenoptera/). (P. Rasmont). Right, summary of the Red List status of European bees (LC= Least Concern, DD= Data Deficient, CR= Critically Endangered, EN= Endangered, VU= Vulnerable, NT= Nearly Threatened). (Ana Nieto & Denis Michez).

Case study 1.2 First ever Red List of European bees

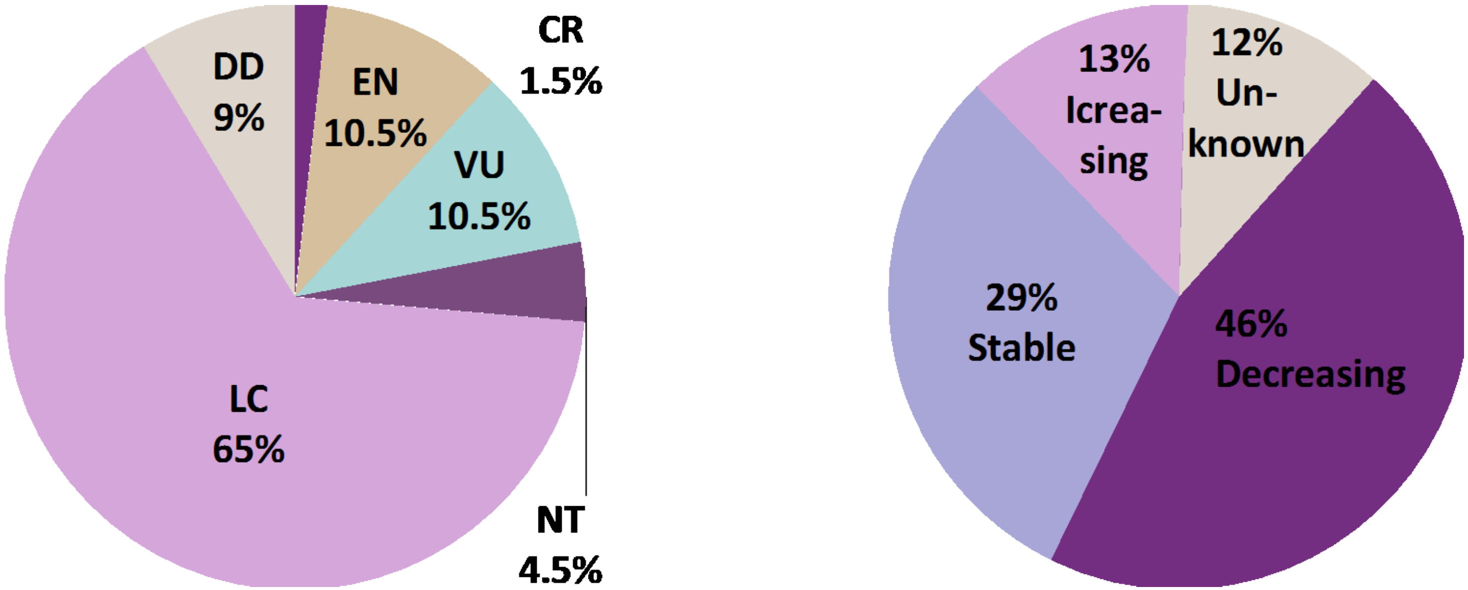


Figure 3. Assessment of the European bumblebees. Left, summary of the Red List status of European bumblebees (LC= Least Concern, DD= Data Deficient, CR= Critically Endangered, EN= Endangered, VU= Vulnerable, NT= Nearly Threatened). (Ana Nieto & Pierre Rasmont). Right, population trends of European bumblebees. (Ana Nieto & Pierre Rasmont)

Reference

Nieto A., **Rasmont P.**, **Roberts S. P.M.**, Kemp J., Kuhlmann M., Bogusch P., Dathe H., De la Rúa P., De Meulemeester T., Dehon M., Dewulf A., García M., Lhomme P., Ortiz-Sánchez F.J., Patiny S., Pauly A., Praz C., **Quaranta M.**, Radchenko V. G., Scheuchl E., Smit J., Straka J., Terzo M., Tomozei B. & **Michez D.** 2014. *Red Book of European bees*. Edition IUCN, Bruxelles.

Case study 1.3 Drastic historic shifts in bumble-bee community composition in Sweden

- Wild bees are threatened by many factors. Two important drivers are land use change and intensification. Declines in species richness of bumble bees have received particular attention, especially in Europe and North America. Many pollinator-dependent crops rely on bees for yield, and the threats that bees are facing have raised concerns that crop pollination might also be at risk. This concern depends on how drastic the changes in bee composition have been, how important the declining bee species are for crop pollination, and the extent to which crop yields are sensitive to changes in pollination service. We addressed these questions, using a historic data for a highly pollination dependent crop – red clover.

- We found drastic shifts in the relative abundance of several bumble bee species over time. Two generalist species had increased in relative abundance, such that they now completely dominate the bee community at the expense of several other more specialized bumble bees, including some that are specialized on pollinating deep flowers, such as red clover.

Case study 1.3 Drastic historic shifts in bumble-bee community composition in Sweden

- We found that this shift in the bumble bee community was related to the loss and fragmentation of key bumble bee habitats, such as hay meadows and semi-natural pastures, in the agricultural landscape.
- We also showed that legumes in general, and especially red clover, as important nectar and pollen resources for bumblebees have become much rarer in the landscape. This reduced availability and increased fragmentation of resources, is a probable reason why only generalist and highly mobile bumble bee species have been able to maintain large populations in intensively managed agricultural landscapes.
- We found that red clover seed yields have declined since the 1960's, and that the variation in seed yields has doubled in the last decades.

Reference

Bommarco R., Lundin O., Smith H.G., Rundlöf M. (2012) Drastic historic shifts in bumble-bee community composition in Sweden *Proceedings of the Royal Society B-Biological Sciences* 279 309-315.

Case study 1.3 Drastic historic shifts in bumble-bee community composition in Sweden

Figure 1. The garden bumble bee (*Bombus hortorum*) on red clover. *B. hortorum* is one of several species that has declined in relative abundance in red clover fields. Photo: Maj Rundlöf.

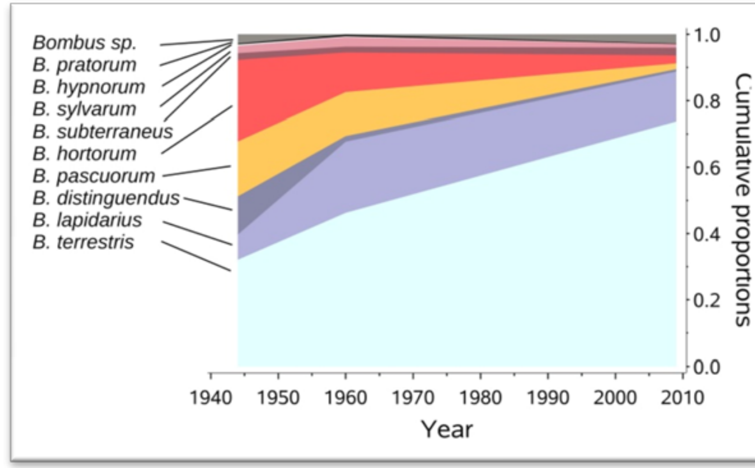


Figure 2. Proportional shifts in bumble-bee community composition in red clover seed fields in Sweden.

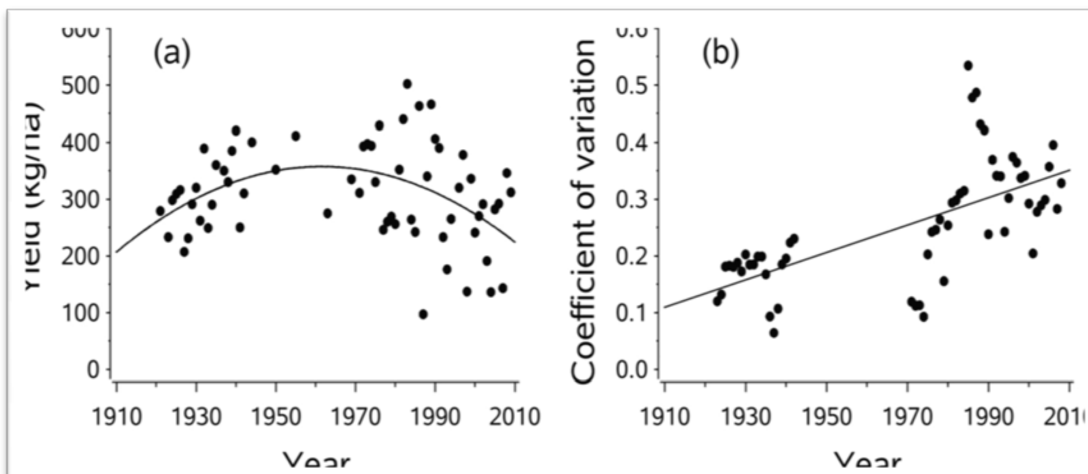


Figure 3. Trends in red clover seed yields in the last 90 years. (a) Yearly statistic of yield per hectare. (b) Variability in yield presented as the coefficient of variation calculated from 5 year moving average (with minimum four values).

Case study 2.1 Combined effects of global change pressures on animal-mediated pollination

- Increasing evidence of pollinator declines has been reported as a consequence of five major global change pressures: climate change, landscape alteration, agricultural intensification, introduction of non-native species, and spread of pathogens. Our study reviewed the current evidence for these drivers on pollination services.
- Climate change entails changes in community composition through shifts in the geographical range and/or phenology of pollinator and plant species. Landscape alteration comprises the degradation, destruction, and fragmentation of natural habitats, resulting in associated changes in landscape configuration, habitat diversity, and community composition.
- Intensive agriculture is characterised by an increase in input of pesticides and fertilisers, farm size, monocultures, and simplified crop rotations. The effects of biological invasions on animal-mediated pollination have usually been addressed by considering non-native plants and non-native pollinators, both affecting the natural patters of plant-pollinator interactions. Further, the huge increase during the past decades in the trade of managed pollinators has promoted pathogen transmission to wild pollinators, and vice versa.

Case study 2.1 Combined effects of global change pressures on animal-mediated pollination

- Global change pressures differ in their biotic or abiotic nature and also in their spatial and temporal scales of actions. For example, climate warming usually acts at the regional scale, while other pressures, such as the spread of pathogens are typically more localized, although they might expand very quickly through the landscape.
- A given pressure can impact animal-mediated pollination directly by disrupting the occurrence, abundance and phenology of flower and pollinator species. However, a pressure can also impact pollination indirectly, by interacting with other pressures, either additively or non-additively. Non-additive effects occur if the impact of a given pressure is amplified (synergistic effects) or buffered (antagonistic effects), when it occurs in combination with another pressure.
- Climate change is expected to cause phenological mismatches in the low diversity plant-pollinator communities of highly modified or intensively cultivated landscapes, jeopardizing both plant reproduction and pollinator feeding. Nevertheless, non-native plants and pollinators could potentially provide food supply and pollination function, respectively, to resident native species in periods where native plants and pollinators have curtailed their phenology.

Case study 2.1 Combined effects of global change pressures on animal-mediated pollination

- As exemplified in figure 1, landscape alteration might impact native pollinators directly by reducing floral and nesting resources. Indirect impacts of landscape alteration include (i) favouring the abundance of non-native pollinators, and (ii) the increase in its per capita impact through resource limitation, which additionally would increase the probability of pathogen spillover.

- Overall, the outstanding challenges are to combine observational and manipulative experimental designs to analyse explicitly pair-wise, and further multiple, interactions between pressures.

Reference

González-Varo J., Biesmeijer J., Bommarco R., Potts S., Schweiger O., Smith H., Steffan-Dewenter I., Szentgyörgyi H., Woyciechowski M., Vilà M. (2013) Combined effects of global change pressures on animal-mediated pollination. *Trends in Ecology and Evolution* 28: 524-530.

Case study 2.1 Combined effects of global change pressures on animal-mediated pollination

Figure 1. The bee *Lasioglossum albocinctum* visiting flowers of Spanish lavender (*Lavandula stoechas*) in a small woodland remnant (Photo: Juan P. González-Varo)

Case study 2.1 Combined effects of global change pressures on animal-mediated pollination

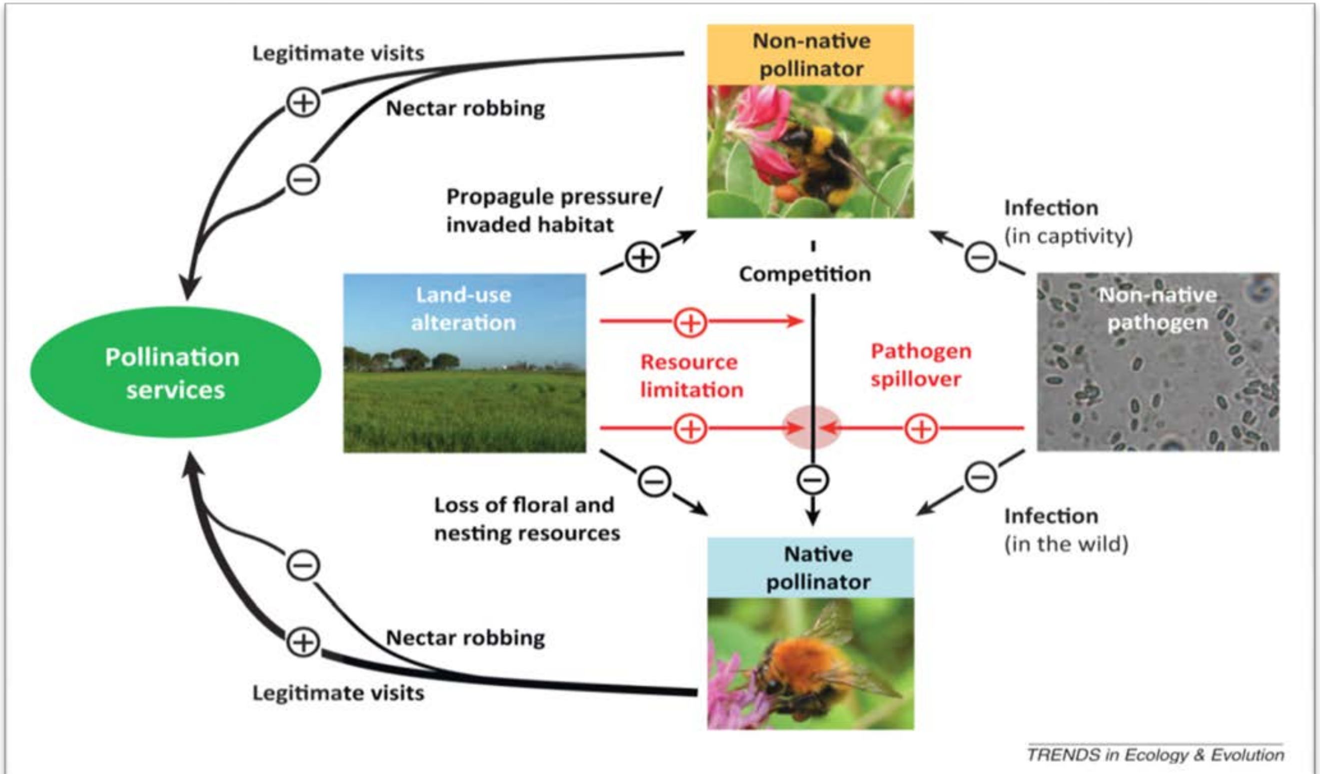


Figure 2. Scheme showing possible synergistic effects between landscape alteration, invasion by a non-native pollinator, and pathogen spread impacting native pollinators and their pollination services. Black arrows represent direct effects, whereas red arrows represent (indirect) interactive effects by which a pressure (landscape alteration or pathogens) change the per capita impact of the non-native pollinator on the native pollinator. Positive or negative signs in the arrows denote an increase or a decrease, respectively, in the variable of study, whereas the text close to each arrow denotes the mechanism(s) responsible for its effects. The shaded ellipse denotes a higher probability of pathogen spillover due to flower resource limitation in altered landscapes. The pollination services provided by both pollinators will depend on whether they perform legitimate visits or nectar robbing. (Photo reproduced with permission from A. Montero-Castaño (top), H. Szentgyorgyi (right), and J.P. González-Varo (bottom and left)).

Case study 2.2 The relative importance of broad-scale drivers for the distribution of European pollinators

STEP

- We explored how major drivers of global change such as climate, land cover, agrochemicals and soil conditions affect the European-wide distribution of pollinators. The relationships of these drivers and the geographical distributions of over 1,000 butterfly, bumblebee, hoverfly, and solitary bee species were modelled at a rather coarse spatial resolution of 50 km x 50 km (Figure 1, 2).

- Climate is the most important driver of the large-scale occurrence of all investigated groups of pollinators in Europe (Figure 3). Land cover and soil conditions are the second most important drivers, but their relative importance differs among the taxonomic groups reflecting their ecological requirements. Most important, agrochemicals like fertilisers and pesticides have a significantly negative impact on pollinators, even at the European scale. Thus, effects of agrochemicals are not restricted to the local scale, as usually thought, but are already affecting large-scale pollinator occurrence across Europe.

Case study 2.2 The relative importance of broad-scale drivers for the distribution of European pollinators

Figure 1. Example of one the analysed species, the mining bee *Andrena hattorfiana* (Photo credit: Markus Franzén)

Reference

Franzén M., Heikkinen R., Gyldenkærne S., Harpke A., Helm A., Kuhlmann M., Michez D., Pauly A., Rasmont P., Settele J., Vujic A., Wiemers M., Welk E., Schweiger O. The relative importance of broad-scale drivers for the distribution of European pollinators. In prep.

Case study 2.2 The relative importance of broad-scale drivers for the distribution of European pollinators

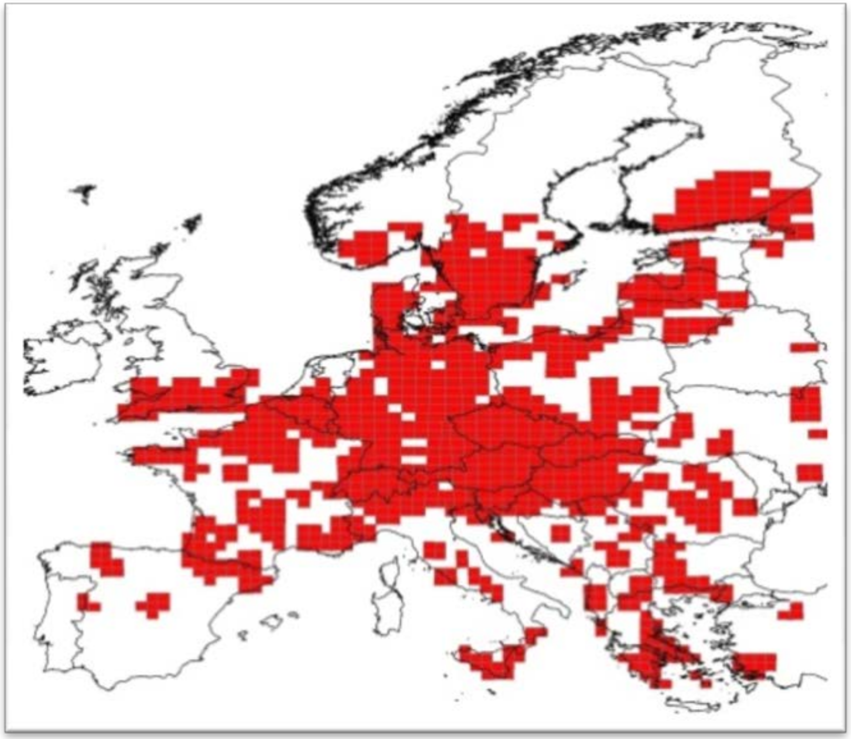


Figure 2. Distribution of the solitary bee *Andrena hattorfiana* in Europe shown as occupied 50 km x 50 km grids in red. (Franzén et al.)

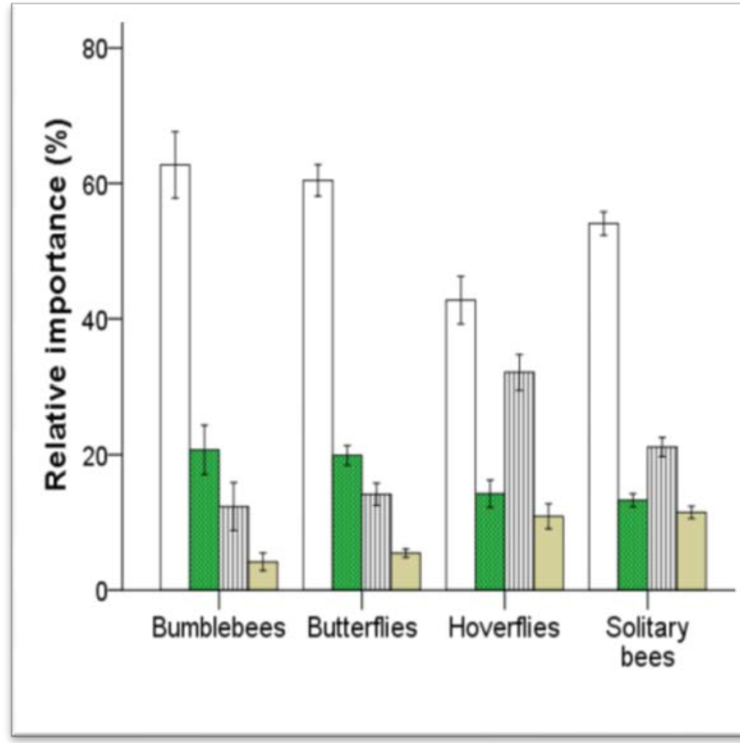


Figure 3. Climatic conditions are the most important drivers for European pollinators. Land cover and soil are the second most important drivers, but their effect size differs among pollinator groups. Also the effects of agrochemicals were considerable at the European scale and were largest for solitary bees and hoverflies. (Franzén et al.)

Case study 2.3 Future climatic risks for European bumblebees

- Bumblebees are an important wild and managed pollinator but future climate change will pose serious risks to them. Based on species distribution data for all 69 European bumblebee species, gathered within STEP (see Atlas Hymenoptera; www.atlashymenoptera.net) and corresponding and biologically relevant climate data, we modelled their climatically suitable areas under current conditions. Based on these models, we projected future suitable areas according to three climate change scenarios for 2050 and 2100:
- (i) SEDGE: Sustainable European Development Goal scenario (expected temperature increase for Europe in 2100 is 3.0° C),
- (ii) BAMBU: Business-As-Might-Be-Usual scenario (expected temperature increase for Europe in 2100 is 4.7° C) and
- (iii) GRAS: GRowth Applied Strategy scenario (expected temperature increase for Europe in 2100 is 5.8° C).

Case study 2.3 Future climatic risks for European bumblebees

- Taking into account a careful assessment of the dispersal capability of the species, we found that the vast majority of the bumblebees (up to 46 species in 2050 and up to 52 species in 2100) will suffer from range contractions. Only four to five species might be able to expand their ranges, and up to eleven species will keep their status quo. The future fate of the bumblebees also differed considerably among the three scenarios. Under the most severe climate change scenario (GRAS), 22 species would lose nearly all their suitable area, leading them at the verge of extinction in Europe. Under the less severe climate change scenarios (SEDGE and BAMBU), it would be only two or three species. These dramatic projections are in accordance with the present conservation status as proposed by the IUCN Red List (see Case study 1.2).

Case study 2.3 Future climatic risks for European bumblebees

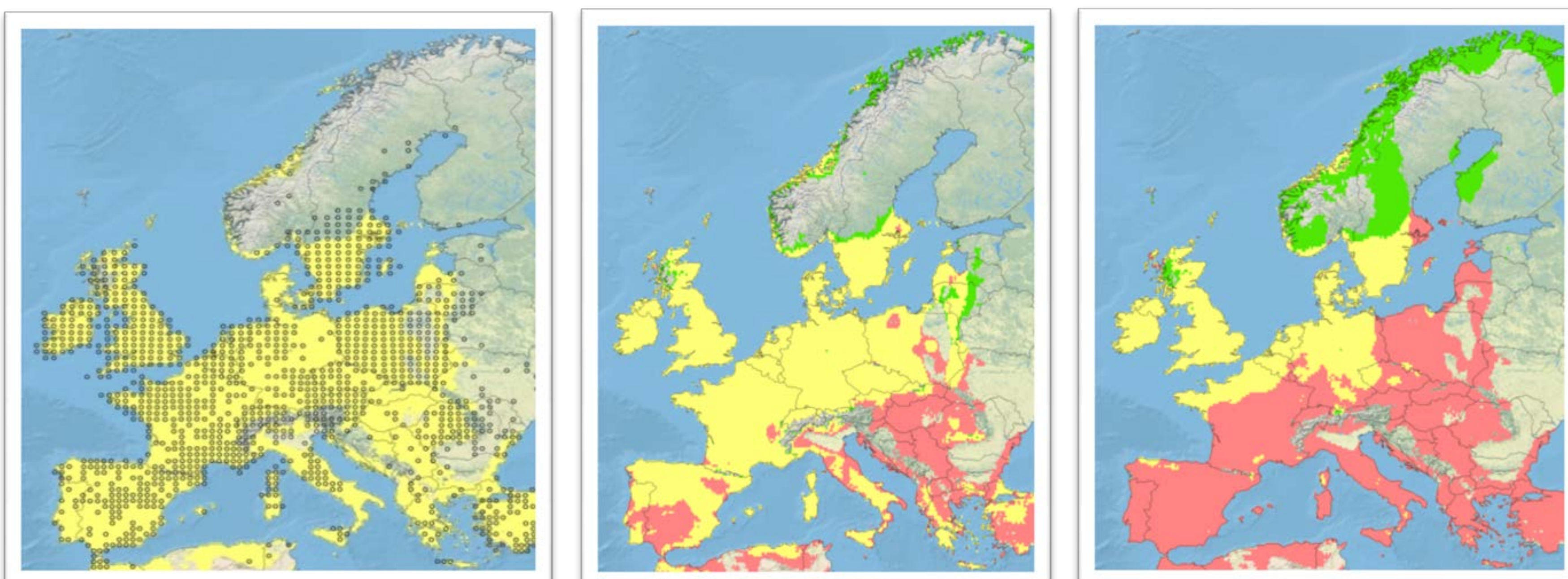
- Future changes in the distribution of single species will finally add up to changes into overall changes in richness species of bumblebees. We found that reductions in bumblebee diversity will already be noticeable in most of the considered areas by 2050 (median potential loss of 22 to 38%) while this reduction will be drastic in 2100 for all scenarios (median potential loss of 42 to 88%). Only a few areas in the north and some mountain areas of Europe would be able to conserve a substantial part of their present diversity.

Reference

Rasmont P., Franzen M., Lecocq T., Harpke A., Roberts S.P.M., Biesmeijer K., Castro L., Cederberg B., Dvorák L., Fitzpatrick Ú., Haubruge E., Mahé G., Manino A., Michez D., Neumayer J., Paukkunen J., Pawlikowski T., Potts S.G., Reemer M., Settele J., Straka J., Schweiger O. (2015) Climatic Risk and Distribution Atlas of European Bumblebees. BioRisk 10, special issue, 234 pp. ISBN 978-954-642-768-7 (hardback) ISBN 978-954-642-769-4 (e-book)

Case study 2.3 Future climatic risks for European bumblebees

Figure 1. A: *Bombus terrestris*, one of the most common European bumblebees; (Pierre Rasmont et al.) B: Starting with actual 1970-2010 distribution (black circles), we assessed the present suitable climatic area of each species (yellow area); here, for *Bombus terrestris*. (Pierre Rasmont et al.) C: Future climatically suitable area for *Bombus terrestris* (GRAS scenario), 2050; at this time, even such an abundant species could already suffer from considerable regression in the south of Europe. (Pierre Rasmont et al.) D: idem, 2100, at this time, all of Europe south of the Paris parallel would present unsuitable climates for *Bombus terrestris*, meaning climatic conditions as warm and dry as presently at the edge of Saharan desert. Red, lost areas with suitable climatic conditions; yellow, still suitable; green, new suitable conditions. (Pierre Rasmont et al.)



Case study 2.3 Future climatic risks for European bumblebees

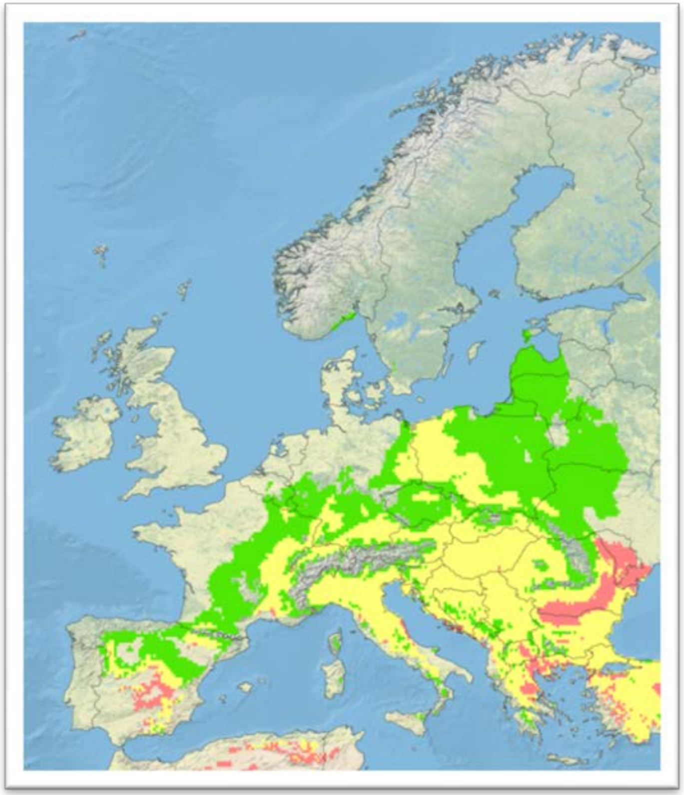


Figure 2. A: *Bombus haematurus*, one of the few bumblebees that would find an expanded suitable area in each of the scenarios. This species is already expanding its distribution towards the west. (Pierre Rasmont) B: Future climatically suitable area for *Bombus haematurus* (GRAS scenario), 2050. Red, lost areas with suitable climatic conditions; yellow, still suitable; green, new suitable conditions. (Pierre Rasmont et al.)

Case study 2.4 Expansion of mass-flowering crops leads to transient pollinator dilution and reduced wild plant pollination

STEP

- Negative consequences of land-use intensification and habitat loss for biodiversity and associated ecosystem services have often been reported, but the exact mechanisms are still poorly understood.

- We conducted a large-scale field study on 67 study sites to assess interactions between mass-flowering oilseed rape and semi-natural grasslands, and their potential effects on wild plants and bees (Fig. 2). Our results show that interactions between these habitats occur at different spatial scales, alter resource use of pollinators and reduce the reproduction of the protected plant *Primula veris* (cowslip) in conservation areas. Abundances of bumblebees, which are the main pollinators of cowslip but also pollinate oilseed rape, decreased with increasing proportion of oilseed rape cover in the landscape. This landscape-scale dilution of pollinators strongly affected bumblebee abundances in oilseed rape fields (Fig. 3A), and marginally in grasslands, where bumblebee abundances were generally low at the time of cowslip flowering. Seed set of cowslip, which is flowering during oilseed-rape bloom, was reduced by 20% when the proportion of oilseed rape in 1 km radius increased from 0 to 15% (Fig. 3B).

Case study 2.4 Expansion of mass-flowering crops leads to transient pollinator dilution and reduced wild plant pollination

- Our data suggests that the current expansion of bee-attractive biofuel crops will increase cross-habitat exchanges of bees and competition between oilseed rape and wild plants for pollinators. Spillover effects of bees from semi-natural nesting habitats to crop habitats, and bee-mediated spillover of food resources from crop to nesting habitats may have a strong impact on population dynamics of bees and plants which depend on pollinators. Although there is little additional evidence up to now, similar spillover effects connecting crop and natural habitats can be expected for many types of species interactions in landscapes where highly productive sites and less productive, more natural sites co-occur.
- In conclusion, mass-flowering crops potentially threaten fitness of concurrently flowering wild plants in conservation areas, despite the fact that in the long run mass-flowering crops can enhance abundances of generalist pollinators and their pollination service.

Reference

Holzschuh A., Dormann C.F., Tscharntke T., Steffan-Dewenter I. (2011) Expansion of mass-flowering crops leads to transient pollinator dilution and reduced wild plant pollination. Proceedings of the Royal Society B, 278, 3444-3451 (open access).

Case study 2.4 Expansion of mass-flowering crops leads to transient pollinator dilution and reduced wild plant pollination

Figure1 Protected semi-natural habitat in a landscape with mass-flowering oilseed rape fields (Photo: Andrea Holzschuh)

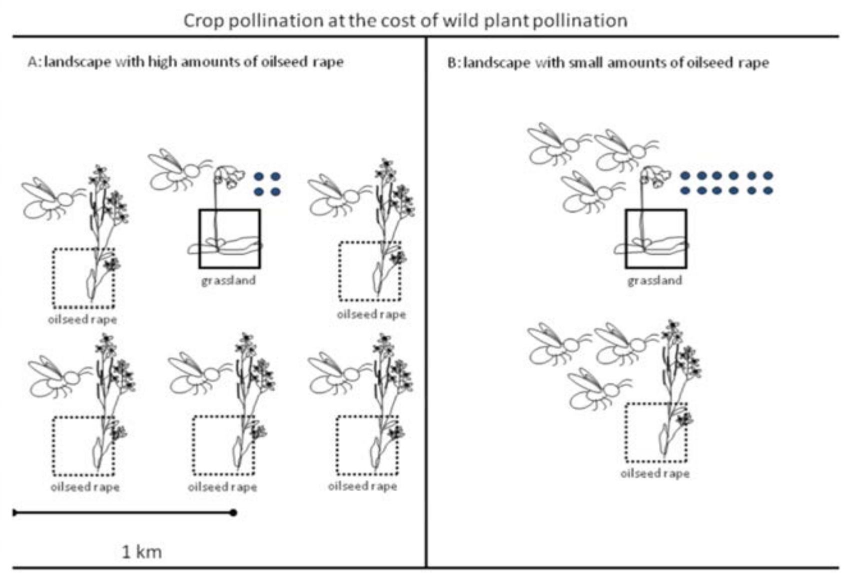


Figure 2 Landscape-scale dilution of bees in oilseed rape, and consequences for pollinator abundances and seed set. The number of black dots indicates number of produced seeds. (A) High amount of oilseed rape results in high dilution of pollinators, in low pollinator abundances per site and low reproduction of pollinator-dependent grassland plants. (B) Low amount of oilseed rape results in high pollinator abundances per site and high reproduction of pollinator-dependent grassland plants. Effects on oilseed rape have not been studied here and hence its seed production is not indicated. (Holzschuh et al.)

Case study 2.4 Expansion of mass-flowering crops leads to transient pollinator dilution and reduced wild plant pollination

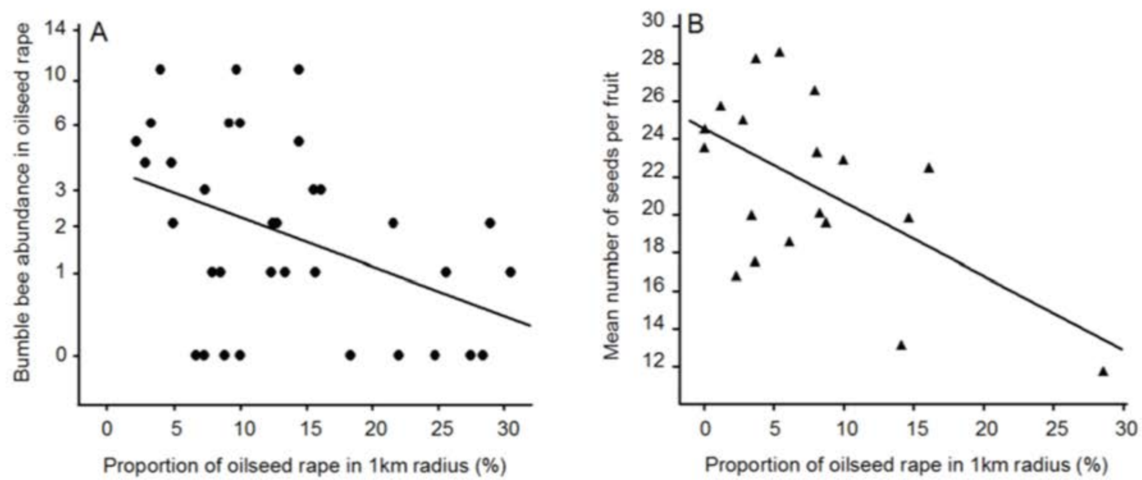


Figure 3 Relationship between the proportion of oilseed rape in 1km radius and (A) bumblebee abundances per 400 m^2 and 60min in oilseed rape fields (simple regression: n=34, F=7.1, P=0.012) and (B) the reproductive success of cowslip (Primula veris) in grasslands, as mean number of seeds per fruit (simple regression: n=19, F=10.3, P=0.005). (Holzschuh et al.)

Case study 2.5 Impact of Chronic Neonicotinoid Exposure on Honeybee Colony Performance and Queen Supersedure

- Honeybees provide economically and ecologically vital pollination services to some crops and wild plants. During the last decade elevated losses of managed colonies have been documented in Europe and North America. Despite growing consensus on the involvement of multiple causal factors, the underlying interactions impacting on honeybee health and colony failure are not fully resolved. Parasites and pathogens are among the main candidates, but sub-lethal exposure to widespread agricultural pesticides may also affect honey bees.

- To investigate effects of sub-lethal dietary neonicotinoid exposure on honeybee colony performance, a fully crossed experimental design was implemented using 24 colonies, including sister-queens from two different strains, and experimental in-hive pollen feeding with or without environmentally relevant concentrations of the neonicotinoids thiamethoxam and clothianidin.

Case study 2.5 Impact of Chronic Neonicotinoid Exposure on Honeybee Colony Performance and Queen Supersedure

- Honeybee colonies chronically exposed to both neonicotinoids over two brood cycles exhibited decreased performance in the short-term resulting in declining numbers of adult bees (-228%) and brood (-213%), as well as a reduction in honey production (-229%) and pollen collections (-219%), but colonies recovered in the medium-term and overwintered successfully (Figure 1, Table 1). However, significantly decelerated growth of neonicotinoid-exposed colonies during the following spring was associated with queen failure, revealing previously undocumented long-term impacts of neonicotinoids: queen supersedure was observed for 60% of the neonicotinoid-exposed colonies within a one year period, but not for control colonies. Linked to this, neonicotinoid exposure was significantly associated with a reduced propensity to swarm during the next spring. Both short-term and long-term effects of neonicotinoids on colony performance were significantly influenced by the honeybees' genetic background.

Case study 2.5 Impact of Chronic Neonicotinoid Exposure on Honeybee Colony Performance and Queen Supersedure

- Sub-lethal neonicotinoid exposure did not provoke increased winter losses of honeybee colonies. Yet, significant detrimental short and long-term impacts on colony performance and queen fate suggest that neonicotinoids may contribute to colony weakening in a complex manner. Further, we highlight the importance of the genetic basis of neonicotinoid susceptibility in honeybees which can vary substantially. Even though honeybee colonies constitute buffered systems, the data show clear effects of the neonicotinoids.

Reference

Sandrock C., Tanadini M., Tanadini LG., Fauser-Misslin A., Potts S.G., Neumann P. (2014) Impact of chronic neonicotinoid exposure on honeybee colony performance and queen supersedure. PLoS ONE 9(8): e103592.

Case study 2.5 Impact of Chronic Neonicotinoid Exposure on Honeybee Colony Performance and Queen Supersedure

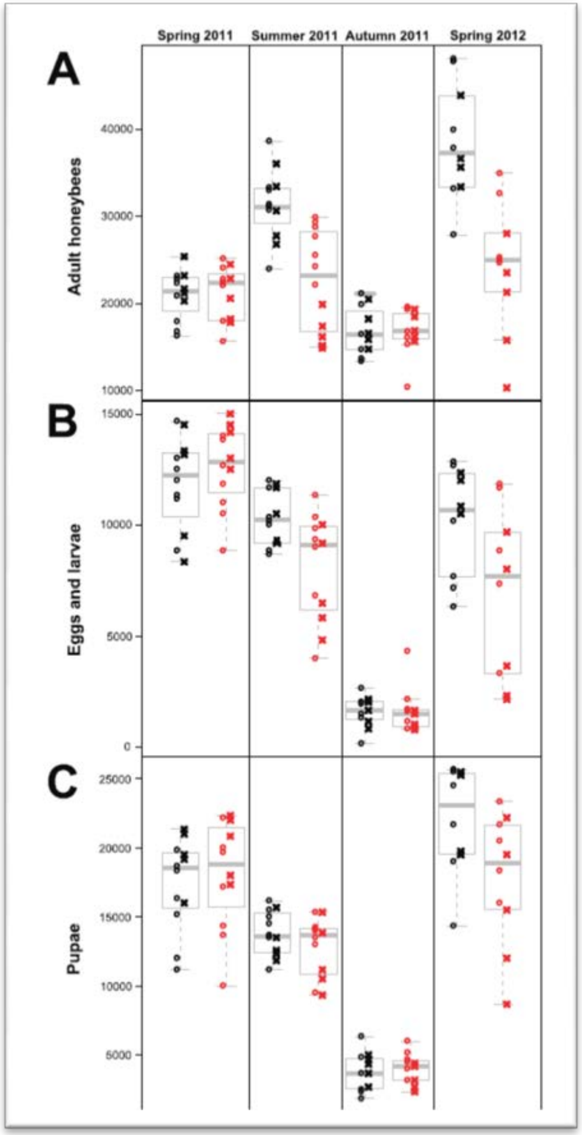


Figure 1. Dynamics of honeybee colony performance. Data of all three endpoints number of adult bees (A), eggs and larvae (B) and pupae (C) for the different pollen feeding treatments (black = control; red = neonicotinoids) and honeybee strains (circles = strain A; crosses = strain B). The data were obtained at four successive colony assessment dates (X-axis subpanels within figures) performed before (Spring 2011) and directly after the 1.5 months of experimental pollen feeding (Summer 2011), 3.5 months after the treatment (Autumn 2011) and one year later (Spring 2012). Estimated numbers on the Y-axes are truncated for adult bees and pupae for better overview.

Case study 3.1 Wild pollinators enhance fruit set of crops regardless of honeybee abundance

- There is an increasing concern that the observed declines of both wild and managed pollinators might impact the pollination, and thereby production, of world agricultural crops negatively. Whether the declines among wild pollinators, or of managed pollinators (mainly honey bees, Apis mellifera), have equally severe consequences for crop yields has, however, remained unclear. It has generally been assumed that most of the pollen in crops worldwide is transferred by honeybees. Wild pollinators have been thought to play a supporting and complementary role to the honeybee in cross-fertilizing crops. Earlier work indicated that wild pollinators might be important as service providers (Garibaldi et al. 2011), so following this we quantified the relative contribution to cross-pollination in crops by managed honeybees and wild insects.
- We first tested whether wild insect and honeybee visitation enhanced pollen deposition on stigmas of crop flowers. Second, we assessed to what extent visitation to the crop flowers by wild insects or honeybees improved fruit set. Third, we explore if visitation by honeybees might affect the benefit derived from wild insects. We wanted to understand whether fruit set is promoted by a higher number of species or individuals of wild pollinator that visit the flowers, only in situations when few honeybees visit the flowers.

Case study 3.1 Wild pollinators enhance fruit set of crops regardless of honeybee abundance

- To reach general answers to these questions, we contacted scientists that perform research on crop pollination from all over the world. We asked them to send us their original data on flower visitation and fruit set in crops. The response was extremely positive, and we were able to collect primary data from 600 agricultural fields on all continents, except Antarctica, and for 41 crops.

- We found a universally positive association of fruit set with increased flower visitation by wild insects in cropping systems worldwide (Figure 1). In contrast, fruit set increased with flower visitation by honeybees in only 14% of the cropping systems included. Overall, wild insects pollinated crops more efficiently than we had previously thought and had hypothesised. In fact, an increase in wild insect visitation enhanced fruit set by twice as much as an equivalent increase in honey bee visitation. Visitation by wild insects and honey bees promoted fruit set independently, such that pollination by managed honeybees supplemented, rather than substituted for, pollination by wild insects. Our results suggest that new practices for integrated management of both honeybees and diverse wild insect assemblages will enhance global crop yields.

Case study 3.1 Wild pollinators enhance fruit set of crops regardless of honeybee abundance

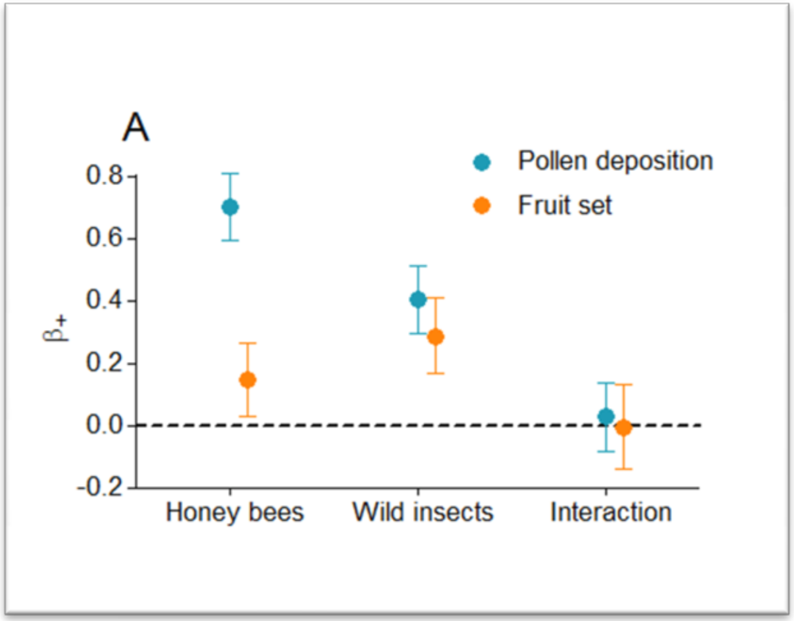


Figure 2. (A) Overall partial regression coefficients (β+ ± 95% confidence interval) for the direct and interacting effects of visitation by wild insects and honey bees on pollen deposition or fruit set (Lucas Garibaldi (reprinted from Garibaldi et al. 2013)

Reference

Garibaldi L.A., Steffan-Dewenter I, Winfree R., Aizen M.A., Bommarco R., Cunningham S.A., Kremen C., Carvalheiro L.G., Harder L.D., Afik O., Bartomeus I., Benjamin F., Boreux V., Cariveau D., Chacoff N.P., Dudenhöffer J.H., Freitas B.M., Ghazoul J., Greenleaf S., Hipólito J., Holzschuh A., Howlett B., Isaacs R., Javorek S.K., Kennedy C.M., Krewenka K., Krishnan S., Mandelik Y., Mayfield M.M., Motzke I., Munyuli T., Nault B.A., Otieno M., Petersen J., Pisanty G., Potts S.G., Rader R., Ricketts T.H., Rundlöf M., Seymour C.L., Schüepp C., Szentgyörgyi H., Taki H., Tscharntke T., Vergara C.H., Viana B.F., Wanger T.C., Westphal C., Williams N., Klein A.M. (2013) Wild pollinators enhance fruit set of crops regardless of honeybee abundance. Science 339: 1608-1611.

Case study 3.1 Wild pollinators enhance fruit set of crops regardless of honeybee abundance

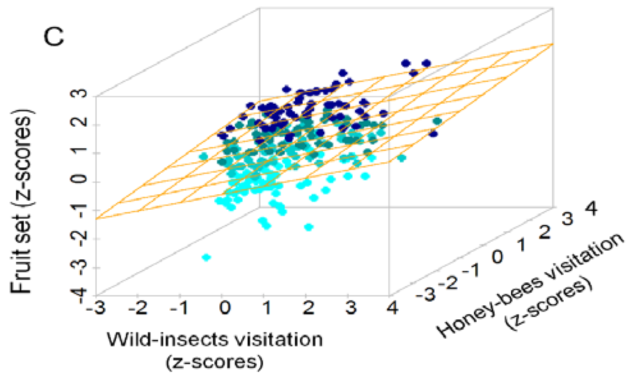


Fig. 2 (C) Visitation rate to crop flowers by wild insects enhances reproduction in all crops examined, whereas honey bee visitation has weaker effects overall. Maximum fruit set is achieved with high visitation by both wild insects and honey bees (upper right side of the figure). Fruit set increases from cyan to dark blue (Lucas Garibaldi (reprinted from Garibaldi et al. 2013)

Fig. 3 A bumble bee (*Bombus* sp.) worker collecting nectar and pollen from an oilseed rape field and at the same time pollinating the crop flowers (Maj Rundlöf)

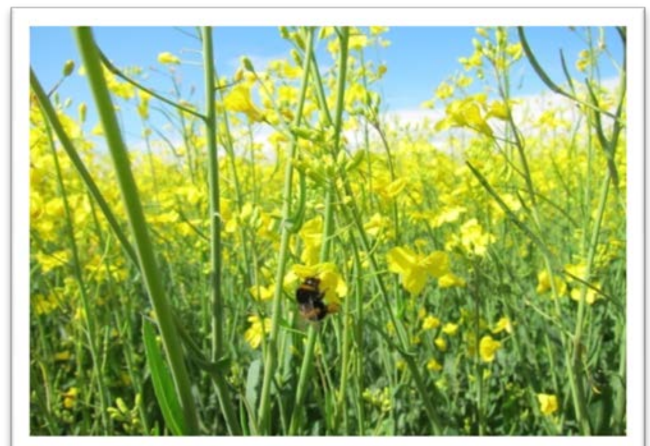


Fig. 4 A red-tailed bumble bee (*Bombus laipdarius*) pollinating a red clover seed field while collecting nectar and pollen (Maj Rundlöf)

Case study 3.2 Agricultural Policies Exacerbate Honeybee Pollination Service Supply-Demand Mismatches Across Europe

- Many European farmers rely on insect pollination services to ensure the best possible yields and are directly affected by changes in the availability of this service. As such, understanding the supply and demand of pollination services is essential to understand how vulnerable European agriculture is to changes in pollinator populations or increasing demands for pollination services. Although they are not the main pollinators in many crops (see case study 3.1), managed honeybees represent an important insurance asset to European crop production. This study examined the security of European pollination services by comparing the available supplies of honeybees with demand for pollination services across the continent in two years, 2005 and 2010.
- Using official statistical data from 41 European countries, the supply of honeybee pollination services was estimated as double the number of honeybee colonies in each country. These values were doubled to represent the capacity for beekeepers to move their hives between two different crops in a single year. Total demand for pollination services was estimated by multiplying the area of each insect pollinated crop by research estimates of the number of colonies recommended to provide pollination services to that crop. Summed over all crops, this produced an estimate of total national demand. By dividing supply by demand the study was able to estimate the capacity of each country's honeybee stocks to supply recommended levels of pollination services.

Case study 3.2 Agricultural Policies Exacerbate Honeybee Pollination Service Supply-Demand Mismatches Across Europe

The findings indicate that, in both years, 22 of the 41 countries had insufficient honeybee colonies to supply their demands for pollination services alone. Of these, The UK and Moldova had the lowest supply relative to their demands in both 2005 and 2010. By contrast Slovenia and Norway had several times as many colonies than their farming sectors demanded. Taken as a whole, total stocks in all 41 countries were able to supply approximately two thirds of European demands in both years. Although the total number of honeybee colonies increased across Europe, total demand grew nearly five times as much in the same time. Most of this increase was due to substantial growth in the area of oilseed rape and sunflowers, both commonly used as biodiesel stock. This was particularly noticeable in Greece where the area of oilseed rape grew by over 700%. This increase in demand relative to supply was most notable in Latvia, Lithuania, Estonia and Finland where the capacity of honeybees to supply services fell below 25%. Many countries that saw increased honeybee stocks were often those that already had more colonies than they required.

Reference

Breeze T.D., Vaissiere B., Bommarco R., Petanidou T., Seraphides N, Kozák L., Scheper J., Biesmeijer J.C., Kleijn D., Gyldenkærne S., Moretti M., Holzscuh A., Steffan-Dewenter I., Stout J., Pärtel M., Zobel M. & Potts S.G. (2014) Agricultural policies exacerbate pollination service supply-demand mismatches across Europe. PLoS ONE 9(1): e82996

Case study 3.2 Agricultural Policies Exacerbate Honeybee Pollination Service Supply-Demand Mismatches Across Europe

Figure 1. Honeybee colony (Jake Bishop)

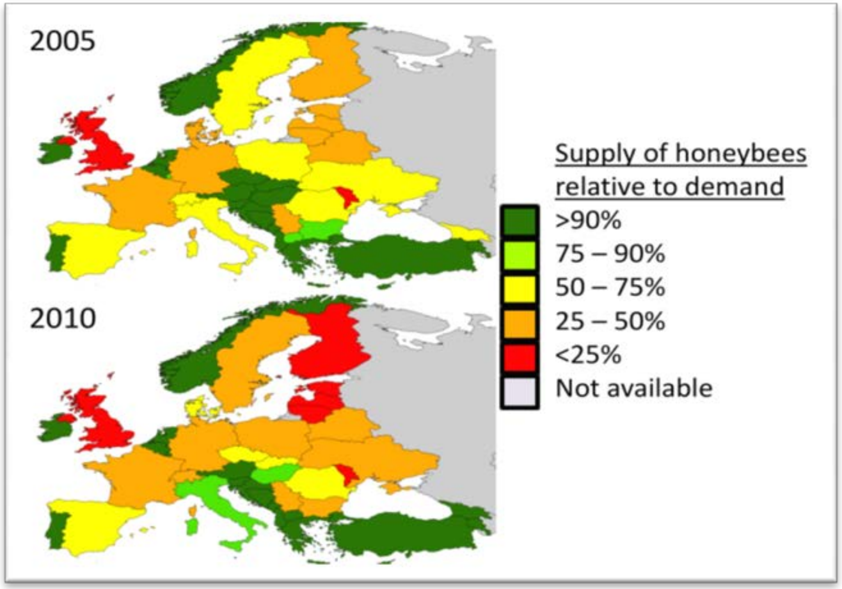


Figure 2. Capacity of honeybee colonies to supply demands for pollinaion services at a national level (Breeze et al. (reprinted from PLoS One))

Case study 3.3 Contribution of pollinator-mediated crops to nutrients in the human food supply

- Several studies have been conducted to evaluate monetary values of pollination services on crop pollination. However, it is difficult to assign monetary values to pollination services because they are frequently not traded on the marketplace and values differ widely depending on methods, value systems, and scales of analysis.

- Staple crop production (e.g. cassava, corn, potato, rice, wheat, yam) has doubled in the past 50 years due to new crop strains, increased use of agrochemicals, irrigation and new agricultural techniques. These grains and starchy vegetables are mostly wind-pollinated, self-pollinated, or vegetatively propagated crops. While they provide the majority of calories in the human diet, they are poor sources of most micronutrients. Dependence on these staple crops due to food system failures and declines in diet diversity are responsible for micronutrient deficiency ('Hidden Hunger') in over two billion people worldwide, especially in underprivileged areas. This underscores the importance of diet diversity and the need for animal-pollinated plants to prevent micronutrient deficiency. However, the contribution of these plants to worldwide micronutrient availability has not been quantified.

Case study 3.3 Contribution of pollinator-mediated crops to nutrients in the human food supply

We evaluated the nutritional composition of animal-pollinated world crops. We calculated pollinator dependent and independent proportions of different nutrients of world crops, employing FAO data for crop production, USDA data for nutritional composition, and pollinator dependency data. Crop plants that depend fully or partially on animal pollinators contain more than 90% of vitamin C, the whole quantity of Lycopene and almost the full quantity of the antioxidants β-cryptoxanthin and γ-tocopherol, the majority of the lipid, vitamin A and related carotenoids, calcium and fluoride, and a large portion of folic acid (see Fig. 1 for the proportion of fat-soluble vitamins attributed to animal pollination in yellow). This biophysical evaluation of the importance of pollination services for the production of vitamins and minerals highlight that ongoing pollinator decline may exacerbate current difficulties of providing a nutritionally adequate diet for the global human population.

Reference

Eilers E.J., Kremen C., Greenleaf S., Garber A.K., Klein A-M. (2011) Contribution of pollinator-mediated crops to nutrients in the human food supply. PLoS-One 6(6): e21363.

Chaplin-Kramer R., Dombeck E., Gerber J., Knuth K.A., Mueller N.D., Mueller M., Ziv G., Klein A-M. 2014 Global malnutrition overlaps with pollinator-dependent micronutrient production. Proc. R. Soc. B 281:20141799.

Case study 3.3 Contribution of pollinator-mediated crops to nutrients in the human food supply

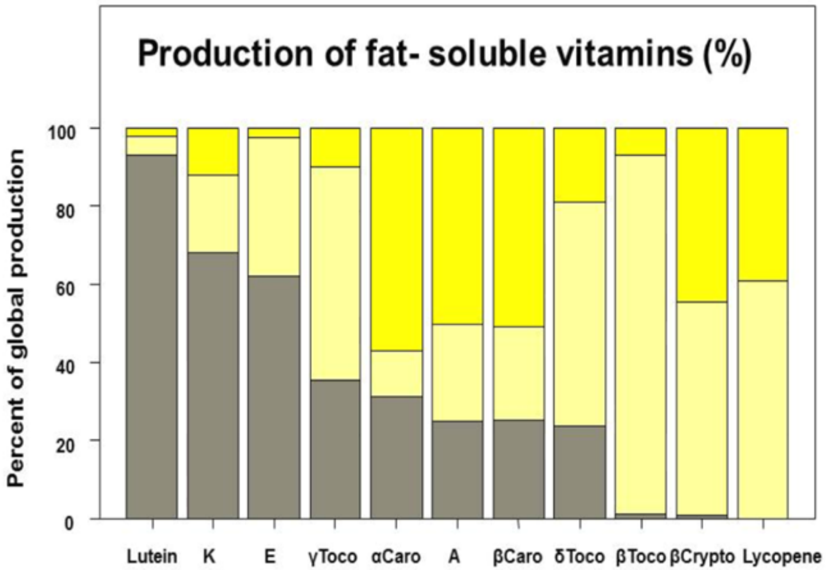


Figure 1. Proportion of fat-soluble vitamins (K= vitamin K, E= vitamin E, γToc= γ – tocopherol, αCar = α-carotene, A= vitamin A, βCar = β-carotene, δToc= δ – tocopherol, βCry = β - cryptoxanthin, βToc= β – tocopherol) in global crop production (%) produced without pollinators (grey), produced with pollinators but attributed to autonomous self- or wind pollination (light-yellow), produced with pollinators and directly attributed to animal pollination (yellow) (the figure is a modified Fig. 2 of the Plos One article)

Case study 3.4 Ecological intensification: harnessing ecosystem services for food security

- With global population growth, and associated demand for agricultural goods, there is ever-increasing pressure on farming to intensify production. However, this poses greater risks to environmental quality if conventional approaches to intensification are followed. A major opportunity for increasing production sustainably (i.e. ensuing environmental impacts are minimised while production is maintained or enhanced) is by integrating ecosystem services into agricultural systems. This can be achieved by replacing and/or augmenting anthropogenic inputs (e.g. fertilizers and pesticides) with ecosystem services such as pest regulation by natural enemies, pollination and soil fertility building. This approach is called “Ecological Intensification” and seeks to manage the biodiversity underpinning the ecosystem services which ultimately support food production (Figure 2).

- Many fruit, vegetable and arable crops show a deficit in pollination services, meaning that they could produce more yield or better quality products if pollination was improved (Figure 1). There are several ways to do this. Farmers could augment pollination services with managed pollinators such as honeybees, bumblebees or mason bees. Alternatively they could improve the area and quality of habitats that support pollinators on their farms or in the surrounding landscape. Sowing flower-rich field margins is one example where pollinator-friendly habitat is established next to a field where there is a high demand for pollination services. The underlying rationale being that a small economic investment in pollinator habitats could result in a long-term boost to productivity and profit. Studies are emerging showing that this approach is valid, yet there is much that research needs to address before this is established as a robust management practice for different farming systems across continents.

Case study 3.4 Ecological intensification: harnessing ecosystem services for food security

- A smart approach to ecological intensification is to identify win:win practices which can benefit multiple ecosystem services simultaneously. For instance, if flower margins can support the natural enemies of crop pests (e.g. carabids beetles, spiders and parasitoid wasps), as well as pollinators, then these beneficial insects could also spill-over in to the crop and reduce yield losses. Field margins can also play a role in soil protection, help buffer water courses from agricultural pollutants, and help support other wildlife valued by the society, such as birds.

- As energy prices and population are projected to go up in the next few decades, farming needs to shift increasingly from being highly dependent upon synthetic inputs to utilising biodiversity driven ecosystem services. Ecological intensification shows huge promise in helping this transition and will be an indispensable tool to reconcile the demands of food security, biodiversity conservation and sustainable societies (Figure 3).

Reference

Bommarco R., Kleijn D., Potts S.G. (2013) Ecological intensification: harnessing ecosystem services for food security. Trends in Ecology and Evolution 28: 230–238.

Case study 3.4 Ecological intensification: harnessing ecosystem services for food security

Figure 1. Bumblebee (*Bombus lapidarius*) visiting oilseed rape flowers (Jennifer Wickens)

Case study 3.5 Annual dynamics of wild bee densities: attractiveness and productivity effects of oilseed

STEP

Oilseed rape is one of the most important insect-pollinated mass-flowering crops in the European Union. Understanding the factors that determine the density and species richness of pollinators on such mass-flowering crops is mandatory for an efficient management of pollination services and stable crop yields. Principally, two different factors play a role for pollinator densities. First, the attractiveness of oilseed rape in comparison to other floral resources and the production area of oilseed rape in relation to pollinator population size determine densities (Fig. 3.5.1). High attractiveness of oilseed rape and a large cover of oilseed rape in a landscape lead to the dilution of pollinators and a potential deficit in pollination service. Second, oilseed rape provides large amounts of pollen and nectar resources that can increase population growth of wild solitary and social bee species. High cover of oilseed rape can result in larger bee populations and thus higher pollinator densities in the following year (Fig. 3.5.1). Solitary bee species that reproduce during the flowering period of oilseed rape may benefit more from additional pollen resources than social bee species that require a resource continuum from spring to autumn. Importantly, distinguishing among these two factors in agricultural landscapes requires data from more than one year and the parallel inclusion of attractiveness effects, i.e. the dilution or concentration of pollinators in dependence on the relative cover of oilseed rape in a landscape, and population growth effects, i.e. the annual dynamics of pollinator population size in dependence on the availably of oilseed rape pollen in the previous year.

Case study 3.5 Annual dynamics of wild bee densities: attractiveness and productivity effects of oilseed

In a case study in lower Franconia, Germany, we selected 16 landscape sectors of 1 km radius with high to low oilseed rape cover and monitored pollinator densities and oilseed rape cover changes in the consecutive years. We developed a mechanistic model to evaluate the combined effects of oilseed rape cover on the dilution or concentration of pollinator densities and the reproduction of bees. By fitting our empirical data with the mechanistic model we can show that a high cover of oilseed rape in the previous year enhances the densities of solitary wild bees in the respective landscape in the following year (Fig. 3.5.2A, Fig 3.5.3). However, for bumblebees with season-long colonies, no positive effect on the densities in the following year could be found (Fig. 3.5.2B). Presumably, bumblebees require other floral resources in semi-natural habitats or later flowering crops (see case study 4.4) to enhance the production of young queens and drones. We conclude that mass-flowering crops can affect the dynamics of wild bee populations but effect sizes depends on the flight period, social status and annual changes in oilseed rape cover.

Reference

Riedinger V., Mitesser O., Hovestadt T., Steffan-Dewenter I., Holzschuh A. (2014) Annual dynamics of wild bee densities: attractiveness and productivity effects of oilseed rape. Ecology, in press.

Case study 3.5 Annual dynamics of wild bee densities: attractiveness and productivity effects of oilseed

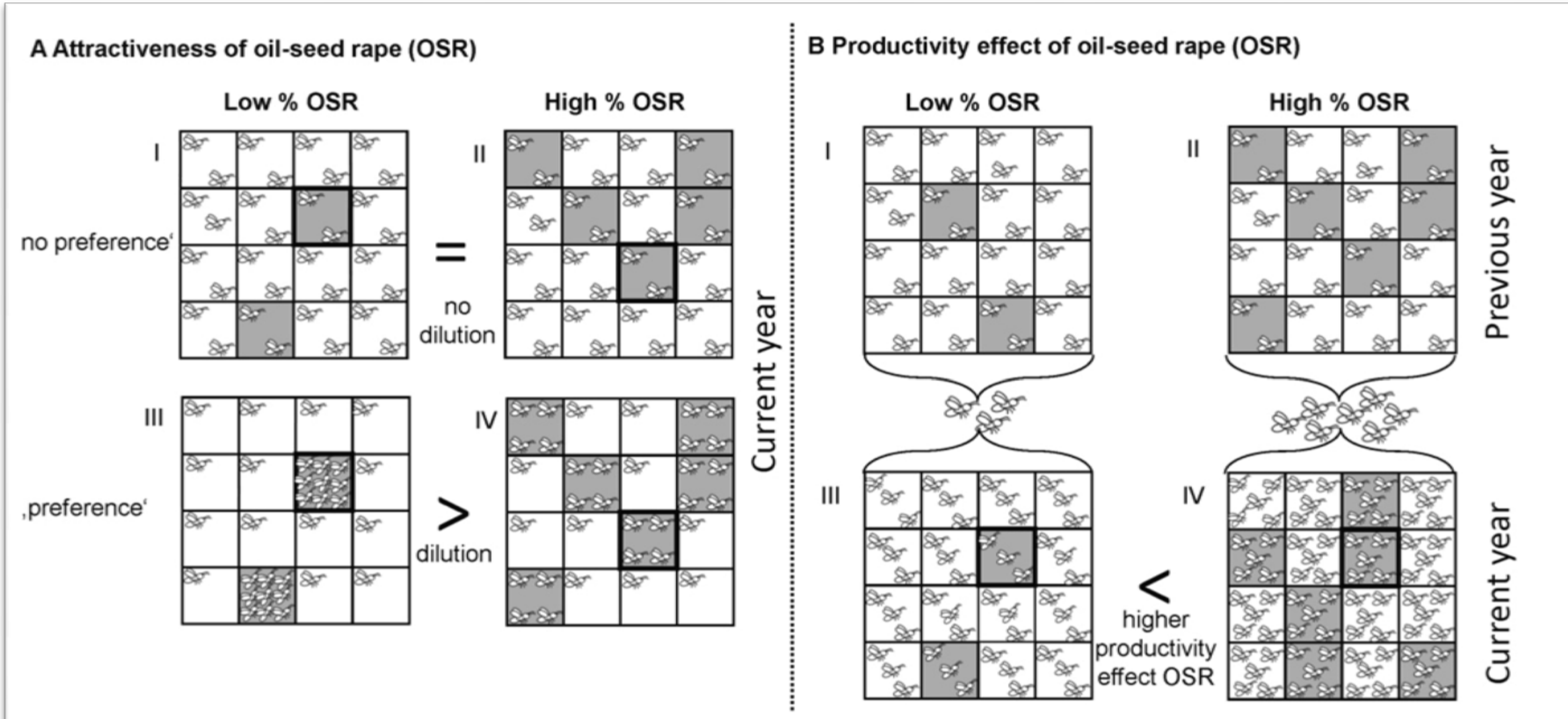


Figure 3.5.1 Conceptual model of attractiveness and productivity effects of oilseed rape on pollinator densities. (A) Preference of pollinators for oilseed rape leads to higher densities in oilseed rape fields compared to other habitats and dilution in landscapes with high oilseed rape cover. (B) Higher population growth rates in oilseed rape result in higher pollinator densities in the consecutive year.(Figure from Riedinger et al. (in press) Ecology doi: 10.1890/14-1124.1))

Case study 4.1 Environmental factors driving the effectiveness of European agri-environmental measures in mitigating pollinator loss – a meta-analysis

STEP

- Farmland represents one of the dominant land-uses in Europe, covering more than 45% of the area of the European Union. In Europe, farmland has traditionally supported high levels of biodiversity and about half of the species are associated with habitats that have been shaped by agriculture. However, the intensification of agriculture since the second half of the 20th century has caused severe declines in farmland biodiversity. Agri-environment schemes are the main tool to counteract the decline in farmland biodiversity. Yet, the impact of agri-environment schemes on biodiversity is variable and unpredictable. The variable effectiveness has been hypothesized to be caused by factors such as landscape structure, farming intensity and the extent to which agri-environmental prescriptions succeed in improving habitat quality for the targeted species.

- Focusing on pollinating insects, we provide the first comprehensive analysis of the factors that potentially influence the effectiveness of agri-environment schemes. We perform a quantitative analysis of published studies examining the effectiveness of agri-environment schemes. Although thus far most agri-environment schemes are not specifically targeted at pollinators, many schemes may potentially be beneficial to pollinators. For instance, schemes reducing the intensity of farming practices and schemes involving the creation or restoration of non-cropped farmland habitats can, either directly or indirectly, enhance the availability of floral resources and nesting sites and/or reduce sources of mortality (i.e. pesticides).

Case study 4.1 Environmental factors driving the effectiveness of European agri-environmental measures in mitigating pollinator loss – a meta-analysis

- Our results show that by improving floral resource availability, agri-environment schemes generally promote pollinators in agricultural landscapes. However, it is easier to enhance resource availability in structurally simple (few semi-natural habitats) than in cleared (no semi-natural habitats) or complex landscapes (many semi-natural habitats) and in croplands than in grasslands. In complex landscapes, availability of floral resources and nesting sites is already high and introducing additional resources by means of agri-environment schemes results in relatively small increases. Simple landscapes and arable farming systems are much more devoid of essential pollinator resources, making it easier to increase resource availability significantly with agri-environmental management. This results in the counter-intuitive situation that the most pronounced increases in pollinator diversity can be obtained in landscapes with low levels of biodiversity where measures will mainly benefit the species that are least affected by agricultural intensification.

- Different types of measures showed significant differences in their effects on pollinators. Sowing flower strips generally resulted in the largest increase and organic farming in the lowest increase (Fig. 4.1.1). The response of pollinators to individual measures also seemed to be mediated by their effect on floral resources. For example, pollinator species richness and abundance in sown flower strips were generally positively related to the number of flowering plant species that were sown (Fig. 4.1.2).

Case study 4.1 Environmental factors driving the effectiveness of European agri-environmental measures in mitigating pollinator loss – a meta-analysis

STEP

Fig. 4.1.3 Intensively farmed landscapes generally contain very few of the floral resources on which pollinators rely for food. In such landscapes it is relatively easy to enhance resource availability of pollinators, for example by establishing wildflower strips, but only common pollinator species benefit from such measures. Flevopolders, the Netherlands (photo: David Kleijn).

Reference

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: 912-920.

Case study 4.2 Late-season flowers benefit bumble bees

- Wild bees need a safe nesting place and flowering plants, providing nectar and pollen, to thrive. The intensified management of agricultural landscapes that has occurred in many parts of the world has, however, reduced and separated nesting and foraging resources for bees.
- In the agricultural landscape, we wanted to find effective measures which can be used to support bee populations and potentially also the pollination services that they provide. Sown flower strips are seen as a promising measure to support bees. Several previous studies have focused on the attractiveness of such flower strips to bees and other pollinators, but this says little about the influence of the flower strips on bee populations in the wider agricultural landscape.
- Bumblebees have annual colonies of one queen and several workers. The colony grow over the season and, hopefully, produces new queens and males at the end of the season. The new queens are essential, because they form the basis for next year's bumble bee population. Bumblebee populations have been suggested to be limited by the availability of late-season flower resources. We have tested this hypothesis in a study with replicated landscapes, by examining whether an addition of a 4-16 ha field of late-season flowering red clover (*Trifolium pratense*) to a ~1,200 ha landscape, affect worker, queen and male bumble bee densities.

Case study 4.2 Late-season flowers benefit bumble bees

- In our study we show two things. First we show that the vibrantly pink red clover fields (fig. 4.2.1) are a favoured forage habitat over wild flowers in uncultivated field borders for bumble bee workers and queens (fig. 4.2.2a). Secondly, we show that five times more queens and 71 % more males are found in landscapes with red clover fields compared to in control landscapes (fig. 4.2.2b), despite these fields constituting less than 0.2 % of the landscape surface area. This support the conclusion that reduced flower resource availability, particularly in late season, may in fact be key in the changes we can see currently in bumble bee communities.

- The results from our study support the use of flower strips as a measure to mitigate loss of bumblebees in agricultural landscapes, but the resources need to be provided at the right time. Late-season resources are lacking and are particularly important to bumblebees, with their long colony cycles compared to other wild bees. Red clover is such a late-season flowering plant which could be used to provide nectar and pollen (fig. 4.2.3).

Reference

Rundlöf M., Persson A.S., Smith H.G., Bommarco R. (2014) Late-season mass-flowering red clover increases bumble bee queen and male densities. Biological conservation 172: 138-145.

Case study 4.2 Late-season flowers benefit bumble bees

Figure. 4.2.1 Red clover field in southern Sweden where clover is grown to produce seeds, used in grass-clover leys for animal fodder or as green manure. Photo: Maj Rundlöf.

Figure. 4.2.1 Red clover field in southern Sweden where clover is grown to produce seeds, used in grass-clover leys for animal fodder or as green manure. Photo: Maj Rundlöf.

Case study 4.3 Landscapes with wild bee habitats enhance pollination, fruit set and yield of sweet cherry

- For the vast majority of crops it is unknown whether managed honey bees or wild bees are the most efficient pollinators, and how the pollination service provided by wild bees can be ensured. Cherries production is in excess of 2 million metric tons annually, and is one of the leading global food crops which greatly depend on animal pollination (Fig. 1). Honeybees have been assumed to be the main pollinators in cherry, but there is anecdotal evidence that wild bees provide better pollination services than honey bees in cherry. Although cherry producers might strongly depend on pollination services provided by bees, there has been no replicated study assessing the relative importance of honeybees and wild bees for cherry production to date.

- We assessed in a landscape-scale study how sweet cherry production is influenced by (1) high-diversity bee habitats, and (2) flowering vegetation which might compete with cherry for pollinators or might facilitate cherry pollination. Comparing fruit set of a bagged branch where insects could not access with fruit set of an open-pollinated branch on 32 cherry trees, bagged flowers produced only 3 % of the fruits produced by open-pollinated flowers. Although two thirds of all flower visitors were honeybees, fruit set increased with wild bee visitation only (Fig. 2A, B), presumably due to the higher pollination efficiency of wild bees. The low fruit set in orchards with low wild pollinator visitation was experimentally shown to be due to pollen limitation. Wild bee visitation increased with the proportion of high-diversity bee habitats in the surrounding landscape (1 km radius) and consequently also fruit set increased with the proportion of high-diversity bee habitats (Fig.2C, D). An increase in the proportion of high-diversity bee habitats from 20% to 50% enhanced fruit set by 150%. Neither flower cover of ground vegetation nor bee densities on ground transects were related to flower visitation in trees or fruit set suggesting that ground vegetation neither might compete with cherry for pollinators nor facilitates cherry pollination.

Case study 4.3 Landscapes with wild bee habitats enhance pollination, fruit set and yield of sweet cherry

- Our findings show that the increase of wild bee visitation and fruit set with the proportion of high-diversity habitats is linear at least up to a proportion of 55 % of high-diversity habitats in the landscape. This is particularly remarkable because the study region is characterized by relatively high proportions of high-diversity habitats (>18%) compared to many other agricultural regions in central Europe. We conclude from our results that farmers cannot maximize yield by only ensuring small amounts of high-diversity bee habitats in the surrounding of their orchards, and we expect that a decline in high-diversity habitats has an even stronger negative effect on yield in regions where the proportion of high-diversity habitats is already lower than in our study region.

Reference

Holzschuh A., Dudenhöffer J-H., Tscharntke T. (2012) Landscapes with wild bee habitats enhance pollination, fruit set and yield of sweet cherry. Biological Conservation, 153, 101-107.

Case study 4.3 Landscapes with wild bee habitats enhance pollination, fruit set and yield of sweet cherry

STEP

Figure 1. Cherry trees in bloom (Photo: J.-H. Dudenahöffer).

Figure 3. Landscape with arable lands and high-diversity bee habitats surrounding a cherry orchard in the lower middle of the photo (Photo: J.-H. Dudenhöffer).

Case study 4.4 Early mass-flowering crops mitigate pollinator dilution in late-flowering crops

To ensure high yield quantity, quality and stability in these crops, an efficient management of pollinators in agroecosystems is mandatory. Pollination services can be provided by a broad variety of insects including non-managed wild bees, syrphid flies and honey bees managed by beekeepers. The advantage of honeybee management is the ease of moving colonies to landscapes or regions with high cover of insect-pollinated crops based on agreements between farmers and beekeepers. However, new diseases and parasites, negative impacts of pesticides as well as socioeconomic constrains in beekeeping have recently resulted in significant declines of honey bees in central Europe. Thus, instead of relying solely on honeybees to maintain pollination services, a mix of different crop cultures and green infrastructure elements in an agricultural landscape could be used to build up diverse pollinator communities throughout the season. Single crops typically flower only for a limited time of the year leading to peaks in resource availability at certain times and a shortage after flowering has ceased. For example, oilseed rape is one of the most dominant mass-flowering crops in central Europe during spring providing high densities of nectar and pollen. This resource pulse has been shown to foster the success of nest-founding bumble bee queens, to enhance the size of bumble bee colonies in landscapes with high oilseed rape cover, and, as a consequence, the density of foraging bumble bees latter in the season.

Case study 4.4 Early mass-flowering crops mitigate pollinator dilution in late-flowering crops

STEP

In a case study in Germany, we evaluated the seasonal dynamics of pollinator densities in landscapes with low or high proportion of early and late mass-flowering crops and semi-natural habitats. We selected 16 landscapes that differed in the relative cover of oilseed rape as an early mass-flowering crop, in the relative cover of sunflowers, and in the relative cover of semi-natural habitats. Our results indicate that densities of bumble bees in late-flowering sunflower fields were enhanced in landscapes with high cover of early-flowering oilseed rape (Fig. 4.4.1a) whereas syrphid flies and honey bees showed no increase (Fig. 4.4.1c-f). Highest bumblebee densities in the late-flowering crop were reached in landscapes that combined a high cover of oilseed rape and semi-natural habitats. Further, a low relative cover of oilseed rape in spring led to the dilution of bumblebee densities in late-flowering sunflower fields in landscapes with high cover of sunflower fields (Fig. 4.4.1b, Fig. 4.4.2 and 4.4.3), whereas in landscapes with a high relative cover of oilseed rape, no dilution of bumble bees was found (Fig 4.4.1a). Thus, our results indicate that early mass-flowering crops can mitigate pollinator dilution in crops flowering later in the season.

Reference

Riedinger V., Renner M., Rundlöf M., Steffan-Dewenter I., Holzschuh A. (2014) Early mass-flowering crops mitigate pollinator dilution in late-flowering crops. Landscape Ecology 29: 425-435

Case study 4.4 Early mass-flowering crops mitigate pollinator dilution in late-flowering crops

Sunflower field in the study region in lower Franconia, Bavaria, Germany (photo: Marion Renner)

Flower-visiting bumble bee (Bombus terrestris) on sunflower (photo: Marion Renner)

Case Study 5.1 How can Pollination Ecology research help answer important questions?

- While pollination has been studied for centuries, it remains a dynamic field of scientific research constantly adopting novel methods and improving our understanding of the interactions between plants and their pollinators. A recent paper (Mayer et al. 2011) listed the main scientific questions that still need to be addressed in this field focusing on the ecological and biological system itself. These questions were put together from a long list of suggestions from scientific experts in the pollination research field.
- To complement the effort of the Mayer et al. (2011) paper, we developed a simple framework integrating ecological, societal and socio-ecological issues relevant to pollinators and pollination and outlined a pathway to come to a ‘whole-society’ list of key questions for future research in the field of pollination ecology (Biesmeijer, Sorensen & Carvalheiro, 2011). This case study is an excerpt of the latter paper.
- There are different types of questions one can ask about pollinators and pollination. For instance, questions in the Mayer et al. (2011) paper range from “What is the lifespan of pollen grains”, a very specific mechanistic question, to “How can we better employ plants and their pollinators as educational tools for public awareness?”, an educational-societal question. In fact, questions may address four major, partly separate, realms (figure 1), namely:

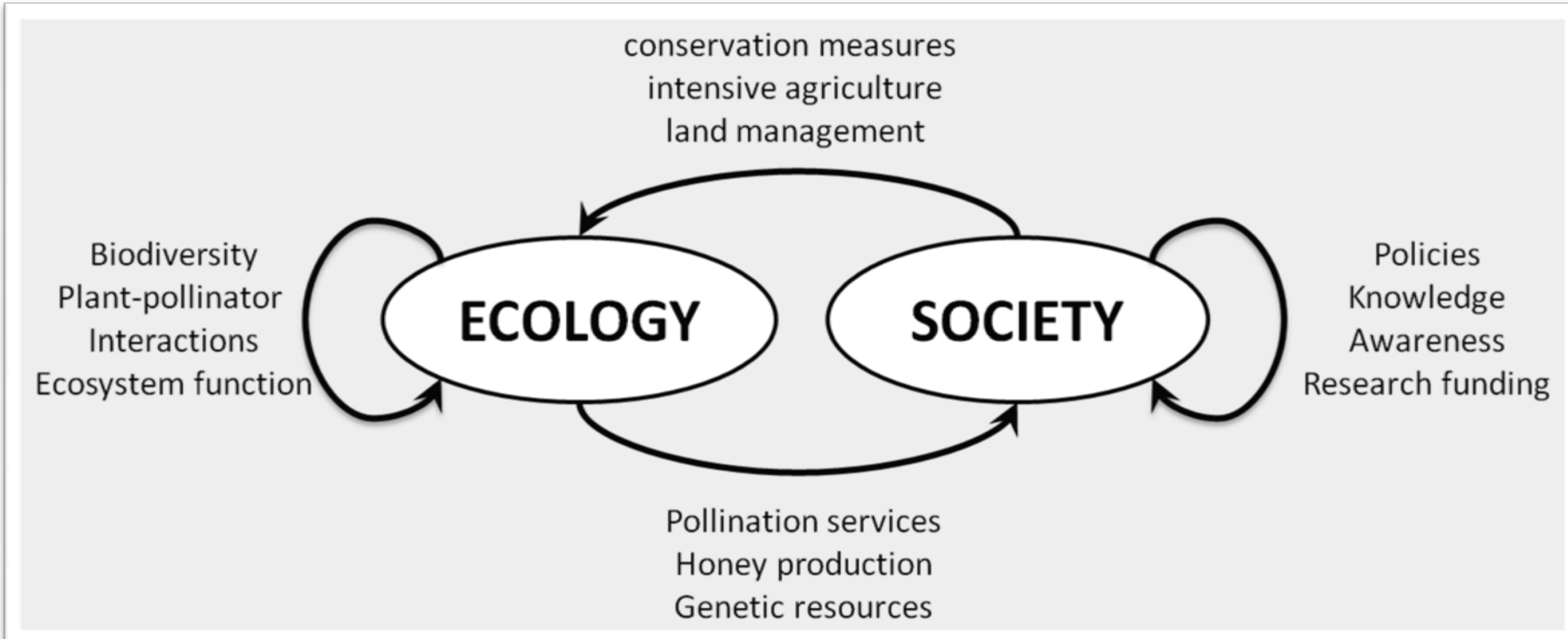
Case Study 5.1 How can Pollination Ecology research help answer important questions?

- (1) Questions dealing with the workings of nature, including ecology, evolution and behaviour; in Figure 1 referred to as “ECOLOGY”.
- (2) Questions about how ecosystems and biodiversity provide human society with goods and services, including crop pollination, honey production and genetic resources of managed pollinators. (ECOLOGY SOCIETY)
- (3) Societal issues in which pollinators and pollination play a role, including policies such as the convention of biological diversity, Natura 2000, habitat directive, but also funding for research and awareness of the general public. (SOCIETY)
- (4) Questions about how societal actions affect pollinators and pollination. These include land management and intensive agriculture, but also the impact of conservation measures. (SOCIETY ECOLOGY)
- Policy makers, conservation managers, school teachers, researchers, and other stakeholders, might ask very different sub-questions when asked to answer a broad question (figure 2). However, only all these questions together address the broad question fully. It is therefore important to reach out to the wider stakeholder community to address broad, policy relevant, questions.

Reference

Biesmeijer J.C., Sorensen P., Carvalheiro L. (2011) How Pollination Ecology research can help answer important questions. Journal of Pollination Ecology 4: 68-73

Case Study 5.1 How can Pollination Ecology research help answer important questions?



Schematic representation of the pollinator-relevant issues in natural systems (ECOLOGY) in society and linking both

Case Study 5.1 How can Pollination Ecology research help answer important questions?

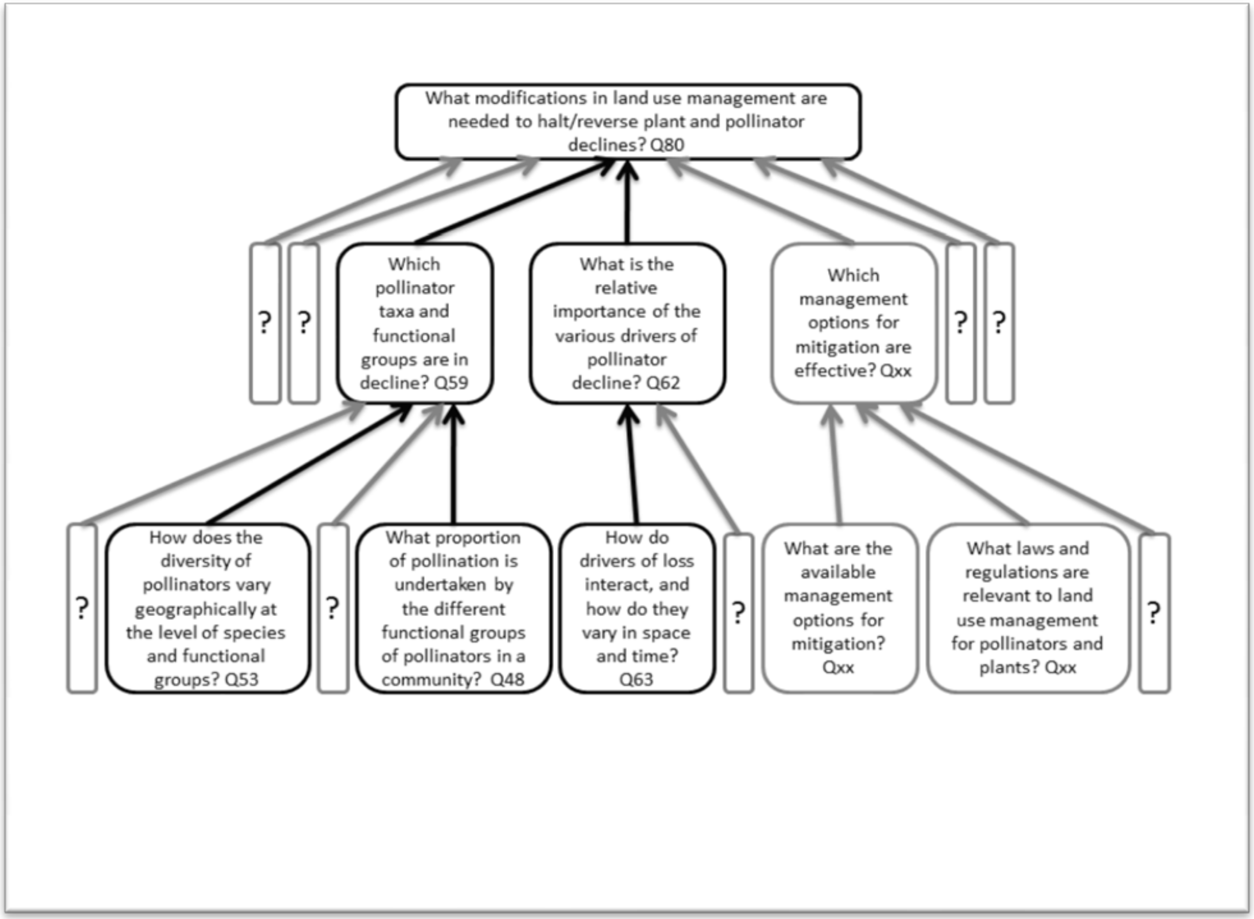


Illustration of the possible relationships and hierarchy of some of the questions presented in Mayer et al 2011 (highlighted in black) and others identified by us (in grey). The broad question (Q 80 at the top) needs input from many different areas some already listed by Mayer et al. 2011 (Q48, Q53, Q59, Q62, Q63), some identified by us (Qxx), some not yet identified (boxes with question marks)

Case study 5.2 Multi-level Analysis of Mismatch and Interplay between Pollination-related Policies and Practices

STEP

- This study explores the governance of pollination services from a multi-level policy perspective in order to identify links, potential mismatch and potential opportunities using three different case studies: first, formalised group discussions in Brussels between 21 EU level stakeholders, including major national research organisations, NGOs and national government representatives aimed at understanding the factors influencing governance of pollination services at a national and cross national level. Second, a series of interviews with six Finnish stakeholders was conducted to explore the factors affecting local governance of pollination services. Finally a review of existing policy affecting pollination services was conducted. Relevant policies were identified through their direct connection to pollination services or the factors influencing their declines.
- Participants at the Brussels workshop identified four major concerns relating to the impacts of pollinator losses; biodiversity, agriculture, ecosystem services and functions and human health. The impacts of biodiversity were the primary concern of this group, but in particular what the loss of pollinator diversity may have on agriculture and human wellbeing. By contrast, most of the Finnish stakeholders interviewed regarded pollination services by honeybees to be the most, or only, important aspect of the service and were primarily, or solely, focused on the economic effects of pollination on agriculture. Analysis of relevant policy identified 15 International policies that affect pollination services. Most of these concerned agriculture (e.g. the EU's Common Agricultural Policy) or biodiversity (e.g. the UN's Convention on Biological Diversity) although some broader policies were also found to be relevant (such as the Plant Protection Products Directive). While many of these policies directly affect pollination services, pollinators were not explicitly referenced in most.

Case study 5.2 Multi-level Analysis of Mismatch and Interplay between Pollination-related Policies and Practices

The findings of these case studies highlight a mismatch between EU and local governance concerns surrounding the loss of pollination services. National and EU stakeholders focused on the impacts of pollination on biodiversity while local stakeholders were mostly concerned with the agricultural impacts. This mismatch is further represented in the policy review with biodiversity policy taking little account of agricultural impacts and farming policy often encouraging practices detrimental to biodiversity.

Reference

Ratamäki O., Jokinen P., Sørensen P., Breeze T.D. and Potts S.G. (in press) Multi-level Analysis of Misfit and Interplay between Pollination-related Policies and Practices. Ecosystem Services

Case study 5.2 Multi-level Analysis of Mismatch and Interplay between Pollination-related Policies and Practices

STEP Stackeholders meeting, Brussels, September 2010. (Photo: Pavel Stoev)

Case study 5.3 Conceptual model for evidence analysis to support policy

- The summary of the conceptual model is based on Sørensen et al. (in prep.) and the governing question: "How to manage ecosystems to protect bees (native/domestic)?". The general structure is shown in Figure 1, which defines a three step approach .
- Step1: Aims to identify a "complete" list of factors that control the presence and abundance of bees, including the human activities that have an influence on these factors. If the defined list of factors is "incomplete", then the subsequent understanding, based on the concept model, will also be incomplete and important topics may be ignored. This is a fundamental problem in modelling (Walker et al., 2003 and Sørensen et al., 2010) and it is, thus, important to make a careful mind map in Step 1 to define factors in order not to overlook topics that may have high relevance to the governing question, see Figure 2. The method in Step 1 is a refinement of the method suggested by Sørensen et al. (2010) and is combined with the hierarchical sub-divisions of questions suggested by Biesmeijer et al. (2011), which identified important pollination ecology research questions. Figure 2 shows the principle applied here using a simple example for illustration. The complete conceptual model can contain up to 100 factors. Too many factors will make the model inaccessible for practical management purposes and too few factors will make the model too broad and, thus, result in only trivial conclusions.

Case study 5.3 Conceptual model for evidence analysis to support policy

- Step 2: In Step 2, some factors are defined to have casual effects on other factors. This is shown through an example in Figure 3, where the application of an insecticide can cause contamination of pollen and thereby expose both larvae and worker (and the other life stages of a bee; not shown in our simple example). Thus, in Figure 3, arrow No. 1 relates contamination of pollen to negative effects on the larvae, while arrow No. 2 relates insecticide application to contamination of pollen. These two relations are different in the way that arrow No. 1 not only considers insecticides, and arrow No.2 does not consider how contaminated pollen can affect larvae, but rather how insecticides can end up contaminating pollen; this is a subtle, but important, difference for science based understanding. The final conceptual model is much more complex, having hundreds of relations in a network connecting the factors.

Case study 5.3 Conceptual model for evidence analysis to support policy

Step 3: The importance of the relations defined in Step 2 (shown as arrows in Figure 3) are evaluated based on available lines of evidences. This forms an efficient way to map the knowledge and to integrate different pieces of evidence into a coherent analysis of understanding and uncertainty. The pieces of evidence are collected from research results and can include a broad range of sources, such as peer-reviewed studies and expert opinions. Once populated with evidence, the conceptual model can then facilitate policy and practitioners to identify the key relevant evidence available to help inform decision making on a particular aspect of pollinators.

Reference

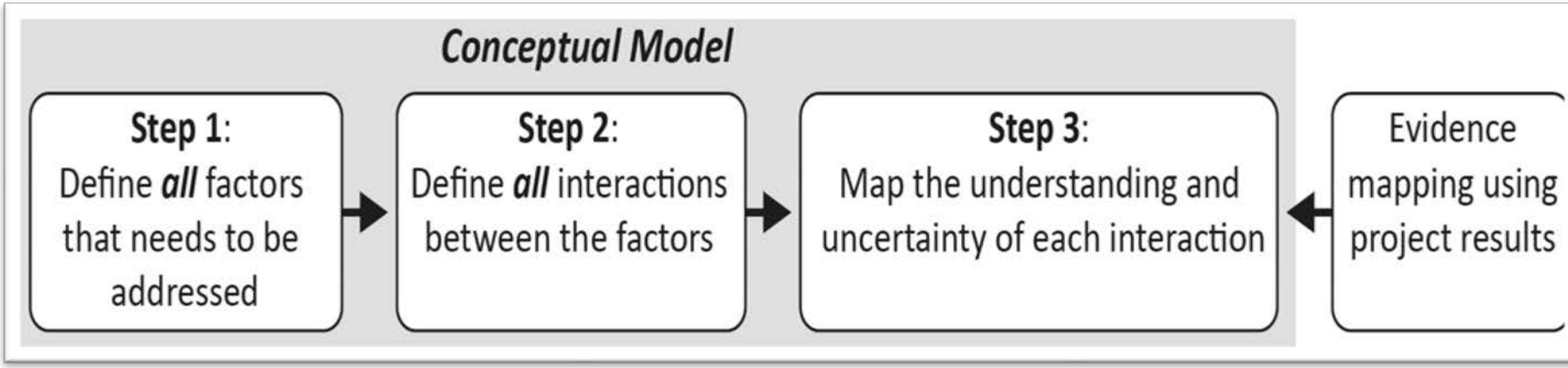
Sørensen P., Damgaard C., Brüggemann R. 2015, Conceptual model for evidence analysis to support policy, in preparation, (for status of the paper contact: pbs@dmu.dk).

Biesmeijer J.C., Sorensen P.B., Carvalheiro L.G., HOW POLLINATION ECOLOGY RESEARCH CAN HELP ANSWER IMPORTANT QUESTIONS, Journal of Pollination Ecology; 2011; 4; (9): 68-73

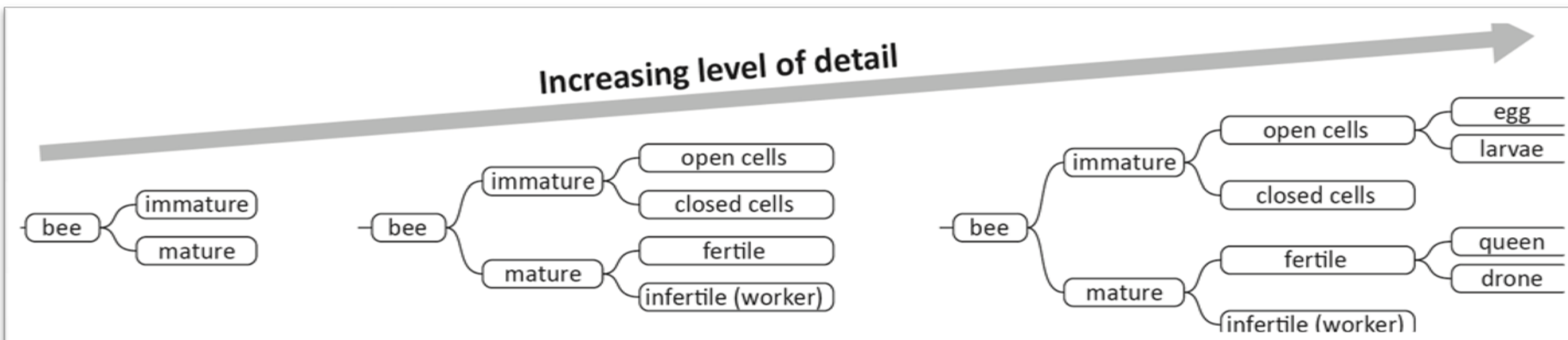
Sørensen P.B., Thomsen M., Assmuth T., Greiger K.D., Baun A., Conscious worst case definition for risk assessment, part I A knowledge mapping approach for defining most critical risk factors in integrative risk management of chemicals and nanomaterials, Science of the Total Environment 2010; 408: 3852–3859

Walker W.E., Harremoes P., Rotmans J., Van Der Sluijs JP, Van Asselt M.B.A., Janssen P, Krayer Von Krauss M.P. Defining uncertainty, a conceptual basis for uncertainty management in model-based decision support. Integrated Assessment 2003;4 (1): 5-17

Case study 5.3 Conceptual model for evidence analysis to support policy

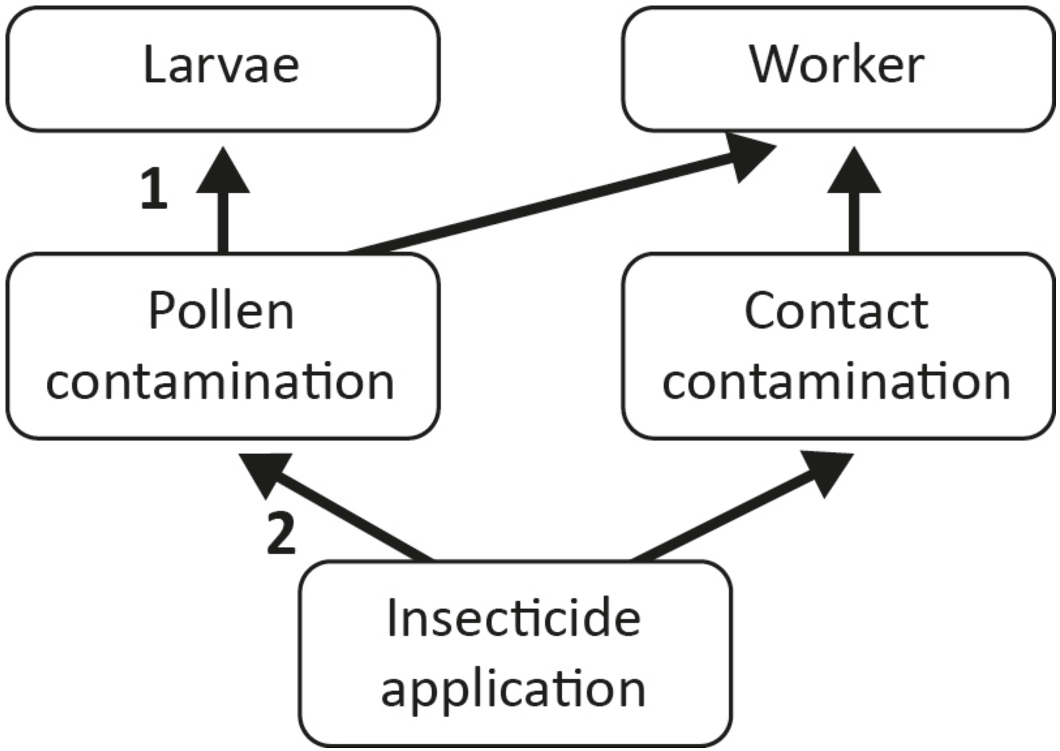


General structure of the concept model. The steps 1, 2 and 3 are explained in the text below.



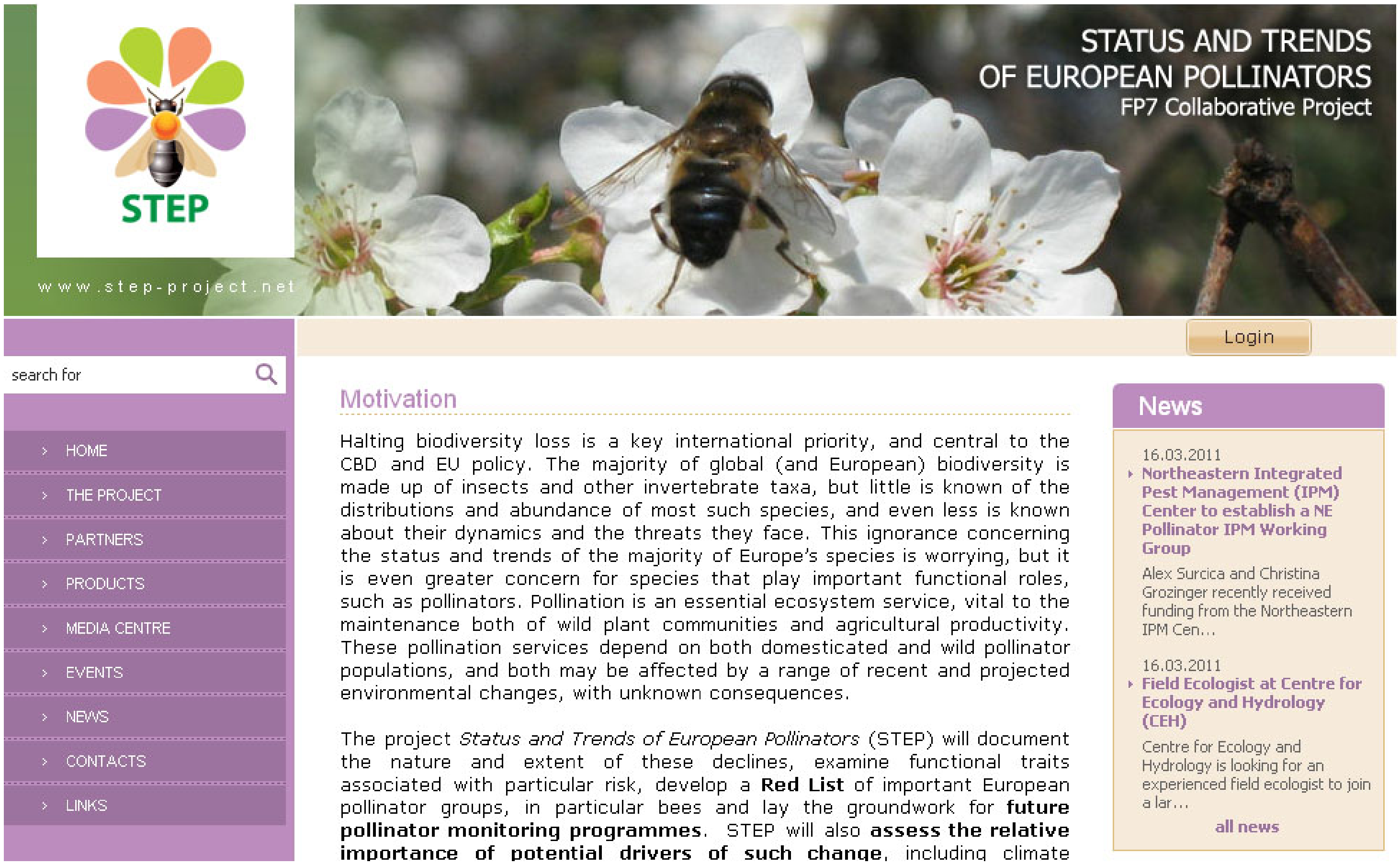
Example of systematic subdivision into detailed factors (life stages of bees). The final factors of "egg", "larvae", "closed cells", etc. are added to the list of factors used for Step 3.

Case study 5.3: Conceptual model for evidence analysis to support policy



Example showing relations between factors

WP7: Communication, Dissemination, and Training



STEP website www.step-project.net

Outreach materials


STEP-project Fact Sheet

Pollinators Support Farm Productivity

STEP

Pollinating insects contribute to agricultural production in 150 (84%) European crops

These crops depend partly or entirely upon insects for their pollination and yield

The value of insect pollinators is estimated to be €22 billion a year in Europe

Wild bees and other insects are important pollinators, as well as honeybees

Status and trends of European pollinators STEP-project www.step-project.net

Bumblebees are important pollinators in several crops. Photograph Maj Rundlöf

Insect pollinators are essential for the productivity of a wide range of economically important European crops by increasing yield and improving crop quality (Box 1). While managed honeybees can provide pollination services for some crops, it is the wild pollinators such as bumblebees, solitary bees and hoverflies which may be the most important pollinators across Europe. For instance in the UK, there are only enough honeybees to pollinate a third of the crops needing this service, with wild pollinators doing the majority of the work.

Box 1: Crops that benefit from insect pollination

- Fruits – apple, orange, tomato, pear, peach, melons, lemon, strawberry, raspberry, plum, apricot, cherry, kiwifruit, mango, and currants
- Vegetables – carrot, onion, pepper, pumpkin, field bean, courgette, French bean, eggplant, squash, cucumber and soy bean
- Industrial crops – cotton, oilseed rape, white mustard, and buckwheat
- Seeds and nuts – sunflower, almond and chestnut
- Herbs – basil, sage, rosemary, thyme, coriander, cumin and dill
- Forage crops for animals – alfalfa, clover and sweetclover
- Essential oils – chamomile, lavender, and evening primrose

STEP newsletters

NEWSLETTER

STEP

The purpose of this newsletter is to disseminate the results of the project Status and Trends of European Pollinators (STEP) among stakeholders and the general public and to continue the dialogue between administrators, managers and policy-makers from one side and the scientific community on the other side on pollinator-related issues. It will be used as a communications tool for dissemination of information to interested parties and will keep them informed of all planned activities and recent news. The STEP project will run from February 2010 until January 2015.

To subscribe to this newsletter please contact: pavel.e.stoev@gmail.com

Dear readers,

We are proud to present the second ne will provide you information about the p activities related to pollinators and inse on our website www.step-project.net. V in-depth information about project resu as well as detailed partner information. workshops can also be found there. Th administrations and NGOs in the policy working on scale-related biodiversity c

We hope this newsletter will keep you i in the field of pollinator biodiversity and your work.

Kindest regards,

Prof. Simon G. Potts
STEP Project Co-ordinator

SEVENTH FRAM PROGRAMM

CONTENTS:

2 Recent progress and results
3 Selected recent outputs from
8 Conferences
8 Partnering projects

STEP

1. Recent progress

STEP Stakeholder Worksho most important governing q

One of the goals of STEP is to es ers across Europe and beyond, i and the general public. To iden related to pollinator loss, in Sept stakeholder groups were invited ing researchers, officials from D administration, nature conservat tendees discussed and identifie These include loss of biodiversi issues related to agricultural pro profound links to biodiversity lo particular. Pollinator loss is a m negative effects on human wellb culture).

STEP coordinator gives an overview of our current understanding of pollinator loss to the workshop participants. Photo: Pavel Stoev.

STEP 2nd Annual meeting, Fr

Forty five members of the STEP c to date and formulate plans for of existing datasets on pollinato declines in Europe; progress on habitat loss, pesticides, disease impacts of pollinator loss; assess tecting European pollinators; fina and policy and dissemination ac

STEP were very pleased to welco workshop on "Linking land use, Kennedy, Claire Kremen, Eric Lo tions and wide ranging discussi ties for the future. We look forwa as we face the same fundamen of the Atlantic.

Break out group discussing the various impacts of pollinator loss on agricultural production. Photo: Simon Potts.

Attendees at the STEP Annual meeting in Fruška Gora, Serbia. Photo: Riccardo Bommarco.

Issue 2, January 2012

STEP

2.4 Natural areas stabilize crop pollination services

Natural areas near to agricultural land stabilize fruit set of flowering crops world-wide by increasing the average and decreasing the variability of pollination services, according to a new study published in the international journal Ecology Letters.

The article reports collaborative work produced by researchers from 11 countries. The study tackles an important topic for ecosystem services delivery, asking if the pollination stability over space and time is affected by isolation of crop fields to natural and semi-natural areas. The research team synthesized for the first time data from 29 studies in contrasting biomes, crop species, and pollinator communities. Landscape effects on the stability of pollination services have seldom been analyzed even in individual studies.

The team found that increasing distance to natural or semi-natural areas reduced the spatial and temporal stability as well as mean levels of flower-visitor richness, flower-visitation rate (all insects except honey bees), and fruit set. In contrast, honey bees, which are managed in many agroecosystems and represented >25% of visits in most studies, showed no changes in the magnitude or stability of visitation to crop flowers. Thus further highlights the importance of wild flower-visitors contributions to crop productivity and reliability. These results suggest common effects of landscape change on the stability of pollination services for contrasting crops and landscapes around the world. Therefore policies favouring the incorporation of natural or semi-natural areas into agricultural landscapes are highly valuable.

Pollination service in Grapefruit plantations (*Citrus × paradisi*) in NW Argentina is provided by the nearby Yungas forest. Photo: Natacha P. Chacoff and Carolina Monmany.

A ground-nesting, non-managed sand bee *Andrena* spp. visiting blueberry flowers (*Vaccinium corymbosum*) to collect pollen and nectar and in return delivers valuable pollination services to the crop. Photo: Rufus Isaacs.

Some non-managed, ground-nesting bee species provide pollination services to Almond orchards (*Prunus dulcis*) but only when semi-natural areas like Chaparral in California are nearby. Photo: Alexandra-Maria Klein.

Garibaldi, L.A., Steffan-Dewenter, I., Kremen, C., Morales, J.M., Bommarco, R., Cunningham, S.A., Carvalheiro, L.G., Chacoff, N.P., Dudenhöffer, J.H., Greenleaf, S.S., Holzschuh, A., Isaacs, R., Krewenka, C., Mandelik, Y., Mayfield, M.M., Morandin, L.A., Potts, S.G., Ricketts, T.H., Szentgyörgyi, H., Viana, B.F., Westphal, C., Winfree, R., Klein, A.M. 2011. Stability of pollination services decreases with isolation from natural areas despite honey bee visits. Ecology Letters, 14 (10): 1062-1072.

Policy briefs

Science for Environment Policy

Early-flowering crops may increase bumblebee numbers for late-flowering crops

22 May 2014
Issue 373

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Source: Riedinger, V., Renner, M., Rundlöf, M. *et al.* (2014). Early mass-flowering crops mitigate pollinator dilution in late-flowering crops. *Landscape Ecology*. 29:425–435. DOI:10.1007/s10980-013-9973-y

Contact: verena.riedinger@uni-wuerzburg.de

Read more about: Biodiversity, Agriculture

1. 'Status and trends of European pollinators' (STEP) project funded under the European Commission's Seventh Framework Program for Research and Technical Development. http://www.step-project.net/

Planting early-flowering crops, such as oilseed rape, boosts the numbers of bumblebees available to pollinate late-flowering crops, such as sunflowers, according to recent research. Carefully managing the timing and coverage of flowering crops in the landscape could therefore ensure pollination services and increase yields, say the researchers.

The value of insect pollinators cannot be underestimated. They are essential for the production of many crops and help improve yields and quality. However, there is a worrying decline in the numbers of pollinators and it is increasingly recognised that management of the agricultural landscape is crucial to conserving these insects and the services they provide.

This is the first study to investigate the effects of growing mass-flowering crops at different times of the year. Carried out as part of the EU-funded STEP[1] project, the researchers counted the number of bumblebees, hoverflies and honeybees they saw during surveys of 16 sunflower fields in Bavaria, Germany, during July and August 2011.

The study site is intensively farmed and includes oilseed rape, which flowers from late April until early June, and sunflowers, which flower in July and August. The researchers estimated the area covered by oilseed rape, sunflowers and semi-natural habitats (mainly grasslands, forest edges, hedgerows, fallow land and orchard meadows) within a 2 km radius around the sunflower fields. Pollinators were expected to use this area for foraging and nesting.

Overall, the researchers found that having early-flowering oilseed rape in the landscape boosted the numbers of bumblebees found in the later-flowering sunflower fields. Bumblebee numbers were highest in sunflower crops where the landscape included both relatively large areas of oilseed rape (more than 7.5% of the land) and semi-natural habitats (more than 6% of the land). The latter are important because they provide nesting sites and a continuous supply of food for bumblebee colonies. This combination of food and breeding habitats boosts the early establishment of bumblebee colonies.

However, bumblebee numbers were lower in areas where the sunflower fields covered a large proportion of the landscape in relation to oilseed rape cover. As the area covered by sunflowers increased relative to oilseed rape, the numbers of bumblebees per unit area of sunflowers fell. This reduced density or 'dilution' of bumblebees can affect pollination services and, potentially, crop yields.

This suggests that flowering crops grown earlier can reduce the dilution effect on bumblebee numbers that sometimes occurs when large areas of mass-flowering crops are grown later in the season.

This positive feedback between oilseed rape, semi-natural habitats and sunflowers was not seen for hoverflies or honeybees. For hoverflies this may be because they can disperse more widely than bumblebees and can find alternative nesting sites when the oilseed rape crops are harvested. For honey bees it could be because they depend more on beekeeping activities than on the landscape itself.

Overall, these results suggest that bumblebees and the pollination services they provide could benefit from careful management of early and late mass-flowering crops in the landscape.

Science for Environment Policy

DG Environment News Alert Service

European Commission

10 November 2011

Animal-pollinated crops provide essential nutrients for humans

Crop pollination is a vital ecosystem service, yet the numbers of animal pollinator species, such as bees, are in decline. Now, a team of German and American researchers have demonstrated how crops that provide the highest levels of vitamins and minerals essential to our diet globally depend heavily on animals for pollination.

Most calories consumed by people around the world are provided by staple crops that either self-fertilise or rely on the wind or vegetative propagation (reproduction without seeds or spores). However, many other crops containing micronutrients (nutrients required in small quantities, such as vitamins and minerals) essential to our health are solely, or mostly, pollinated by animals.

Researchers have known for some years that the numbers of animal pollinator species are falling. As well as the well-publicised colony collapse disorder that is devastating honey bee colonies in Europe and elsewhere, habitat degradation, often caused by intensive farming methods, has caused the numbers of many other pollinator species to fall.

To establish how significant a problem this could be for human health, the researchers, partly funded by the EU STEP project[1], quantified the amount of nutrients produced by animal-pollinated crops using US Department of Agriculture information on the nutrient content of 150 crops. They combined this with data from the Food and Agriculture Organization of the United Nations (FAO) on the worldwide production of these crops.

The data revealed that most of the crops that produce lipids, vitamin A, vitamin C and vitamin E are pollinated by animals. A large proportion of some minerals in our diet, such as calcium, fluoride and iron, also come from such crops. For instance, the researchers noted that over 98% of vitamin C from crops produced annually around the world comes from those that are animal-pollinated. The majority of this comes from citrus fruit and other fruit and vegetables.

Similarly, 55% of the folic acid available around the world comes from animal-pollinated crops. Folic acid is particularly essential during pregnancy. Of the minerals found in crops, 62% of the available fluoride and 58% of the calcium come from crops such as beans, fruits and nuts, all of which rely on animal pollination to some degree.

Crops also produce a number of micronutrients that play a role in reducing the risk of cancer. Of these, more than 98% of the global crop production of carotenoids, including cryptoxanthin and lycopene, comes from animal-pollinated crops, such as red, orange and yellow fruits and vegetables.

Although dietary supplements and fortification of some foods with micronutrients is possible, and is mandatory in some countries, the researchers suggest such an approach would not be able to address the potential deficiencies globally. In particular, the researchers note that a decline in the availability of micronutrients is likely to most severely affect developing nations, where people do not have access to dietary supplements.

They also note that the plants from which supplements are created also require pollination, so costs would rise as pollinator numbers fall. Additionally, crops contain other, as yet unidentified, nutrients that appear to provide health benefits, such as lowering the risk of cardiovascular disease and some kinds of cancer, which supplements cannot replace.

1. STEP (Status and Trends of European Pollinators) is supported by the European Commission under the Seventh Framework Programme. See www.step-project.net

Source: Eilers, E. J., Kremen, C., Smith Greenleaf, S., Garber, A. K. & Klein, A-M. (2011). Contribution of Pollinator-Mediated Crops to Nutrients in the Human Food Supply. *PLoS ONE* 6 (6) e21363. This study is free to view at: www.plosone.org/article/info:doi/10.1371/journal.pone.0021363
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Theme(s): Agriculture, Biodiversity, Environment and health

Policy briefs

STEP

European Commission

Science for Environment Policy

Patches of flowers boost pollinator diversity and lead to higher crop yields

Falling levels of insect pollination are causing declining yields of important agricultural crops. However, new research from South Africa now indicates that planting small patches of native flowers in agricultural fields can be a profitable and sustainable method of increasing pollination and yield.

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Issue 316

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Source: Carvalheiro, L. G., Seymour, C. L., Nicolson, S. W., *et al.* (2012). Creating patches of native flowers facilitates crop pollination in large agricultural fields: mango as a case study. *Journal of Applied Ecology*. 49: 1373-1383.

DOI: 10.1111/j.1365-2664.2012.02217.x

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Theme(s): Agriculture, Biodiversity

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Insect pollination is a vital ecosystem service as animal-pollinated crops form an essential part of the human diet. However, yields of crops that are dependent on insect pollination have been falling as a result of declining numbers of pollinators and the isolation of crops from natural insect habitats. This can lead to destruction of natural habitat as more land is needed to produce the same amount of food.

In this study, researchers examined the effects of planting small plots of native flowers to encourage pollination of crops, using mango orchards as a case study. Four mango farms in north-east South Africa were chosen, all of a similar size and with similar management practices. On each farm, a 25 m^2 flower plot was planted in an orchard margin to ensure they did not use viable agricultural land, or interfere with management. Two species of native flowering plants were used: the spotted aloe (*Aloe greatheadii*) and the bush violet (*Barleria obtuse*).

During the mango flowering season, surveys of insect pollinators were carried out within the flower plots and in orchards. Effects on ultimate crop yield were assessed by recording the total kilograms of ripe fruit per tree. The researchers also recorded the distance of orchards from natural habitat.

The results demonstrated that increased distance from natural habitat reduced both crop production and the abundance and diversity of flying pollinators. However, the presence of flower plots substantially reduced this negative effect. For example, orchards without flower plots at 300m from natural habitats suffered a reduction of pollinator diversity of 47% compared to orchards nearer natural habitat. Those with flower plots, however, showed a reduction of only 7%. This effect also translated into crop production. Orchards that had no natural habitat nearby, but did have flower plots, produced 1.5kg of ripe fruit per tree more than those without flower plots.

Importantly, the rise in yields more than compensated for the cost of the flower plots. After accounting for the initial investment, analysis showed profits of €213-237 per hectare. Profit could be increased still further, say researchers, by growing flowers from seed rather than buying adult plants as in this study.

Researchers stress that this study used only two species of flowering plant and further studies are required to identify the optimum mix of species and size of plot. However, they conclude that combining native flower plots with areas of natural habitat can boost pollination and yields, while at the same time, helping to prevent loss of natural habitats to agriculture.

European Commission

Science for Environment Policy

Do agri-environmental schemes benefit insect pollinators?

Agri-environmental schemes (AES) do successfully enhance the number and variety of insect pollinators, research suggests. They are particularly effective when implemented in arable landscapes which also contain some semi-natural habitat.

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Source: Scheper, J., Holzschuh, A., Kuussaari, M., *et al.* (2013). Environmental factors driving the effectiveness of European agri-environmental measures in mitigating pollinator loss – a meta-analysis. *Ecology Letters*. 16: 912–920. DOI: 10.1111/ele.12128.

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AES were introduced in Europe in the early 1990s in response to declining farmland biodiversity. However, evaluations of their efficacy for biodiversity conservation have presented mixed results. With biodiversity continuing to decline, it is important to understand which factors explain the success or failure of AES.

This study, conducted under the EU STEP Project[1], provides a review of previous research that investigated the factors influencing AES performance with regards to biodiversity and abundances of insect pollinators (bees, hoverflies, butterflies and moths). The review covered 71 studies from Europe that compared AES sites and conventionally managed sites.

Overall, the review demonstrated that agri-environmental measures have had significant positive effects on the number of different types of pollinator species ('species richness') and their abundances. This has been observed in both arable fields and grasslands and a general comparison of the effects of these measures indicated they were stronger in arable fields. The researchers suggested this may be because grasslands are usually less disturbed by agricultural management, particularly tilling, so the impacts of AES measures, such as sowing flowers or grasses, may not be so observable in grasslands which already contain these features.

However, this result should not be interpreted as meaning AES are less effective on all grasslands. The effect will depend on the type of grassland and how much semi-natural habitat it contains. In addition, it should be remembered that AES also help prevent intensified use and abandonment of grassland

The greatest impact of AES has been observed in landscapes with 1-20% semi-natural habitat. These landscapes have enough semi-natural habitat on which the schemes can build, but not so much that the impacts are masked. AES have had smaller effects in landscapes with more than 20% semi-natural habitat, and no effect in cleared landscapes with less than 1% semi-natural habitat.

Different AES practices, such as sowing strips of flowers or grass in field margins, or using organic farming methods, have had differing effects on pollinator species richness and abundances. In croplands, all such measures have increased species richness, but flower strips have had the greatest impact on abundances.

Flower strips have also had the biggest effect on species richness and abundances in grasslands. This suggests that the availability of flowers is an important driver of AES impact.

Overall, the effects of AES have been greatest when practices have included sowing flower strips in arable landscapes with intermediate levels of semi-natural habitat. Therefore, to ensure provision of pollination services, these landscapes should be targeted.

However, the study's authors highlight the fact that implementing AES in landscapes with more semi-natural habitats may be of value to protect biodiversity, rather than pollination services. Biodiversity conservation and the provision of ecosystem services are not exclusive, they conclude, but slightly different approaches may be needed to ensure that both occur.

1.STEP (Status and Trends of European Pollinator Species) is supported by the European Commission under the Seventh Framework Programme. See: www.step-project.net

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Basic and Applied Ecology

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Functional complementarity and specialisation: The role of biodiversity in plant–pollinator interactions

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Abstract

Ecological niche breadth (specialisation) and niche differentiation (complementarity) play a key role for species coexistence and hence biodiversity. Some niche dimensions of a species represent ecosystem functions or services such as pollination (functional niche). When species differ in their contribution to some collective function (functional complementarity), this implies that functions from several species are required for a high overall functional performance level. Applied to plant–pollinator interactions, functional

Review

Global pollinator declines: t[...] impacts and drivers

Simon G. Potts[1], Jacobus C. Biesmeijer[2], Claire Kremen[3], Pe[...]
Oliv[...]

[1] Cent[...] 6AR
[2] Earth[...]
[3] Depa[...]
[4] Swis[...] Switz[...]
[5] Depa[...] Germ[...]

Pollin[...] provi[...] plant[...] wild [...] in the[...] natur[...] poter[...] and [...] speci[...] them[...]

Oecologia

DOI 10.1007/s00442-012-2271-6

PLANT-ANIMAL INTERACTIONS - ORIGINAL RESEARCH

Insect pollination enhances seed yield, quality, and market value in oilseed rape

Riccardo Bommarco · Lorenzo Marini · Bernard E. Vaissière

Received: 12 July 2011 / Accepted: 23 January 2012

Abstract The relationships between landscape intensification, the abundance and diversity of pollinating insects, and their contributions to crop yield, quality, and market value are poorly studied, despite observed declines in wild and domesticated pollinators. Abundance and species richness of pollinating insects were estimated in ten fields of spring oilseed rape, *Brassica napus* var. SW Stratos™, located along a gradient of landscape compositions ranging from simple landscapes dominated by arable lan[...] erogeneous landscapes with extensive cover of se[...] ral habitats. In each field, we assessed the contrib[...] wind and insect pollination to seed yield, seed[...] (individual seed weight and oil and chlorophyll c[...] and market value in a block experiment with four t[...] and two treatments: (1) all flowers were acces[...] insects, self and wind pollination, and (2) flowers [...] in tulle net bags (mesh: 1 × 1 mm) were accessibl[...] wind and self pollination. Complex landscapes e[...] the overall abundance of wild insects as well [...] abundance and species richness of hoverflies. Thi[...] translate to a higher yield, probably due to c[...]

pollination by hone[...] pollination experim[...] weight per plant by[...] quality was enhan[...] heavier seeds as w[...] contents, clearly showing that insect pollination is required to reach high seed yield and quality in oilseed rape. Our study demonstrates considerable and previously underes-

Communicated by Jason Tylianakis.

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ELSEVIER

Pollination services in the UK: How important are honeybees?

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Abstract

Pollination services are known to provide substantial benefits to human populations and agriculture in particular. Although many species are known to provide pollination services, honeybees (*Apis mellifera*) are often assumed to provide the majority of these services to agriculture. Using data from a range of secondary sources, this study assesses the importance of insect pollinated crops at regional and national scales and investigates the capacity of honeybees to provide optimal pollination services to UK agriculture. The findings indicate that insect pollinated crops have become increasingly important in UK crop agriculture and, as of 2007, accounted for 20% of UK cropland and 19% of total farmgate crop value. Analysis of honeybee hive numbers indicates that current UK populations are only capable of supplying 34% of pollination service demands even under favourable assumptions, falling from 70% in 1984. In spite of this decline, insect pollinated crop yields have risen by an average of 54% since 1984, casting doubt on long held beliefs that honeybees provide the majority of pollination services. Future land use and crop production patterns may further increase the role of pollination services to UK agriculture, highlighting the importance of measures aimed at maintaining both wild and managed species.

Highlights

► Insect pollinated crops cover 20.4% of UK cropland. ► These crops represent 19.3% of total UK farmgate [...]

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REVIEW AND SYNTHESIS

Stability of pollination services decreases with isolation from natural areas despite honey bee visits

FREE

Lucas A. Garibaldi[1,2,*], Ingolf Steffan-Dewenter[3], Claire Kremen[4], Juan M. Morales[1], Riccardo Bommarco[5], Saul A. Cunningham[6], Luísa G. Carvalheiro[7,8,9,10,†], Natacha P. Chacoff[11], Jan H. Dudenhöffer[12], Sarah S. Greenleaf[4], Andrea Holzschuh[3,12], Rufus Isaacs[13], Kristin Krewenka[12], Yael Mandelik[14], Margaret M. Mayfield[15], Lora A. Morandin[4], Simon G. Potts[16], Taylor H. Ricketts[17], Hajnalka Szentgyörgyi[18], Blandina F. Viana[19], Catrin Westphal[12], Rachael Winfree[20], Alexandra M. Klein[21]

Issue

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BIOLOGICAL REVIEWS

Cambridge Philosophical Socie[...]

Multiple stressors on biotic interactions: how climate change and alien species interact to affect pollination

Oliver Schweiger[1,*], Jacobus C. Biesmeijer[2], Riccardo Bommarco[3], Thomas Hickler[4], Philip E. Hulme[5], Stefan Klotz[1], Ingolf Kühn[1], Mari Moora[6], Anders Nielsen[7], Ralf Ohlemüller[8], Theodora Petanidou[7], Simon G. Potts[9], Petr Pyšek[10], Jane C. Stout[11], Martin T. Sykes[4], Thomas Tscheulin[7], Montserrat Vilà[12], Gian-Reto Walther[13], Catrin Westphal[14,15], Marten Winter[1,16], Martin Zobel[6], Josef Settele[1]

Issue

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