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Executive summary

STEP, the Status and Trends of European Pollinators project, brought together more than 100 of Europe’s leading scientists in a five year project (2010-2015) to address the challenges of pollinator conservation and the management of pollination services. The project met its aims which were to: (1) document the current status and future trends of wild and managed pollinators and the crops and wildflowers they pollinate; (2) characterise the drivers, individually and combination, causing shifts in pollinators; (3) assess the impacts of pollinator loss on food production, biodiversity and wider society; (4) evaluate the effectiveness of mitigation options for pollinator and pollination service loss; (5) provide evidence-based recommendations for policy makers and practitioners and disseminate the project findings to a broad range of stakeholders.

STEP provided the first systematic assessment of the numbers of honeybee colonies and beekeepers across Europe, documenting widespread declines in many countries over the last few decades. The project also revealed that the substantial declines in bumblebees, solitary bees, hoverflies, butterflies and insect-pollinated wild flowers prior to the 1990's in three European countries (Belgium, Holland and UK) have slowed down, but pollinator communities have homogenised with many of the most sensitive species already lost. In collaboration with the IUCN, STEP produced the first ever European Red List for bees which identified those species most threatened and reported the main causes to be climate change and agriculture intensification. The Red List is an essential tool to inform policy decisions on conservation.

STEP has reviewed the current literature on global drivers of pollinator declines and identified habitat loss and fragmentation, agrochemicals, pathogens, alien species and climate change as being of particular concern. The project has also synthesised knowledge in two new areas: the impacts of drivers on pollination services and the effects of combinations of drivers. In addition, STEP has delivered a portfolio of studies looking at the impacts of farm management practises (such as mass flowering crops, field margins, pesticides and organic farming) as well as other drivers such as invasive flowers, heavy metals and herbicides.

STEP provided strong evidence that wild insects, mainly bees, and not managed honeybees, are the main pollinators of global, European and national crops. Europe has an insufficient supply of managed honeybee colonies to meet current demands from pollination-dependent crops. While a few countries have sufficient supplies, the majority of do not highlighting the dependency growers have on wild insects to provide pollination services. STEP has led to a better understanding of the relative contribution of wild pollinators to crop yield, quality, production stability and commercial profit, thereby informing growers of the values of pollinators for production and apprising policy makers on the role of pollination services in food security.

STEP showed that in arable systems, floral margins, naturally regenerating grass margins and organic farming all supported more pollinators, as did low input meadows and flower margins, but not organic farming, in pastoral systems. The types of landscapes in which agri-environment scheme options are placed has major influence on their effectiveness in supporting pollinators. The project also strengthened evidence showing that wild pollinator diversity and abundance on crops declines with increasing distance from protected areas or other semi-natural features in the landscape.

STEP evaluated current options for the mitigation of pollination service loss through supplementation with commercial managed pollinators and habitat provision for wild pollinators. It concluded that while augmentation with managed pollinators may work for some crops as short-term solution, longer-term solutions through the provision of habitats for wild pollinators, especially for wild bees and hoverflies, represents a more sustainable and potentially lower cost solution.

STEP has already produced 155 peer-reviewed papers, many in the highest impact journals, with many further expected. The project has delivered more than 600 dissemination activities including, international and national conferences, workshops, TV, radio and press coverage and produced a wide range of materials such as policy briefs, press releases and best practice guidelines. The webpage (www.STEP-project.net) hosts many of these materials and has been visited by more 28,000 users. The STEP legacy includes the establishment of an active network of researchers interacting with practitioners and ongoing contributions to European and national policies for agriculture, conservation and bee health.
Summary description of project context and objectives

Project Context

Halting biodiversity loss and sustainably managing natural resources are key international priorities embedded in the Convention on Biological Diversity, EU and Member State policies. The majority of global (and European) biodiversity is made up of insects, but little is known about the distribution and abundance of most species, and even less is known about their dynamics and the threats they face. This lack of knowledge on the status and trends of the majority of Europe’s species is of concern, and is particularly worrying for species that play important functional roles, such as pollinators. Pollination is a key ecosystem service, vital to the maintenance both of wild plant communities (Ollerton et al. 2011) and agricultural productivity (Klein et al. 2007). Pollination is delivered by both wild and domesticated pollinators, and both groups are affected by a variety of environmental pressures with poorly understood implications for wider biodiversity conservation and food security.

Status and trends of pollinators

The most widely managed pollinator in Europe is the honeybee (*Apis mellifera*), which was assumed to be the species that provides the majority of pollination services to European crops. Most wild and feral honeybees have been lost in Europe due to *Varroa* mites and associated pathogens, with the remaining colonies managed by beekeepers. Managed colonies have been shown to have undergone severe and widespread declines throughout much of Europe (Potts et al. 2010a). Wild pollinators in Europe are dominated by ~2,000 species of wild bees (e.g. bumblebees and solitary bees) and hoverflies, with a smaller contribution of butterfly, beetle and other fly species. Declines in wild bees and hoverflies have been clearly documented in some parts of Europe (e.g. the Netherlands and the UK; Biesmeijer et al. 2006), however, the geographic extent, scale and identity of those species in decline is largely unknown for most of Europe. While several European countries have a Red List for bees, there is no European Red List with which to help direct conservation priorities at the continental scale.

Drivers of pollinator declines

Many individual causes of pollinator decline have been documented and include habitat loss and fragmentation, pesticides, loss of floral resources, pests and diseases, alien invasives and climate change (Potts et al. 2010b). However, the relative importance of these drivers and their interacting effects have been poorly explored until recently.

Consequences of pollinator declines

The majority, 84%, of European crops benefit, at least in part, from insect pollination (Williams 1994) and 78% of temperate wildflowers need biotic pollination (Ollerton et al. 2011). An estimated 10% of the total economic value of European agricultural output for human food which amounted to €22 billion in 2005 (£14.2 for the EU) was dependent upon insect pollination (Gallai et al. 2009). However, more information is needed on the vulnerability of crops and regions to pollination loss, and also on the contribution of insect pollinated crops to food security. Likewise the impacts of pollination deficits on wildflowers and associated fauna have not been studied in depth at the European level.

Mitigation of pollinator declines

Loss of pollinators can be mitigated through a number of interventions including on-farm management (e.g. flower-rich field margins, Potts et al. 2009) and protection of semi-natural habitats in the wider landscape (e.g. Ricketts et al. 2008). However, we lack an overview of the range of mitigation options available in Europe and their relative effectiveness in delivering pollinator conservation. Further, while there are a variety of options for enhancing pollination, such as supplementing managed pollinators, supporting wild pollinators and artificial pollination, there is no broad picture of these practices across Europe.
Project Objectives

The STEP project has seven broad objectives (corresponding to the seven RTD workpackages), each of which comprises several specific sub-objectives or ‘Tasks’.

**Objective 1: Document the status and trends of pollinator (managed honeybees, wild bees and hoverflies) and animal-pollinated plant populations.**

- To compile distributional information on European pollinators and animal-pollinated plants (Task 1.1);
- To document recent changes in honeybee and wild pollinator populations and communities, and in those of animal-pollinated plants, at local to continental scales (Task 1.2);
- To assess trait correlates of pollinator and plant declines relevant to their interaction, in particular of pollinator foraging traits and plant floral rewards (Task 1.3);
- To develop a European Red Data Book of endangered bees (Task 1.4);
- To develop sampling protocols and automated identification methods for monitoring future change in pollinator populations and communities (Task 1.5).

**Objective 2: Determine and analyse the 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.**

- To identify fundamental environmental pressures on pollinator and animal-pollinated plant occurrence and performance (Tasks 2.1, 2.3);
- To quantify the relative importance of the identified environmental pressures (Tasks 2.6, 2.7, 2.9);
- To analyse potential interactions between the identified environmental pressures (Tasks 2.4, 2.5, 2.8);
- To develop predictive models for pollinator and animal-pollinated plant species, functional groups and pollination-relevant species traits (Tasks 2.2, 2.10).

**Objective 3: Assess the impact of changes in pollinator populations and communities on wild plants and crops and changes in floral resources on pollinators.**

- To assess the impacts of honeybee declines on wild plant and crop pollination and interactions with wild bees (Task 3.1);
- To assess the impacts of pollinators shifts on wild plant pollination and of shifting floral resources on pollinator populations (Task 3.2);
- To assess the impacts of pollinator shifts on crop pollination and cropping patterns on pollinators (Task 3.3);
- To assess the impact of changes in pollination on economic values and human health issues (Task 3.4).

**Objective 4: Evaluate and synthesize strategies to mitigate the impacts of changes in pollinators and animal-pollinated plants.**

- To evaluate the strategies available for mitigation of pollinator and pollination loss in Europe (Task 4.1) and assess their effectiveness (Task 4.2);
- To identify the mechanisms common to successful mitigation measures (Task 4.3);
- To identify species traits associated with positive and negative responses to mitigation measures to enhance the effectiveness of mitigation strategies (Task 4.4);
- To improve existing options and identifying new mitigation options (Task 4.5).
Objective 5: Assess how multiple drivers affect pollinators and animal-pollinated plants at local and landscapes scales using focused empirical tests and observations.

- To establish a network of study sites across Europe to perform joint empirical research on the combined effects of multiple pressures on pollinators and pollination functions (Task 5.1);
- To measure the impacts of multiple environmental pressures on community composition, population densities and genetic diversity of pollinators (Task 5.2);
- To assess pollination functions of focal wild plant species including seed or fruit set, genetic diversity and offspring fitness in response to environmentally driven shifts in pollinator diversity (Task 5.3);
- To assess yield quantity and quality of focal crop species in response to habitat fragmentation, land use intensification and related shifts in pollinator diversity (Task 5.4);
- To quantify the dependence of perennial fruit crops on insect pollination (Task 5.5);
- To analyse beneficial and antagonistic spill-over effects from agricultural to natural habitats on wild pollinators and plant-pollinator interactions (Task 5.6);
- To quantify the occurrence of invasive plant species in relation to habitat fragmentation and land use intensification and to evaluate combined effects on pollinator webs and pollination functions (Task 5.7);
- To implement and evaluate the ecological and economic benefits of different mitigation strategies (Task 5.8).

Objective 6: Analyse and improve the interface between the scientific knowledge-base on pollinator change assessment and policy instruments to reduce pollinator/pollination loss and mitigate its effects.

- To identify and analyse the most important governing questions relevant to the drivers and pressures of pollinator and pollination loss (Task 6.1);
- To derive and apply Evidence-based Decision Support (EDS) to map state of the art knowledge onto the governing structures behind the drivers and pressures which lead to pollinator loss (Task 6.2);
- To identify, analyse and develop innovative policy instruments and mechanisms at the EU and national level to address pollinator-related problems (Task 6.3).

Objective 7: Develop 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.

- To establish a general communication and dissemination strategy to specialist and non-specialist target groups (Task 7.1);
- To disseminate, publish, promulgate, and exploit the major project results (Task 7.2);
- To train and share skills between researchers, managers, beekeepers, farmers, horticulturalist, veterinarians, PhD students, and postdocs (Task 7.3);
- To increase public awareness and societal education levels (Task 7.4).

References
WP1: DOCUMENTING THE STATUS AND TRENDS OF POLLINATOR AND ANIMAL-POLLINATED PLANT POPULATIONS

Task 1.1: Compiling distributional information on European pollinators and animal-pollinated plants

We managed to link up with many data-holders (e.g. more than 32M records on plants, bees, butterflies and hoverflies were used in Carvalheiro et al. 2013) and compiled a database for European bees, now consisting of >2.5M records from 54 providers, that has been the basis of several papers, the IUCN Red List (Nieto et al. 2015) and the Bumblebee Climate Risk Atlas (Rasmont et al. 2015). Such databases can only be used if species have been identified reliably. A group of STEP and other bee taxonomists (led by Michael Kuhlmann) have drawn up a full checklist of European bee species (Kuhlmann et al. 2012; http://westpalbees.myspecies.info/). Overall, data on the European distribution of more than 1100 bee species, 800 hoverfly species, 400 butterfly species and 2000 host plant species has been compiled and butterfly distributional data have been published (Kudrna et al. 2011). Based on these distribution data, a database on climatic niche characteristics of European butterflies has been published (Schweiger et al. 2014).

Task 1.2a: Documenting change in domestic honeybee population

Changes in numbers of managed honeybee colonies, numbers of beekeepers and production of honey in the EU over the last decades were reported by Potts et al. (2011). We found consistent declines in colony numbers in central European countries and some increases in Mediterranean countries. Beekeeper numbers have declined in all of the European countries examined. Our data support the view that honey bees are in decline at least in some regions, which is probably closely linked to the decreasing number of beekeepers. Our findings must, however, be interpreted with caution due to different approaches and socioeconomic factors in the various countries. We therefore make specific recommendations for standardized methodologies to be adopted at the national and global level to assist in the future monitoring of honey bees.

Task 1.2b and c Documenting change in wild pollinator assemblages and animal-pollinated plant populations and communities

By analysing changes in pollinator diversity at different spatial scales, we found (Carvalheiro et al. 2013) that extensive pollinator species richness loss and biotic homogenisation occurred before 1990, whereas these negative trends became substantially less accentuated during recent decades, being partially reversed for certain taxa (e.g. bees in Great Britain and Netherlands). These results highlight the potential to maintain or even restore current species assemblages (which despite past extinctions are still of great conservation value), at least in regions where large-scale land-use intensification and natural habitat loss has ceased. Moreover, our results suggest that changes are not parallel in time: although richness declines were detected for both pollinator dependent plants and pollinators at some point, they occurred in distinct time periods. However, we found evidence that biotic homogenisation (loss of beta diversity) continued unabated into recent decades. Similar analyses have been performed for Danish butterflies (Eskilden et al. submitted). Over the last 100 years 10% of the species went extinct in Denmark and severe declines of specialist species in particular at smaller scales caused biotic homogenisation (Eskildsen et al. submitted). A follow-up study confirmed general patterns of decline in butterfly species richness across Europe but also showed that declines are most severe in continental and Atlantic regions. Using temperature requirements of European butterfly species it was also evident that communities already responded to climate change during the last 20 years but their reaction is delayed corresponding to a 135 km lag behind climate (Devictor et al. 2012).

Task 1.3: Documenting simultaneous changes in the distribution of pollinator and plant traits.

UT has completed the milestone 1.8 (Database on species traits relevant to interpretation of linkages between pollinators and animal-pollinated plants completed) and has created the meta-database with
relevant sources for species trait data for both plants and pollinators. Database has been made available for STEP partners. UT has combined two European plant species distribution/occurrence maps - Atlas Flora Europaea (AFE) and Hultén atlas. With the combined atlases, we have obtained currently the most comprehensive map of insect-pollination dependant plant species richness in Europe.

Task 1.4: Developing a Red Data Book for European pollinators

One of the main challenges of the STEP project was to assess the risk of extinction for the 1,965 bee species native in Europe. Together with the IUCN (International Union for Conservation of Nature) we used the IUCN Red List procedures to develop the Red Data Book for European bees (Nieto et al. 2015). A team of more than 40 people (i.e. taxonomists, ecologists, IUCN experts) participated in the development of the assessments and the review process.

Of the 1,965 European native bees, 663 species were assessed as Least Concern; 101 species as Near Threatened; 24 as Vulnerable; 46 as Endangered; 7 as Critically Endangered; and 1,101 as Data Deficient. The main threats identified were habitat loss as a result of agriculture intensification (e.g., changes in agricultural practices including the use of pesticides and fertilizers), urban development, increased frequency of fires and climate change. Some life history traits were associated to the most threatened species: sociality (e.g. bumblebees), host-plant specialisation and habitat specialisation (e.g. bee species associated to coastal areas). Based on the distribution data we were also able to precise the spatial distribution of bee species diversity in Europe. Hotspots of species diversity are Mediterranean Peninsula: Iberia, Italy and Greece. High level of endemism are also noted in these Peninsula, Islands (e.g. Canary Island) and also montane areas.

Task 1.5a: Developing pollinator monitoring protocols.

STEP contributed to reviewing different methods for monitoring pollinators. As a result of an international workshop, a study was published which is regarded now as a standard work for pollinator monitoring (LeBuhn et al. 2013). The two most widely recommended pollinator monitoring approaches are (i) pan-traps and (ii) transect walks. STEP members are now involved in setting up a National pollinator monitoring protocol in the UK. As part of this they carried out field tests assessing the effects of pan size, colour, pattern (with or without nectar guides) and trapping duration on the trapping effectiveness of pan-traps, as well as pollinator surveys using this approach across wide ranges of landscapes.

Task 1.5b Exploring automated identification methods.

Identification of bees and other pollinators is very difficult. Therefore, STEP explored the available methods for automated identification. This has revealed that DNA barcoding methods are becoming standard tools for identification and monitoring, but are still expensive and depend on reliable sequences deposited in GenBank and other repositories. It appeared that programs using wing venation analysis are very promising, but existing initiatives such as Daisy, ABIS and DRAWING have been discontinued. Currently an automated identification of bees based on wing shape and patterns of wing venation is being developed. It has already led to description of new fossil bee species (Dehon et al. 2014) and will be rolled out in the Netherlands in 2015.

References


WP 2 MULTIPLE PRESSURES ON POLLINATORS AND ANIMAL-POLLINATED PLANTS

Current knowledge about relevant environmental pressures on European pollinators and animal-pollinated plants

In a review article, we identified habitat loss and fragmentation, agrochemicals, pathogens, alien species and climate change as major drivers of pollinator declines. We concluded that these declines can result in loss of pollination services which have important negative ecological and economic impacts that could significantly affect the maintenance of wild plant diversity, wider ecosystem stability, crop production, food security and human welfare (Potts et al. 2010).

In a second literature review (Gonzalez-Varo et al. 2013), we highlight that the identified drivers may impact animal-mediated pollination interacting in a non-additive way (synergistically or antagonistically). This would imply that management actions aimed to buffer the effects of a particular pressure may become ineffective if another pressure is present. However, only few studies have explicitly tested combined effects, most of them being pair-wise interactive effects, highlighting that our knowledge is still limited.

Based on a literature survey, we also found that a combination of climate change and alien species will ultimately lead to the creation of novel plant and pollinator communities in which essential interactions are disrupted while new ones may emerge. Alien species can both partly compensate for the often negative effects of climate change but also amplify them in some cases (Schweiger et al. 2010).

Combined effects of climate, land use, fragmentation, nitrogen deposition and pesticide pressure at different spatial scales

Using large-scale distribution data of European pollinators, we showed that climate is the most influential driver determining current species distributions. In addition to that, also land cover and notably also agricultural intensity have an impact on the European distribution of pollinators (Franzén et al. in prep. a). In combination with landscape- and local-scale data we further found that land cover and soil conditions gain importance at smaller scales. Yet, the impact of different drivers such as climate, land use and agricultural
intensity differs between pollinator and plant communities and different levels of biodiversity, e.g. species richness and functional diversity. For instance, at larger scales, climate warming has the potential to decrease the average body size of pollinators with potentially severe consequences for pollination success of wild and crop plants (Franzén et al. submitted).

In a study system in the east-Pyrenees we found that annual climatic variation is correlated with the variation in bumblebee community composition (Iserbyt & Rasmont 2012) and that heat waves are a main factor of local bumblebee regression (Rasmont & Iserbyt 2012), while species-specific resistance to hyperthermic stress seems to be a key factor of the resistance of species to heath-waves (Martinet et al. submitted). Climate change can also lead to a spatial mismatch of interacting species as a consequence of individualistic responses (Schweiger et al. 2012).

In a study on the susceptibility of pollinators to recent landscape change (Aguirre-Gutiérrez et al. submitted), we found that the effects of landscape changes vary among the different pollinator groups. While bumblebees responded mostly to changes in landscape composition, other bees responded to interacting effects between landscape fragmentation and composition. Butterflies and hoverflies responses were mainly restricted to changes in landscape characteristics that affect the potential for spill-over effects. These findings emphasize the limited value of a one-size-fits-all biodiversity conservation measure. This study also shows that recent pollinator richness changes are greatly conditioned by past landscape characteristics. These results alert for possible delayed effects that landscape modification and habitat loss might have on biodiversity responses.

The colony development and resource use of honeybee colonies in relation to different land use types has also been analysed. The results indicate that colonies prefer mixed pollen nutrition even in the presence of dominant mass-flowering crop pollen sources such as maize or oilseed rape in the surrounding landscape (Danner et al. 2014).

Analysing pollination syndromes and floral traits of European plant species, we found that there are more insect-pollinated species in more diverse landscapes, in regions with higher temperatures, larger wind-speed and with larger diversity of both plants and pollinators (Helm et al. in prep. a). The relative distribution of intermediate vs. strictly pollinator-dependent species is additionally strongly determined by land-use patterns. There are relatively more intermediately pollinator-dependent plant species in open landscapes with more humans, less precipitation, higher annual temperatures and larger wind-speed. Amount of nectar is highest in regions with low diversity and larger body-size of bees, lower temperatures and more precipitation (Helm et al. in prep. b).

We also found interaction effects between agricultural intensity and climate, indicating that climate warming will also increase the negative effects of fertilisation and pesticides on European pollinators and insect-pollinated plants (Franzén et al in prep. b). With respect to fertilisation we developed a trait-based conceptual model on the stoichiometric relationship between the size of butterfly and moth species, their diet breadth and plant nitrogen content. With this model we aimed to explain how the impacts of soil nitrogen enrichment cascade via various plant-herbivore interactions, and thus eventually strengthen the opposite trends observed in insect herbivores feeding on either oligotrophic or eutrophic plant species (Pöyry et al. submitted). This model is further supported by a study of historic data on pollinator distribution. Here we found that richness declines detected before 1990 were most accentuated for non-nitrophilous species, while increases detected post 1990 were mostly detected for nitrophilous species (Carvalheiro et al. in prep.). This pattern was strongest for butterflies, specialist species being the most susceptible to negative impacts.

**Effects of pathogens, pesticides and environmental pollutants on wild pollinators**

The potential of pathogen transfer from managed to wild pollinators has been studied with managed greenhouse bumblebees in Poland showing that managed bumblebees usually are infected by various diseases (Rożej et al. 2012) and can be a source and vector of pathogens for nearby wild populations (Rożej 2011). Spreading of diseases from greenhouses to wild populations can thus possibly cause declines in the diversity of wild bees.
To assess the transferability of using honeybees for the usual risk assessment during the approval procedure of pesticides we conducted a lab experiment and assessed the effects of sub-lethal dosages of pesticides on wild pollinators. We found that such effects differed considerably among different groups of pollinators (wild bees, butterflies and hoverflies) and call for broadening the taxonomic spectrum used for pesticide approval procedures.

We also conducted a field experiment to analyse indirect effects of herbicides and nitrogen on pollinators by affecting floral resources. We found that high levels of either herbicides or fertilisation leads to a reduced diversity of insect pollinated plants. When applied in combination, plant diversity is increased but these plant communities are much poorer in terms of nectar resources for flower-visiting insects.

In terms of environmental pollutants, we analysed wild bee species diversity and fitness in Poland, UK and Russia and showed that wild bees can be considerably affected by heavy metals (Moroń et al. 2012, 2014). However, it was also shown that social species (bumblebees) were less affected by heavy metals than solitary species (Szentgyörgyi et al. 2011).

**Combined effects of pesticides and pathogens on honeybees and wild bees.**

Within an experimental setup, we analysed the role of stressors and stressor interactions in bumblebees, *Bombus terrestris*, and in managed honeybees, *Apis mellifera*. The results showed that both bumblebees and honeybees can be affected by systemic (neonicotinoid) pesticides (Sandrock et al. 2014 a, 2014 b) and also that pathogens and pesticides can significantly interact in bumblebees (Fauser-Misslin et al. 2014). Taken together with the clear evidence in other species and with other substances, it is now obvious that systemic neonicotinoids most likely compromise the pollination ecosystem service in Europe and elsewhere via weakening of bee populations. While the EU ban of the neonicotinoids was a first significant step, further policy actions must be taken to safeguard pollination in Europe, e.g. widening the ban to include other neonicotinoids and application forms.

A dynamic population model for the combined effects of pesticides and pathogens

We developed a dynamic population model for the bumblebee *Bombus terrestris* simulating the combined sub-lethal effects of a neonicotinoid pesticide and the protozoan parasite *Crithidia bombi* on the fitness of bumblebee queens, colony performance and survival. We found that even sub-lethal effects of the neonicotinoid can lead to the local extinction of the bumblebee colonies which can be even amplified by the parasite. Survival and time to extinction crucially depend on the amount of agricultural fields treated with the neonicotinoid in the landscape (Schweiger et al. in prep.).

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STEP WP 3: IMPACTS OF POLLINATOR CHANGE ON WILD PLANTS AND CROPS

Task 3.1 Assessing the impacts of honeybee declines on wild plant and crop pollination

The STEP research has improved our understanding of the potential consequences of honeybee declines for crop pollination services across Europe. We have estimated the overall value of insect-moderated crop pollination services: This accounts for 14.6 billion Euro annually; is something of broad interest; and shows a comparatively high reliance of European agriculture on insect pollination (Gallai et al. 2009). The STEP country- and crop-specific economic estimates provide for the first time a more reliable basis for the development of targeted, regionalised incentives to maintain or protect pollination services. Such measures can be also informed by quantitative measure on local and landscape effects on pollinator diversity (Kennedy et al. 2013).

An important aspect of potential consequences of honeybee declines concerns the proportional contribution of honey bees to crop pollination and resilience of pollination services in case of severe colony density declines - e.g. after a year with high winter mortality rates. Our results indicate that pollination services could be optimised and vulnerability reduced by a diversification strategy that favours both honey bee densities and wild pollinator diversity. Our results indicate that diverse pollinator communities provide better pollination services due to spatial, temporal and functional niche complementarity, resulting in higher amounts of yield, better yield quality and more stable yields (Garibaldi et al. 2011, 2013). However, results by Leonhardt et al. (2013) suggest that honeybees also contribute to yield stability. Earlier estimates suggested that honey bees provide up to 90% of all crop pollination services. Taking into account more recent results on the quantitative contribution of wild pollinators, this estimate seems too high. Nonetheless, honeybees still provide the backbone of pollinators for mass-flowering crops in many agricultural landscapes with low densities of wild pollinators. Therefore a bimodal strategy for managing pollination services is required that addresses the needs of honey bees and wild pollinators in parallel. The temporal trends in honeybee stocking rates show that honeybee colony densities do not generally decline across Europe but mainly in central Europe where wild pollinator diversity is comparatively low and production area covered by crops that rely on insect-pollination is steadily increasing (Breeze et al. 2014). The gap between estimated required stocking rates compared to available mean colony densities per country suggests significant mismatches between available and required colony densities. Taking into account the clumped distribution of beekeeping activities by mainly hobby beekeepers, with much higher colony densities in settlement areas and close to semi-natural habitats, this gap in pollination services might be even larger. In conclusion, the STEP findings demonstrate the need for efforts to protect wild as well as managed pollinators in order to maintain pollination service security in the face of intensive agriculture and climate change, and highlight a number of critical gaps in current understanding of pollination service supplies and demands.

Task 3.2 Assessing the impacts of pollinator shifts on wild plant pollination and of plants shifts on pollinators

This work was initiated in the first period through the Wild Plants Pollination workshop on 20-22 September 2010 which rendered output in terms of concrete research plans in WP3 tasks 3.1 and 3.2. From discussions and group work we identified information gaps and set up a working programme for STEP to fill these gaps, focusing on providing syntheses of existing data. Many additional internal and external partners have since then been engaged at the STEP annual general meeting and by contacting research groups for collaborations and data sharing. Several lines of research were defined and work load was divided among partners.

Central results include that changes in visitation rates, and thus pollination potential, can be predicted based on plant species’ resource abundance, flower traits and phylogenetic distance (Carvalheiro et al 2014, Chamberlain et al 2014). Plant traits play an important role in defining groups of species that are more likely to interact with each other via shared pollinators. Considering flower traits and phylogenetic similarity can improve predictions of impacts due to loss of insect pollinated plant species or increased flowering plant abundance within habitats, and can inform management of invasive plants and designing functional mitigation strategies such as flower strips to optimize wild plant pollination.
With a global data set, we showed that in contrast to expectation, biotic specialization of plant-pollinator networks is significantly lower at tropical than at temperate latitudes. Our data suggests that high specialization of plant-pollinator interactions is a response of pollinators to low plant diversity (Schleuning et al. 2012).

Based on a pan-European approach we have shown that grassland plants pollinated by a wide array of pollinators, such as hoverflies and short-tongued bees, are likely to fare better in structurally simplified agricultural landscapes than plants strictly pollinated by bees (Clough et al. 2014). Since hoverflies have not declined as much as bees in Western Europe, such shifts in pollinator communities may have resulted in continent-wide shifts in plant communities in semi-natural grasslands.

With a large dataset of wild bee and butterfly abundances collected across Europe, we showed a clear negative effect of area and a weaker, but positive effect of connectivity on evenness in pollinator communities. Communities in small habitat fragments were mainly composed of mobile and generalist species. Trait analysis suggested an increasing importance of dispersal over local recruitment (Marini et al. 2014).

A large dataset based on sampling in 546 grasslands across Europe revealed vast differences in remnant grassland habitat area among regions. In Eastern Europe and in traditional landscapes in Sweden, grasslands are 40 times larger than in western Europe. Grasslands are larger in regions characterized by recent history of habitat loss and low land-use intensity in the past 100 years. This has delayed extinctions of grassland plants. Therefore, large grasslands in more traditional landscape still experience extinction debt, also affecting plant pollination mode in these communities. The larger the grassland, the more mixed pollination syndrome was prevailing, while wind-pollination was decreasing. Plant dispersal ability is also affected in small grasslands, where species characterized by short dispersal distances are more common. We conclude that species dispersal ability and inversely related local persistence ability are the key factors influencing species vulnerability to habitat loss (Helm et al in prep).

In an opinion piece, we argue that both conservationists and ecologists need ecologically relevant metrics to quantify the condition of plant and animal communities. Current metrics fail to address the invasion of species native to different community types in the same region. We proposed novel approach to re-conceptualize community biodiversity based on the composition of historically developed habitat-specific species pools. Total observed community diversity can be divided to characteristic diversity, consisting of species belonging to habitat-specific species pool, and derived diversity, consisting of either native or non-native species not typical to a given community and whose presence is driven by adverse human impact (Helm et al. 2015).

We extracted plant species-specific data from The Red Data Book of Rare and Threatened Plants of Greece, Flora Europaea, Flora of Turkey and the East Aegean Islands and the Mountain Flora of Greece for 469 rare and threatened plant species in 71 families. We tested whether rarity and vulnerability is associated with specific plant traits, such as life form, life reproductive mode, flower colour and shape, endemism and conservation status. We found that plant vulnerability increases with floral trait complexity (Tscheulin et al manuscript)

STEP has contributed to the understanding of factors that drive wild pollinator community composition and how this affects their interactions with wild plant communities. Future research need to explore how the structure of pollinator communities and food webs translates into wild plant pollination and plant community development.

**Task 3.3: Assessing the impacts of pollinator shifts on crop pollination, and cropping patterns on pollinators**

Several topics on crop plant pollination that were defined in the first period in an international workshop on Crop Plant Pollination on 25-26 March 2011 in Novi-Sad, Serbia, have been realized, and have resulted in a number of research reports that are now published in international scientific journals.

In a series of global and European syntheses based on primary data, supplemented with strategically placed empirical case studies, we have demonstrated that conserving, restoring, and re-creating high quality semi-
natural or natural habitat to wild pollinators in the agricultural landscape provides a basis for abundant and species rich bee communities. Such efforts can, together with diversifying and lowering the intensity of local agricultural practices, offset negative impacts on pollinator communities of intensive monoculture agriculture. These results are remarkably consistent across the world’s biomes (Kennedy et al 2013, Bommarco et al 2013, Bommarco et al 2012b, Garibaldi et al 2011, Bartomeus et al 2014, Garibaldi et al 2014).

Access to natural habitat enhances crop pollination level and stability across the world. We found that wild pollinator visitation decreased with distance from natural areas, resulting in decreased crop fruit set and stability of pollination services (Garibaldi et al 2011, Kennedy et al 2013, Bartomeus et al 2014).

Wild insects, compared with honey bees (Apis mellifera), pollinated crops more effectively than previously thought. 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, so pollination by managed honey bees supplemented, rather than substituted for, pollination by wild insects (Garibaldi et al 2013). Considering functional composition, instead of taxonomic composition, of pollinators improves predictions of pollination success (Garibaldi et al manuscript). The benefit we can draw from pollination for crop yield depends on other factors such as pest attacks (Lundin et al 2013).

Species numbers of wild pollinators have declined in the last decades, but information on potential shifts in abundances are lacking. In a unique case study we found that the relative abundance of pollinating bumble bees has shifted dramatically in the last 70 years. Some previously common species have become rare and even red-listed. This has likely resulted in lower average and higher variability of realized yields in a pollination dependent crop (Bommarco et al 2012a).

Promising practical solutions to bolster crop pollination in intensive agricultural landscapes have been developed and tested (e.g. Rundlöf et al 2014, Marini et al 2012). More needs to be done, and there is a particular need to address the strong geographic bias of pollination research concentrated in the developed countries. We also call for long term ecological and economic monitoring of pollination services in agriculture (Garibaldi et al 2014).

Farmers are compensating loss of pollination provided by wild insects with honey bees, at least in highly pollination dependent crops (e.g. Marini et al 2012). Still, honeybee stocks appear to be insufficient to fulfil the demands in a majority of countries across Europe (Breeze et al 2014). Our findings emphasises the importance of protecting wild as well as managed pollinators, and to test and valuate the contribution of wild pollinators in countries and crops across Europe.

**Task 3.4: Assessing the impacts of pollinator shifts on society.**

A workshop on the Economy and Societal Impacts of Pollination was held in Toulouse, France on 3-5 December 2012. About participants defined a framework to approach pollination economics, identified knowledge gaps, and set up a working programme for STEP in the interdisciplinary area of economics related to pollination. Participants included economists as well as ecologists, and several participants were invited experts external to the STEP-project. Topics for further research were defined and divided among partners and collaborating scientists.

We evaluated the contribution of nutrients from animal pollinated world crops, something that has not previously been done as a measure for the value of pollination services. We calculated pollinator dependent and independent proportions of several nutrients of world crops, based on crop production data from FAO and USDA, nutritional composition, and pollinator dependency. We found that crop species 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 b-cryptoxanthin and b-tocopherol, the majority of vitamin A and related carotenoids, calcium and fluoride, and a large portion of folic acid. Ongoing pollinator decline may thus exacerbate current difficulties of providing a nutritionally adequate diet for the global human population (Eilers et al 2011).
Across Europe, crop pollination by insects accounted for 14.6 billion EUR annually from 1991 to 2009, which equalled 12% of the total economic value of annual crop production. Our results show that whereas dependency on insect pollination increased from the colder north to the warmer south, variation in economic gain from insect pollination decreased, indicating that Mediterranean countries had more stable yields of pollinator-dependent crops across years and thus more reliable gains from pollination services (Leonhardt et al. 2013).

We assessed the capacity of honeybees to provide optimal pollination services to agriculture in Europe, given the current and projected cultivation of pollination dependent crops and the availability of honey bees in the UK and across Europe (Breeze et al. 2011, Breeze et al. 2014). For the UK, insect pollinated crops have become increasingly important and, as of 2007, accounted for 20% of UK cropland and 19% of total farmgate crop value. Current UK honeybee hive numbers 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 (Breeze et al 2011). In the European-wide analysis including 41 countries, the recommended number of honeybees required to provide crop pollination has risen 4.9 times faster than the honeybee stocks between 2005 and 2010. Honeybee stocks were insufficient to supply >90% of demands in 22 countries. There is an urgent need for policy to account for pollination service demands and supplies. It further emphasises the importance of protecting wild as well as managed pollinators, and to test and valuate the contribution of wild pollinators in countries and crops across Europe (Breeze et al 2014).

In a choice experiment survey we examined the UK public’s willingness to pay to conserve insect pollinators in relation to the levels of two pollination service benefits: maintaining local produce supplies and the aesthetic benefits of diverse wildflower assemblages. The UK public have an extremely strong preference to avoid a status quo scenario where pollinator populations and pollination services decline. Total willingness to pay was high and did not vary between the two pollination service outputs, producing a conservative total of £379M over a sample of the tax-paying population of the UK, equivalent to £13.40 per UK taxpayer p.a.. Using a basic production function approach, the marginal value of pollination services to these attributes is also extrapolated (Breeze et al 2014).

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Submitted manuscripts to peer reviewed scientific journals in Work Package 3
Tscheulin et al"Winners and losers of climate change for the genus Merodon (Diptera: Syrphidae) across the Balkan Peninsula" Ecological Modelling submitted

Manuscripts in preparation linked to Work Package 3
WP 4 MITIGATION MEASURES FOR POLLINATOR AND POLLINATION LOSS

Strategies to mitigate pollinator loss

The two types of mitigation actions that can be taken to counteract pollinator loss are the establishment of protected areas and the implementation of agri-environment schemes (Rundlöf & Bommarco 2011). In addition, growth of mass-flowering crops, which may provide abundant forage resources for flower visiting insects (Walther-Hellwig & Frankl 2000), could be considered an additional potential mitigation measure.

Protected areas, such as Natura 2000 sites or other nature reserves, are important in particular because they provide permanent habitat. In many intensively farmed countries protected areas are the only place where threatened bee species persist. Approximately 13% of Europe’s land surface is protected but few protected areas specifically target pollinators (except some flagship butterfly species) (Rundlöf & Bommarco 2011). Nevertheless they play an important role in the maintenance of a diverse pollinator community not only inside the protected areas but also in the surrounding countryside. Pollinator diversity and abundance in agricultural landscapes near protected areas is generally higher than far away from such source habitats (Kohler et al. 2008). A range of studies have examined the role of natural areas for the provision of pollination services (e.g.). Pollination services have been linked to the diversity of the pollinator community and the percentage or distance to (semi-) natural habitat (Garibaldi et al. 2011, Holzschuh et al. 2012). These studies generally show that pollination by wild pollinators declines with decreasing diversity of the pollinator community or increasing distance from natural areas.

The objectives and specific conservation measures included in agri-environmental programs vary a lot between European countries (Kleijn & Sutherland 2003). Agri-environment schemes rarely target pollinators directly, with some schemes in the UK being a notable exception. Nevertheless, many agri-environment schemes that target biodiversity more generally have the potential to increase the availability of foraging and breeding habitat for pollinators (Scheper et al. 2013). Agri-environmental measures include creation and restoration of semi-natural habitats, establishment of wildflower strips, planting of flowering trees and bushes, organic farming, reduction of agro-chemical inputs or introduction of unsprayed field margins (Rundlöf & Bommarco 2011). The uptake of probably the most widely implemented measure, organic farming, ranged from 0 to 16% of the agricultural land in European countries, with an average of 4%. Quantitative information on the uptake of other mitigation measures is largely missing.

A study by Scheper et al. (2014), confirmed the generally held assumption that loss of preferred floral resources is one of the key drivers of bee decline. The importance of floral resources was furthermore highlighted by a meta-analysis examining the impacts of agri-environment schemes on pollinators (Scheper et al. 2013). This study found that the response of pollinators to agri-environment schemes is largely determined by the extent to which floral resources are enhanced by agri-environment schemes (i.e. the ‘ecological contrast’ created by schemes; Kleijn et al. 2011). Measures that introduce floral resources directly, such as wildflower strips, were most effective in promoting pollinators, with the effect increasing with increasing number of introduced wildflower species. Extensification of grassland management or establishing naturally regenerated or grass field margins along arable fields was considerably less effective and the effects of organic farming had the lowest effect on pollinator biodiversity (Scheper et al. 2013). Furthermore, the effects of measures were moderated by landscape context and farmland type, with more positive responses in croplands than in grasslands. Also, effects of schemes are more pronounced in landscapes that are structurally simple (semi-natural habitats covering 1-20% of the landscape) than in cleared (<1% semi-natural habitats) or complex (>20% semi-natural habitats) landscapes. These findings were further nuanced by a field experiment carried out within the framework of WP5 in which wildflower strips were established in four European countries using the same seed mixture of forage plants (Scheper et al. in review; Scheper & Kleijn 2014). Effectiveness increased with the local contrast in flower richness created by the wildflower strips but was additionally influenced by the availability of floral resources in the surrounding landscape both early in the season, prior to the flowering of the wildflower strips, and later in the season concurrently with the peak flowering of the strip. Floral resource availability early in the season is largely determined by the cover of mass-flowering crops which currently cover around 7% of the agricultural
land in Europe (Rundlöf & Bommarco 2011). Mass-flowering crops can therefore effectively mitigate loss of pollinator populations in combination with other mitigation measures or all by itself or provided the flowering period matches the flight period of the bee species and the crop plant can be used by the bee as forage (see below). The effects of wildflower strips on bees seem therefore to be largely driven by the extent to which flower richness is increased relative to the situation before planting and compared to the surrounding countryside. This suggests that the effectiveness of measures mitigating pollinator loss can be enhanced by maximizing the number of bee forage species in mitigation sites. Nevertheless, mitigation strategies will only be effective for specific bee species if they target the specific host plants of these species (Scheper et al. 2014). If the preferred host plant of a bee species is absent from the seed mixture, conservation benefits for that species will be negligible.

Most studies examining the effectiveness of agri-environment schemes study responses in species richness or abundance and cannot be used to infer responses at the level of bee populations (Kleijn et al. 2011). Recent studies in the USA suggest, however, that enhancing floral resources does have positive effects on bee population sizes (Morandin & Kremen 2013, Blaauw & Isaacs 2014). This conclusion is largely based on the observation that measures enhancing floral resources for pollinators result in higher species richness and abundance of pollinators in the wider countryside (i.e. spill-over of pollinators from mitigation patches into the agricultural matrix). The picture that is slowly emerging is that establishment of wildflower strips in agricultural landscapes is indeed enhancing local pollinator populations of the species that can use the introduced wildflower species. However, population responses generally only become apparent after two years or more. This emphasizes the importance of perennial mitigation measures and suggest that annual measures offer little sustainable have little to offer for pollinators

The few studies that have looked at this specifically indicate that threatened bee species rarely occur in intensively farmed agricultural landscapes (Kleijn et al. 2006). This was further confirmed by a meta-analysis of 19 European studies examining the bee communities on insect-pollinated crops that found only 12 threatened species which accounted for 0.3% (s.e. 0.1%) of the individual bees observed on the crops. Species are classified as threatened when their numbers have experienced significant declines or their geographic distributions have contracted. Agricultural intensification is an important driver of species decline (Green et al. 2005). It is therefore perhaps not surprising that, in agricultural landscapes, threatened species contribute little to ecosystem service delivery, and benefit little from general conservation measures (Kleijn et al. 2006). However, in the past many of the species that are now threatened occurred widespread and contributed to pollination services on more extensively managed farmland (Bommarco et al. 2012). Threatened species may also still dominate bee communities in restricted parts of their former distributional range (Iserbyt & Rasmont 2012). Effective conservation measures for threatened species should therefore be targeted towards these bee species and their habitats and not the crops to be pollinated (Kleijn et al. 2011, Pywell et al. 2012).

Strategies to mitigate pollination loss

Information at the national level on the uptake of measures to mitigate pollination loss is scarce in Europe (Rundlöf & Smith 2011). One exception may be the occurrence of managed honeybee colonies. The average number of honeybee colonies in Europe is 1.3 colonies/ha insect pollinated crops. Breeze et al. (2014) show that total honeybee stocks across 41 European countries rose by 7% between 2005 and 2010, but that demand for (honey bee) pollination has risen 4.9 times as fast in the same time period. Sole reliance on a single species is a risky strategy, especially since beekeeping is under pressure following the spread of the varroa mite, various diseases and dwindling numbers of beekeepers (Vaissière 2011). The bumble bee species *Bombus terrestris*, the solitary bee *Osmia bicornis*, and to a limited extent *Osmia cornuta*, are also commercially reared in Europe to provide crop pollination. Sale of bumblebee colonies is increasing rapidly, with an estimated 1.1 million bumble bee colonies sold in 2010 in Europe. A disadvantage of managed bumblebees is that their use under open field conditions may contaminate the feral bumble bee populations with genes and pathogens (Otterstatter & Thomson 2008, Kraus et al. 2011, but see also Ings et al. 2010), which may result in the decline of local feral populations of bumble bees.
Other measures to mitigate the loss of pollination include the enhancement of pollination effectiveness of managed pollinators, provision of artificial nests for pollinators, artificial pollination, crop breeding for less pollinator-dependent crops, crop management methods and information dissemination (Rundlöf & Smith 2011). Information on uptake of these measures is virtually missing, probably because implementation is limited due to the low (cost-) effectiveness of most of these measures (Vaissière 2011). Plant breeding offers some long-term solutions for some crops, but past results suggest that altering the biological pathway of fruit and seed production may also result in negative traits from a consumer standpoint and this should not be overlooked.

For optimal and resilient pollination of wild plants and crops, enhancing natural pollinators appears to be the most promising alternative to managed pollinators. In North-American blueberry crops, enhancing wild pollinators by means of planting wildflower strips cost-effectively increased yield and thus combined biodiversity benefits with economic benefits for the farmers (Blaauw & Isaacs 2014, Garibaldi et al. 2014). Whether this approach can also cost-effectively be used in lower revenue crops such as oil seed rape, sunflower or field bean remains to be seen.

Sustainable strategies to enhance pollinators and pollination services

At present European policy instruments rarely explicitly take into account pollinator conservation or the management of pollination services. However, several policy areas, such as agriculture, rural development, climate change and conservation have major direct and indirect impacts on pollinators. Effective conservation of pollinators and pollination services requires an integration of conservation, agricultural and agri-environmental policies because: (I) Agricultural policy influences the supply of pollinators by (mostly negatively) affecting pollinator habitat quality (Schepet al. 2014) and the demand for pollination services by influencing the uptake of insect-pollinated crops (Breeze et al. 2014). (II) Agri-environmental policies provide the main instruments that can be used to mitigate the loss of endangered pollinator species in agriculturally marginal areas and the pollination services in intensively farmed areas (Kleijn et al. 2011). (III) Conservation policies determine the uptake and conservation focus of protected areas that are essential for the conservation of endangered pollinator species in intensively farmed areas and additionally provide spillover of pollination services into the surrounding countryside. To date, no studies have linked local conservation effects to pollinator trends (Kleijn et al. 2011; see Donald et al. 2008 for an example of birds). It is therefore unknown how the extensive European agri-environmental budget for conservation on farmland contributes to the policy objectives to halt pollinator decline.

Effective mitigation of loss of pollinators and pollination services requires a distinction between strategies to protect and promote endangered pollinator species and strategies to enhance pollinators for the services they deliver (pollination) (Kleijn et al. 2011, Kleijn & Schepet al. 2013, Korpela et al. 2013). A recent meta-analysis (Kleijn et al. in review) shows that almost 80% of the crop pollination services are provided by only 2% of the bee species occurring in the examined countries. Furthermore, the species currently contributing most to pollination service delivery are generally common species, whereas threatened species contribute little, particularly in the most agriculturally productive areas. Thus a strictly ecosystem services based approach to conservation would not necessitate the conservation of threatened species. Third, the most important ecosystem-service providing species are relatively robust to agricultural intensification and furthermore can be easily enhanced in those systems by simple management actions. This suggests that the rarer species, which are already absent from such systems, would benefit less from ecosystem-services based actions than they would from traditional biodiversity conservation that targets threatened species in the areas where they are found.

Strategies to enhance pollination services should therefore be targeted at the more intensively farmed areas because in these areas ecosystem services are likely to be reduced due to the intensive farming practices. Here, as indicated in more detail before, perennial agri-environmental measures promoting floral resources effectively enhance service providing pollinator species. Conservation initiatives with intrinsic biodiversity objectives should focus on protected areas and on High Nature Value farmland where agri-environmental schemes promoting traditional low-input farming practices effectively protect vulnerable pollinator species.
References


**WP 5 EMPIRICAL ASSESSMENT OF MULTIPLE PRESSURES ON POLLINATORS AND POLLINATION SERVICES ACROSS EUROPE**

Recent studies have underlined the importance of pollinator diversity for optimizing crop pollination services. Relying on honeybees as single pollinator species can therefore increase the risk of low or variable crop yields. Thus it is mandatory to understand the environmental factors which in combination cause the loss of pollinator diversity in multiple European regions and to develop mitigation strategies that help to restore pollinator diversity in agricultural landscapes. WP 5 in the STEP project has investigated the combined impacts of habitat loss, agricultural intensification and new biofuel crops on pollinators and pollination services in natural and agricultural habitats and thereby has contributed to understand the driving factors of pollinator loss in representative regions across Europe. Important spatial and temporal interactions between different habitat types and geographical regions have been considered. The results will help to inform EU policy, conservation authorities and regional stakeholders how to reduce negative impacts on pollinators and to maintain or restore pollinator diversity and pollination services.

**Task 5.1 Establish a network of study sites across Europe**

In order to address our objectives in a synergistic and efficient way, a joint study design was successfully implemented in 96 study areas in six countries with up to three habitat types per study area (mass-flowering crop fields, perennial field boundaries, semi-natural habitats). The network was established in a way that
multiple tasks could be included and addressed in parallel and over up to three years. On the respective results we will report below.

**Task 5.2 Community composition, population densities, and genetic diversity of pollinators and temporal stability of pollinator communities and pollinator webs in relation to multiple environmental pressures**

**Pollinator dilution in mass-flowering crop landscapes across Europe**

The expansion of pollinator-dependent mass-flowering crops, often driven by biofuel policies, represents a fundamental land-use change, but their effects on pollinator populations and ecosystem functioning are poorly understood. Across six European countries and two years, we assessed how land-cover of pollinator-dependent crops in the landscape affected pollinator densities in 224 crop and non-crop habitats. Increased cultivation of pollinator-dependent crops reduced densities of all pollinator groups in crop fields, and of bumblebees also in field boundaries and semi-natural habitats. These results were consistent across countries and years and independent of the cover of semi-natural habitats in the landscape. Pollinator abundances appear not to keep pace with the expansion of pollinator-dependent crops, as mass-flowering crop fields attract pollinators from non-crop habitats. The expansion of pollinator-dependent crops combined with ongoing pollinator declines can negatively affect crop yields and plant-pollinator interactions in semi-natural habitats across Europe (Holzschuh et al. 2011, Holzschuh et al. in prep., Deliverable D5.1).

**Temporal dynamics in pollinator densities**

Mass-flowering crops may affect long-term population dynamics but effects on pollinators have never been studied across several years. Our results show that high oilseed rape cover in the previous year enhances – except for bumble bees – current densities of wild bees. Moreover, we show a strong attractiveness of and dilution on (i.e. decreasing bee densities with increasing landscape oilseed rape cover) oilseed rape for bees during flowering in the current year, modifying the effect of the previous year’s oilseed rape cover in the case of wild bees (excl. *Bombus*). As long as other factors such as nesting sites or natural enemies do not limit bee reproduction our findings suggest a long-term increase of solitary but not social bee populations due to mass-flowering crops which possibly help to maintain crop pollination services even when crop area increases. Similar effects are conceivable for other ecosystem-service providing organisms in annual crops and should be considered in future studies (Riedinger et al. in press). Furthermore, we focused on spillover effects between two crop types providing flower resources in non-overlapping time periods. Highest bumblebee densities in the late-flowering sunflower were reached in landscapes that combined high relative covers of early-flowering oil-seed rape and semi-natural habitats. Further, our results indicate that early mass-flowering crops can mitigate pollinator dilution in crops flowering later in the season leading to decreasing pollinator densities with increasing crop area. We conclude that the management of landscape-scale patterns of early and late mass-flowering crops together with semi-natural habitats could be used to ensure crop pollination services. Similar processes could also apply for other species groups and may be an important, but so far disregarded, determinant of population densities in agro-ecosystems (Riedinger et al. 2014, Rundlöf et al. 2014).

**Community composition and life history traits**

It is expected that the patterns of resource use by pollinators are associated with certain ecological traits. We assessed in four countries how floral resources in arable landscapes can contribute towards the conservation of specific pollinator traits and how these traits respond to landscape simplification. The novelty of this study lies in the focus on trait-specific responses of contrasting pollinator groups (bees and hoverflies) to crop floral resources (mass-flowering fields) and non-crop floral resources (semi-natural habitats and sown flower strips) (Wickens et al. in prep.).

**Task 5.3 Pollination functions of focal wild plant species**

Our study of five plant species in three European countries shows that the seedlings of five different plant species originating from populations adjacent to mass-flowering crops were smaller compared with offspring from other populations, although this effect disappeared in the following year. Moreover, genetic diversity (assessed as heritability of performance traits) and thus the potential to adapt to future change, was lower
for populations adjacent to mass-flowering crops than for other populations in one of the studied plant species, but not in others. Mass-flowering crops appear to pose an underestimated threat to wild plants growing in their vicinity. We therefore suggest that the cultivation of mass-flowering crops next to areas and populations of high conservation value should be considered very cautiously (Deliverable D5.2).

**Task 5.4 Yield quantity and quality of focal crop species**

In this task, we showed that red clover in Sweden entirely and sunflower in Germany partly depended on insect pollination for seed production. In both mass flowering crops the dominating wild pollinator group was bumble bees. The results achieved in this task indicate that a combination of early flowering oilseed rape together with a high relative cover of semi-natural habitat could result in a high density of wild pollinators in later flowering crops. Further, in case of red clover, they can increase bumble bee queen and male densities (Riedinger et al. 2014, Rundlöf et al. 2014; Deliverable D5.3). In a further study, we assessed the contribution of insect pollination to crop yield and quality in spring oilseed rape, field bean, strawberry, and buckwheat located in four regions of Europe. Insect pollination enhanced average crop yield between 18 and 71% depending on the crop. Crop quality was enhanced in oilseed rape, buckwheat and strawberries. Yield was consistently enhanced by higher visitation rates, which were highest in complex landscapes for most crops (Bartomeus et al. 2014).

**Task 5.5 Quantifying the dependence of perennial fruit crops on insect pollination**

Although a large number of wild bee species have been recorded visiting apple flowers, we do not have information on how pollinator communities differ among varieties and countries. We surveyed pollinators in eight apple varieties in commercial orchards in four countries. One variety (Braeburn) was common to all study countries (Boreux et al. in prep.). Further experimental studies addressed trade-offs between pollination and spatiotemporal resource allocation in peach and kiwi fruit. Kiwi yield strongly depended on insect pollination. Fruit set of peach was increased by insect pollination compared to wind pollination, but this did not translate into higher yield because of fruit thinning. For both peach and kiwi fruit, a subset of 20 floral flowering limbs provides an acceptable compromise between a reasonable sampling effort and adequate accuracy to assess the dependence on biotic pollination as surrogate for the whole plant. This result is consistent with the scale of photosynthate translocation in peach trees and so this approach could be used to extend this result to other fruit tree species (Le Féon & Vaissiere in prep.).

**Task 5.6 Beneficial and antagonistic spill-over effects from agricultural to natural habitats**

Compiling data from six European countries, we found that the density of wild pollinators decreased in semi-natural with increasing relative cover of mass-flowering crops during mass-flowering, while no such relationship was present after mass-flowering. This indicates little time-delayed spill-over of wild pollinators between mass-flowering crops and semi natural habitats (Deliverable D5.4). However, in Germany, bumblebee densities in semi-natural field boundaries increased with increasing cover of mass-flowering crops after the mass-flowering period (Riedinger et al. in prep.). Therefore, wild pollinator dilution during mass-flowering could have negative impacts on wild plant pollination in semi-natural habitats whereas this study indicates little positive impacts on wild pollinators from cultivation of mass-flowering crops. This highlights the need to apply agri-environmental measures which effectively introduce resources that positively influence wild pollinator population. Such measures could focus on conserving and recreating high quality semi-natural habitats containing both nesting and forage resources.

**Task 5.7 Occurrence and impact of invasive plant species**

In a Mediterranean shrubland in Spain the non-native plant *Hedysarum coronarium* directly and positively affected visitation rate and fructification of native target plants through its floral display. Indirectly, by reducing the diversity of floral resources in recipient communities, the non-native species positively affected visitation rates of native target plants and negatively affected their fructification. Although direct and indirect effects were additive for visitation rates, these direct and indirect effects offset each other for fructification rates, resulting in an overall non-significant effect of the non-native species on the reproductive success of native target plants. By combining field observations with manipulative experiments
our study shows the complexity of direct and indirect effects that non-native species can exert in the reproductive output of native species (Montero-Castaño & Vilà under review).

Task 5.8 Evaluation of ecological and economic benefits of different mitigation strategies

Wildflower strips, which were established in four European countries, generally enhanced local bee abundance and richness, including Red Listed species. Effectiveness of the wildflower strips increased with the local contrast in flower richness created by the strips, and furthermore depended on the availability of floral resources in the surrounding landscape, with different patterns for solitary bees and bumblebees. Effects on solitary bees decreased with increasing amount of alternative floral resources in the landscape, whereas effects on bumblebees increased with increasing early-season landscape-wide floral resource availability. Our study shows that the effects of wildflower strips on bees are largely driven by the extent to which flower richness is increased. The effectiveness of this measure could therefore be enhanced by maximizing the number of bee forage species in seed mixtures used for wildflower strip establishment (Scheper et al. under review, Deliverable D5.6). We used trap nests and a three-year Before-After-Control-Impact (BACI) design to examine whether the establishment of wildflower strips enhances local populations of cavity-nesting bee species. Wildflower strips enhanced reproduction of Osmia spp. compared to control sites, but only in the second year after establishment, and reproduction of none of the other species was significantly affected by wildflower strips. However, the experimental enhancement of nest site availability in wildflower strips and control sites resulted in population growth for all species groups except Megachile spp. This probably suggests that most of the investigated species groups are even more limited by nest site availability than floral resource availability in agricultural landscapes (Scheper et al. in prep.).

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Manuscripts under review:
Montero-Castaño A & Vilà M. Direct and indirect influence of non-native neighbors on pollination and fruit production of a native plant species. PLOS One, under review.

Manuscripts in preparation:
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Holzschuh et al. Pollinator dilution in mass-flowering crop landscapes across Europe, in prep.
Le Féon V., Vaissière B.E., Quantifying the dependence of fruit tree crops on insect pollination, in prep.
Wickens et al. A trait-based approach to understand relationships between pollinators and floral resources in agroecosystems, in prep.

WP6 POLICY TOOLS AND INTEGRATION OF KNOWLEDGE

Task 6.1: Setting up Governing Questions.
Significant results: AU co-organised with SYKE and Reading an international stakeholder workshop in Brussels on 28th September 2010. Attendees included 21 experts from policy, government agencies, NGOs and academia. Three important groups of governing questions were identified: the loss of biodiversity, the loss of ecosystem services and the decline in agricultural production. Pollinator loss is a multiple sustainability issue and potentially has significant negative effects on human wellbeing from many perspectives (e.g. health, economy, and culture). The stakeholder workshop was a valuable input to the project to support relevance and focus towards stakeholder needs (Ratamäki, et al., 2015).

Significant results: A hierarchical concept for structuring questions as presented in Biesmeijer et al., (2011) is further developed to make a structure for evidence mapping. Conventionally integration of scientific knowledge to support management is a challenge that in many projects leads to missing or insufficient results. Task 6.2 has developed a novel approach to handle integration of knowledge in a new way designed for pollination problems. This activity takes place at concept level, where the system (pollinators and the ecosystem) is described as concepts (Sørensen et al., 2014). The findings address the relation between concepts and not the concepts themselves. E.g. the two concepts “pesticide application” and “nectar delivery” was not subject for research in STEP but the relation between pesticide application and nectar delivery is. The platform is Excel and the freeware Freemind. Factors that control the abundance of bees are defined to make a concept of understanding why the abundance and species richness is high/low and which mitigation options can increase abundance and species richness. A factor can be both a physical object and an abstract defined characteristic. If the defined list of factors is incomplete in covering all relevant aspects, then the subsequent understanding, based on the concept model, will also be incomplete, and important relations can be hidden by ignorance. This is a fundamental problem in modelling and it is, thus, important to make a careful mind mapping to define factors in order not to ignore aspects that may have relevance for the governing question. As a supplement Bayesian methods is developed to extract useful ecological knowledge about pollination from ecological data to be used for management (Sørensen et al., 2011).
Task 6.3: Development of innovative policy instrument and mechanisms at the EU and national level to address pollinator-related problems

Significant results: The three main policy areas - conservation policies (Habitats Directive, Bird Directive, EU Biodiversity Strategy), CAP and pesticides policy have a great potential to positively influence pollinators and are described with their relevance to pollinators. Specific measures which potentially deliver most benefits for pollinators are assessed qualitatively with the help of several criteria (ecological effectiveness, predictability, flexibility, costs and acceptability). Options for future adjustments and recommendations in the policy area biodiversity conservation are proposed for (1) the measure “Protected habitats which meet pollinator needs”, (2) the measure “Provide ecological stepping stones, nesting and foraging habitats”, in the policy area Common Agricultural Policy for (3) the measure “Provision of flower resources”, (4) the measure “Provision of nesting and foraging habitats”, and (5) the measure “Pollinator-friendly farming of agricultural land or de-intensification (not necessarily explicitly designed for pollinators)” and in the policy area pesticides (6) the measure “Reduce pollinator mortality”.

Pollination should be considered from a multilevel policy perspective to analyze the institutional fit and interplay of multi-faceted pollination-related policies (Ratamäki et al., 2015). The results show that the policy systems affecting pollination are abundant and that these systems create different kinds of pressure on stakeholders, at several levels of society. The local-level concerns are more about the loss of pollination services than about loss of pollinators. This points to the problem of fit between local activity driven by economic reasoning and biodiversity-driven EU policies. Here we see the concept of ecosystem services having some potential, since its operationalization can combine economic and environmental considerations. Furthermore, the analysis shows how, instead of formal institutions, it seems that social norms, habits, and motivation are the key to understanding and developing effective and attractive governance measures.

Reference


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The potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results

Potential Impact (including the socio-economic impact and the wider societal implications of the project so far)

Typically scientific findings can take many years or even decades before they have a measurable influence on policy and practitioners. However, some outputs of the STEP project have already begun to have impact and the route to further potential impacts are emerging. Documented below are a selection of the key impacts already achieved with descriptions of ongoing and likely future impacts. These are organised around five areas: the current status of pollinators and pollinator-dependent plants; understanding the drivers of change; the effects of shifts in pollinators on wider society; mitigation options for loss of pollinators and pollination services; and policy areas relevant to pollinators.

1. Current status of pollinators and pollinator-dependent plants

STEP and IUCN’s development of the first ever European Red List for bees is a major tool to help direct conservation efforts. Prior to the European Red List there were some Member State Red Lists for bees but no continental overview of the extinction risks facing Europe’s bees. The list identifies those species most threatened and describes the main threats (e.g. climate change, agriculture intensification); this knowledge helps inform species and habitat protection activities and directs them to where they are most needed. The Red List also documents the degree of endemism in Europe and where the hotspots of bee diversity are. Finally, the Red List has revealed that over half of Europe’s bees are data deficient, and therefore their conservation status cannot be assessed, highlighting knowledge gaps, data shortfalls and lack of bee taxonomic expertise across Europe.

Prior to STEP, information on the status of honeybees throughout Europe was fragmented, localised and often lacked robust evidence. The STEP project was able to conduct the first pan-European assessment of the recent trends in the numbers of honeybee colonies and beekeepers. Results showed an overall decline in colony numbers at the European level, with mixed trends across countries, and this information has been used to inform the Commission and Member States about the extent of declines and ongoing trends in honeybees, and identify those regions where honeybee losses are of greatest concern.

STEP was able to advance our knowledge of the trends of wild pollinators in Europe by expanding the geographical scope, timespan and taxonomic coverage. For the first time the trends in bumblebees, solitary bees, hoverflies, butterflies and insect pollinated wild flowers were quantified over several decades in three European countries. This showed that the substantial declines in some pollinator groups prior to the 1990’s has slowed down, but pollinator communities have homogenised as many of the most sensitive species have already been lost. This analysis has provided important baseline data with which to compare future statuses, quantified the extent of losses, provided statistical tools to allow future assessments (if appropriate data is available), and helped inform pollinator-related policies (e.g. England’s National Pollinator Strategy).

Monitoring of pollinators is essential to inform decision making about pollinator conservation and the management of pollination services, and STEP has contributed to the development of ideas and tools for establishing both global and regional monitoring schemes and the taxonomic tools needed to help support them. These tools will be key to assessing the effectiveness of interventions aimed at mitigating pollinator loss and identifying taxa and localities where losses are greatest.

2. Understanding the drivers of change

The Red List documented some of the drivers associated with declining bee species, however, until recently, the information on the range of drivers, their relative importance and interactions were poorly understood. STEP delivered a number of review articles and empirical studies to help bridge this knowledge gap. Specifically, at the start of the project, STEP reviewed the current literature on global drivers of pollinator declines and identified habitat loss and fragmentation, agrochemicals, pathogens, alien species and climate
change as being of particular concern. A second review synthesised knowledge in two new areas: the effects of drivers on pollination services and the effects of combinations of drivers.

In addition, STEP produced a number of studies quantifying: (i) the combined effects of climate, land use, fragmentation, nitrogen deposition and pesticide pressure on pollinators at large spatial scales; (ii) the combined impacts of pesticides and pathogens on pollinators at large spatial scales; (iii) the effects of various farm management practices (e.g. mass flowering crops, field margins, organic farming) on pollinators and pollination services; and, (iv) the impacts of other drivers such as invasive flowers, heavy metals and herbicides. Taken together, this has made a significant contribution to the evidence base on the causes of pollinator losses and helped inform policies (European and Member State) and direct management practices to consider these risks.

3. The effects of shifts in pollinators on wider society

STEP, in collaboration with other partners, has provided strong evidence that wild insects, mainly bees, and not managed honeybees, are the main pollinators of global, European and national crops. This has overturned a widely held belief that honeybees are responsible for most crop pollination. Another study showed that Europe has an insufficient supply of honeybee colonies to meet current and future demands from pollination-dependent crops. While a few Member States have sufficient supplies, the majority of do not highlighting the dependency growers have on wild insects to provide pollination services. STEP also found that the majority of European crops could be potentially pollinated by a very small number of wild bee species (<2% total bee fauna). This change in understanding has been widely adopted by the academic and research communities throughout Europe and is increasingly recognised by European and Member State governments as well as by farmers, beekeepers, land managers and industry. The result is that research funding now increasingly reflects the important role of wild pollinators (e.g. UK Insect Pollinators Initiative) and policies (England’s National Pollinator Strategy) and management plans focus on both wild and managed pollinators.

Other STEP findings have contributed to a better understanding of the relative contribution of wild pollinators to crop yield, quality, production stability and commercial profit thereby informing growers of the values of pollinators for production and policy makers the role of pollination services in food security. STEP has also shown that many of the micronutrients (vitamins and minerals) in human diets are derived from insect pollinated crops. Taken together these findings have helped change behaviours and have moved towards including pollinators as an important agricultural input and a crucial element in sustainable food production.

A portfolio of STEP studies have documented the importance of both wild and managed pollinators in wild flower reproductive success and gone on to describe the links between semi-natural habitats and plant-pollinator communities and networks. This knowledge has helped direct ongoing research into wider ecosystem stability and resilience and helped inform land managers, conservationists and potentially policy makers about the wider contribution of pollinators to biodiversity maintenance.

4. Mitigating pollinator and pollination service loss

STEP has evaluated different approaches to mitigating against the loss of pollinators including the roles of protected areas, agri-environment scheme options and mass flower crops.

In general, studies from STEP and elsewhere show that wild pollinator diversity and abundance on crops declines with increasing distance from protected areas or other semi-natural features in the landscape. This suggests that the Natura 2000 network and other protected areas, as well as some Green Infrastructure elements may be important tools to help protect pollinators and pollination services.

European agri-environment schemes rarely have options that target pollinators specifically (with exceptions such as UK Countryside Stewardship) but are usually aimed at enhancing wider biodiversity. STEP showed that in arable systems floral margins, naturally regenerating grass margins and organic farming all supported more pollinators, as did low input meadows and flower margins, but not organic farming, in pastoral systems. The types of landscapes which agri-environment scheme options are placed in has major
influence on their effectiveness in supporting pollinators. Highly degraded landscapes (with few semi-natural features) tend not to benefit from interventions, whereas diverse, and particularly intermediate, landscapes do. This evidence demonstrates which options are effective at supporting pollinators, and highlights the importance of targeting options within the landscape, and so is helping inform the development of current agri-environment schemes and could inform the CAP review.

Various studies have explored the utility of mass flowering crops for supporting pollinators and they have the potential to do so providing they flower at the same time as pollinators are active, and that there are alternate floral resources available before/after the mass flowering bloom. Mass flowering crops alone are unlikely to have a significant impact of pollinators, however, in conjunction with other interventions they may make a useful contribution.

STEP evaluated current options for the mitigation of pollination service loss through supplementation with commercial managed pollinators and habitat provision for wild pollinators. While managed honeybees, and to a lesser extent managed bumblebees and mason bees, are commercially available to growers there are few other short-term options to overcoming pollination deficits in crops. While augmentation with managed pollinators may work for some crops, other crops cannot be pollinated by them, and this practice also has a cost to the grower which may not be offset by enhanced production value. Longer-term solutions through the provision of habitats for wild pollinators, especially for wild bees and hoverflies, represents a more sustainable and potentially lower cost solution, though evidence is still lacking on the costs and benefits of such approaches. Farmer practices and policy support for food security will benefit from considering ways to safeguard crop pollination services derived from both sorts of mitigation actions but further research is needed before these can be fully integrated into policy and practice.

5. Informing policy areas relevant to pollinators

Overall STEP has provided a sustained body of evidence relevant to a number of policy areas including agriculture, conservation, and bee health. While some areas have already considered evidence generated by STEP, most opportunities to influence policy lie in the near future; outlined below are examples where we expect STEP to have impact.

**Agriculture policies:** Evidence on how farm management affects pollinators, evaluation of agri-environment scheme options and the role of different pollinators in food production, is highly relevant to the expected mid-term review of Common Agricultural Policy in 2017 and the development of new CAP post-2020. Specifically, STEP generated knowledge is informing the minimum the environmental standards needed to support pollinators (CAP Pillar 1) and the potential effectiveness of Ecological Focus Areas, crop diversification and permanent grasslands (CAP Pillar 2, greening measures).

**Conservation policies:** Through the Red List of bees, assessment of the status and trends of wild pollinators and flowering plants, in conjunction with an understanding the role of protected areas and semi-natural habitats, places STEP to contribute to several biodiversity policies. Key areas from 2015 onwards, include the mid-term assessment of the European Union Biodiversity Strategy to 2020, EU State of Nature Report on the status of the habitats and species protected under the Birds and Habitats Directives, and new EU Regulation on Invasive Alien Species. Europe’s Biodiversity strategy not only covers pollinator conservation but also halting the loss of ecosystem services such as pollination, specifically the ‘No Net Loss Initiative’ and policy options for biodiversity offsetting.

**Bee Health policies:** STEP work on the impacts of pesticides and pathogens on wild and managed bee species are highly relevant to several areas including the 2015 EU decisions on how to define endocrine disrupting chemicals and on the current (2013-15) restriction of neonicotinoids, as well as the implementation of the Sustainable Use of Pesticides Directive.

**Other policy areas:** Evidence from the STEP project is likely to shape practice and policy around transport (e.g. management of road and railway verges), trade (e.g. risks of pathogen transfer between managed and wild pollinators and between species) and green infrastructure (e.g. creating green corridors and refuges). Other international initiatives which have already drawn upon STEP outputs, and continue to do so, include:
• **Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services** thematic assessment of ‘Pollinators, pollination and food production’.

• **Convention on Biological Diversity** International Pollinator Initiative.

• **European Academies’ Science Advisory Council** report on ‘Ecosystem services, agriculture and neonicotinoids’.

• **European Food Standards Authority** reports on pesticides.

• **Sustainable pollination in Europe - joint research on bees and other pollinators** COST Action dissemination network.

• **Food and Agricultural Organisation of the United Nations**.

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**Main dissemination activities and exploitation of results**

During the whole lifetime of STEP, information related to the project and its outcomes were widely popularized using a full range of communication and dissemination approaches.

**STEP logo**: designing the STEP logo was one of the first steps taken. It introduced the project and helped the external audience to easily identify it.

**Website**: including an internal communication platform ([www.step-project.net](http://www.step-project.net)) – launched at the very beginning of the project. It was designed in a way to make it user-friendly, interactive, attractive to the different target groups and kept up to date with information. The website has two distinct areas: i) public website area containing general information about the project and its development, accessible to anyone and ii) private (password protected) website area called Internal Communication Platform (ICP) which supported the smooth workflow between project partners. To broaden the impact of STEP and to promote its results to users of the social networks, profiles of STEP were created in Twitter ([@step_project](https://twitter.com/step_project); 240 followers at the end of the project) and Facebook ([https://www.facebook.com/pages/Status-and-Trends-of-European-Pollinators-STEP/177104628996076;](https://www.facebook.com/pages/Status-and-Trends-of-European-Pollinators-STEP/177104628996076; 376 likes received during the project lifetime) with an automated messenger function implemented to inform them for STEP-derived publications and news.

From 1 December 2010 to 31 January 2015 the STEP website has been visited by 28,562 users with a total of 47,911 sessions and 119,823 page views (see below):

<table>
<thead>
<tr>
<th>Sessions</th>
<th>Users</th>
<th>Page/Sessions</th>
<th>Avg. Session Duration</th>
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<tbody>
<tr>
<td>28,562 (958.2/month)</td>
<td>28,562 (643.4/month)</td>
<td>2.50 pages/session</td>
<td>00:02:07 average per session</td>
</tr>
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People who visited the STEP website by years and country:
The STEP website has been visited by people from nearly 200 countries, most visits coming from the United Kingdom, United States, Bulgaria, Germany and Italy, followed by France, Sweden, Spain, Czech Republic and Belgium.

**STEP outreach materials:** these were used to announce the project and provide relevant information to the diverse stakeholders, disseminated in both electronic and printed form. STEP produced:

- An introductory leaflet (http://step-project.net/img/uplf/STEP_Introductory_Leaflet.pdf)
- STEP factsheet for farmers (http://step-project.net/img/uplf/Factsheet-STEP.pdf; available in 15 European languages);
- Two posters (http://step-project.net/page.php?P=4&SP=15);
- Two issues of the STEP newsletter (http://step-project.net/page.php?P=4&SP=23newsletter);
- STEP final brochure (http://step-project.net/img/uplf/STEP brochure online-1.pdf).

**STEP final brochure** (http://step-project.net/img/uplf/STEP brochure online-1.pdf): this consists of 72 pages, and comprises 5 chapters with a total of 20 case studies that summarise some of the key findings of the STEP project as a series of short case studies. Taken together these case studies demonstrate how a large-scale project bringing together a range of international expertise can generate important new knowledge to help safeguard Europe’s pollinators and the benefits they bring to society. All the case studies include members of the STEP team and many also involved extensive collaborative efforts with researchers from all round the globe. The brochure is published by Pensoft Publishers in a circulation of 2000 copies and is also available as e-publication (http://step-project.net/img/uplf/STEP brochure online-1.pdf) on the STEP website.

Press releases (http://step-project.net/page.php?P=4&SP=24): a total of 12 press releases have been prepared and consequently published via EurekAlert, one of world leading distributors of science news. Some of them got widely reflected by the world media. One of the press releases was a joint initiative with IUCN and referred to a study assessing the species group at the European level which is part of STEP project and the European Red List of pollinators, both funded by the European Commission. The most recent press
release “Fighting decline of pollinators in Europe” advertised the Climatic Risk and Distribution Atlas of European Bumblebees as a STEP final output.

**Policy briefs** (http://step-project.net/page.php?P=4&SP=35): STEP research has been featured in 6 issues of Science for Environmental Policy (SEP). Research supported by STEP has been placed among the Top 10 most popular Policy Briefs for 2012 in the classification of Science for Environmental Policy (SEP). The article “Birds and butterflies fail to follow climate change temperature rise” has been placed in 7th position among the most downloaded SEP newsletter items, thus marking great popularity and outreach.

A **multimedia clip** “Pollinators go silent!” (https://www.youtube.com/watch?v=di9D6ySSso4) was produced and released to raise awareness about the loss of pollinators and pollination services in Europe and the required mitigation measures.

**Climatic Risk Atlas of European Bumblebees:** (BioRisk 10, special issue; http://biorisk.pensoft.net/articles.php?journal_name=biorisk&id=4749) is one of the major products of the project. The monograph consists of 234 pages; it is authored by members of the STEP project and external contributors; and designed and published by Pensoft Publishers. The atlas characterises climate-driven risks for bumblebees in Europe, and so provides an important source of information for conservation actions and the management of pollination services. It is an important complement to the earlier Red List of Threatened Species for the IUCN Bumblebee Specialist Group, in which Bumblebee Specialist Group Regional Coordinators, and STEP members Pierre Rasmont and Stuart Roberts took leading roles. The general aims of the Atlas are: i) to inform the broader public about the potential risks of climate change for the future fate of European bumblebees; ii) to aid biodiversity conservation managers and policy makers and iii) to provide background knowledge for critical discussions about the sustainable provision of pollination services in the light of food security.

**Stand-alone power point presentation** (http://step-project.net/img/uplf/STEP_FINAL_STAND-ALONE_PPT.pdf): represents concise yet complete overview of the STEP project and its achievements with an emphasis on the usefulness for both science and policy.
Media presence: STEP appeared in a variety of interviews and broadcast on TV and radio, as well as in regional and national print and web publications across Europe. The project has been featured in a number of documentary productions. For example “The Plight of the Pollinators” (http://www.euronews.com/2014/06/23/the-plight-of-the-pollinators) on Euronews, television and online broadcasted, reached an audience size estimated as 1/3 billion households. More information is available in the list of dissemination activities.

Scientific (peer reviewed) publications – in total 155 scientific papers were published in leading journals in the spheres of Biology, Biodiversity and Ecology, amongst them several of the top 20 scientific journals: Science, Nature, Ecology, Ecology Letters, Journal of Applied Ecology, Oecologia, Trends in Ecology and Evolution, Conservation Biology, Proceedings of the National Academy of Sciences of the USA, etc. About half of the papers (72) are published open access. Final manuscript versions or PDFs of another 74 papers are available through repositories such as Arxiv or Research Gate. Another 17 manuscripts are in preparation, submitted, accepted or in press. Further information is available in the complete list of scientific publications on the website. These are complemented by 24 Master and PhD theses anticipated or completed.

Training and sharing of skills: STEP organized 13 training courses with the participation of around 250 students in total, coming from a biology and veterinary study background. The topics of the courses included: honey bee pathology and apiculture; biodiversity and ecosystem functioning in agriculture and forestry; relationships between vegetation and pollen-visiting insects (data collection and analysis); pollination ecology; biodiversity and climate; bee pathology and general apidology. Part of the training courses (Introduction to statistics (in ecology) using R; Terrestrial ecosystem functions and biodiversity; Species distribution modeling) were organized and led in the framework of the graduate school for doctoral researchers at the Helmholtz Centre for Environmental Research – UFZ HIGRADE. The project organized also two ecological field courses MLU Halle on “Relationships between vegetation and pollen-visiting insects – data collection and analysis” and another two training courses for Master Level II on bee pathology, addressed to the veterinarians of the Italian Public Administration.

Communication and dissemination activities: Good interaction with key stakeholders was insured by STEP partners’ participation in and organization of more than 350 international and national conferences, workshops and meetings dealing with sensitive for the society issues such as the loss of pollinators, the impact on bees on human health, the decrease of the pollination services, etc. A stakeholder workshop Identifying the most important governing questions related to the pollinator loss, held in Brussels in 2010, gathered stakeholders from national and EU levels (administration, entrepreneurs, NGO representatives and researchers). The overarching conclusion of the workshop was that pollinator loss is a multiple sustainability issue and potentially has significant negative effects on human well-being from many perspectives (e.g. health, economy, and culture). The project coordination team gave keynote talks at important meetings, for instance the presentations Bees, food and human health given for the members of the Royal Society of Medicine, UK, and Pollinator declines and consequences for the UK for the Parliamentary Office of Science and Technology, UK. A talk about the challenges to the beekeeping sector was given in the EU Parliament. It is worth mentioning also the talk on the Effects of mass-flowering crops on pollinator communities in agricultural landscapes given at the 5th European Conference of Apidology, Halle/Saale, Germany for scientists from all EU countries. The keynote presentation Pollination, policies and critical gray areas – a regional case study in South-West Finland was given for EU researchers and policy makers at the TEEB conference. STEP organized a symposium Drivers of pollinator loss within the 12th EEF Congress, attended by more than 70 scientists from international level. A STEP partner held a workshop and a talk on event covering biodiversity and ecosystem services: a strategic dialogue between science and policy in European Commission, Brussels. A press conference devoted to the importance of insect pollinators, the multiple pressures affecting bees and our project on neonicotinoids and bees was given in Sweden. Two workshops on plans for action for wild pollinators were held in the French Environment Ministry. STEP was presented to around 50 policy officials in the Parliamentary Office of Science and Technology with the talk Safeguarding the value of British pollinators. STEP coordinators talked on the Innovations from the STEP project to a large audience of scientists, policy experts, NGO, representatives from beekeeping organisations and individual
beekeepers at the one-day Bee Health Conference (Brussels, Belgium) organized by the European Commission where concerns over bee health and bee colony losses were presented and discussed. More details are available in the list of dissemination activities. Finally STEP was featured as success story on the EC Research and Innovation website (http://ec.europa.eu/research/infocentre/article_en.cfm?id=/research/star/index_en.cfm?p=sf-20150115-pollinators&calledby=infocentre&item=Infocentre&artid=33739).