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Pollination and International Development

What do we know, what are the challenges and what more can we do?

A UKCDS report highlighting the relevance of pollination to international development and identifying opportunities for improving development outcomes

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Background

This report is the result of a three month project led by Thomas Timberlake, a pollination ecology PhD researcher from Bristol University, whilst on a three month work placement with the UK Collaborative on Development Sciences. It draws upon the experiences of a range of academics, funders and practitioners working across various disciplines with relevance to pollination and international development. It also incorporates some of the outcomes and points of discussion from a Pollination and International Development Webinar hosted by UKCDS on 26 January 2018. The project was supervised by Vicky Morgan (former UKCDS director) and benefitted from the valuable inputs of the whole UKCDS team.

This report draws upon the experiences of the following consultees to whom UKCDS is extremely grateful:

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Acronyms

AGRA - Alliance for a Green Revolution in Africa
BES-Net - Biodiversity and Ecosystem Services Network
CBD - Convention on Biological Diversity
DAC - Development Assistant Committee
FAO - The Food and Agriculture Organization of the United Nations
FFS - Farmer Field School
GCRF - Global Challenges Research Fund
GEF - Global Environment Facility
ICIPE - International Centre of Insect Physiology and Ecology
IPBES - Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPI - International Pollinators Initiative (formally known as the International Initiative for the Conservation and Sustainable Use of Pollinators)
LMIC - Low and Middle Income Countries
NGO - Non-Governmental Organisation
ODA - Official Development Assistance
OECD - Organisation for Economic Co-operation and Development
UKCDS - UK Collaborative on Development Sciences
UN - United Nations

About UKCDS

The UK Collaborative on Development Sciences (UKCDS) is a group of 14 UK government departments and research funders working in international development. A small coordinating team brings this group together with researchers and other key organisations to share knowledge and identify opportunities for collaboration. By stimulating collaboration, UKCDS ensures the best science is funded and used to benefit international development, as well as the UK.

Introduction

While pollinator declines and their impacts on agriculture and natural ecosystems have received a great deal of attention in developed parts of the world such as Europe and North America, these issues are much less studied in developing countries, particularly across Africa. However there is reason to believe the consequences of pollinator decline could be at least as detrimental to economies, ecosystems and communities in these regions.

Pollinator declines have the potential to negatively affect communities in developing countries in a variety of ways, from reducing crop yields and value of crop products, to increasing the volatility of food prices, reducing access to micronutrient supplies and threatening income from honey production. Existing research into these issues has the potential to inform international development work; for optimum impact, different academic disciplines and institutes would work together to identify research needs and opportunities for collaboration and capacity building. It is also crucial that this information is reaching policy-makers and practitioners – farmers, extension workers and beekeepers – in a relevant format.

This project aimed to explore existing work, highlighting what is known and what is yet to be discovered and implemented; and to identify knowledge, capacity, and policy needs for optimal development outcomes. This includes progress towards the following United Nations Sustainable Development Goals: ‘No Poverty’, ‘Zero Hunger’, ‘Good Health and Well-Being’, ‘Sustainable Cities

and Communities', 'Responsible Consumption and Production' and 'Life on Land'. We also set out to identify opportunities for the UK research and funding community to contribute.

For simplicity, we use the term 'developing countries' to refer to all countries listed in the Organisation for Economic Co-operation and Development's (OECD) Development Assistant Committee (DAC) list of Official Development Assistance (ODA) recipients. This includes countries from a range of economic classifications, from 'Least Developed' to 'Upper Middle Income' which includes the nations of China and Brazil. Whilst we group all these nations under the broad term of 'developing country', we acknowledge the great heterogeneity between them in terms of wealth, development and research capacity. We would also like to clarify that while many gaps exist in our understanding of pollination in developing countries, a number of researchers across the developing world have made substantial and important contributions to this field. This is in spite of the many challenges such as limited resources and the low numbers of researchers in these regions. Africa for example, has only 1% of the world's researchers (UNESCO 2010) despite having 25% of world's population. All research efforts should therefore be considered in the context of these challenges.

Why pollination is important to international development

More than three quarters of global food crops rely to some degree on animal pollination (Klein *et al.* 2007). The benefits that animal pollination brings to these crop products, in terms of increased yield, quality and even longevity makes this service worth between US$235 and $577 billion annually (Lautenbach *et al.* 2012). Aside from these functional and monetary values, pollinators also have important cultural value, acting as a source of inspiration in art, music and folklore (IPBES 2016).

Evidence of severe pollinator declines in various parts of the world has stimulated a wave of international attention and concern, as well as scientific research. However, the majority of this research has been restricted to the developed world, particularly North America and Western Europe (Figure 1). This strong geographic knowledge bias is a concern because there is reason to believe the consequences of pollinator decline may be at least as serious in the developing world, for a number of reasons listed below.

Crop yields

Firstly, declines in pollination services have the potential to greatly impact upon the income and livelihoods of developing communities through reducing crop yields. Over 2 billion people in developing countries are smallholder farmers (Lowder *et al.* 2014), often heavily reliant upon pollinators, without necessarily knowing it. Indeed pollination deficits (reduced yield as a result of insufficient pollination) have already been identified in various studies across the developing world (Garibaldi *et al.* 2016; Samnegard *et al.* 2016).

Some of the most valuable cash crops, such as coffee, cocoa and cashew nuts are highly pollinator-dependent and almost exclusively grown in developing countries, providing communities with important income. Cocoa for example, provides a source of income for over five million smallholders in the tropics and represents 13.4% of the Ivory Coast's GDP (Hoare & King 2017). Global reliance on pollinator-dependent crops has increased fourfold in the last 50 years and most of this increase comes from developing countries (Aizen & Harder 2009) (Figure 2). Indeed, the relative economic impacts of pollinator losses on human welfare are expected to be greatest in western, northern and central Africa (Bauer & Wing 2016). With reducing yields of these pollinator-dependent crops, the land required to meet agricultural demands is also expected to increase, a trend that will be most pronounced in the developing world (Aizen *et al.* 2009).

The lack of economic support systems for farmers in the developing world - insurance packages, financial savings and the ability to take out loans - further increases their vulnerability (Harvey *et al.* 2014). It reduces their ability to buffer fluctuations in crop yields or prices and prevents them from switching to new farming systems (e.g. less pollinator-dependent crops) or investing in new technologies and agricultural inputs (Karlan *et al.* 2012), for example hiring managed pollinators.

Human health

With declining pollination services, not only would calorie intake and income fall, but the balance of people's diets is likely to shift. Some of the most nutritionally important food groups such as fruit, nuts, seeds and vegetables are also the most pollinator-dependent. According to Smith *et al.* (2015), severe pollination declines are therefore predicted to cause many millions of people around the world, and particularly in developing countries, to become newly deficient in important micronutrients such as vitamin A, vitamin C, iron and folate. Complete loss of animal pollination is expected to result in an additional 1.42 million deaths each year as a result of preventable diseases, and 29 million years of healthy life lost (Smith *et al.* 2015). The supplementary appendix of this paper lists the burden of disease for each country of the world as a result of both local and cross-border (imported) pollinator declines. It is clear that much of the burden of disease is a result of pollinator declines within a country, suggesting national-level strategies could be effective in mitigating these threats.

The overlap between malnourished areas of the world and pollinator-dependent micronutrient production (Chaplin-Kramer *et al.* 2014) suggests global malnutrition is likely to be compounded by pollinator declines. This may have implications for meeting the UN Sustainable Development Goal of 'Good Health and Well-Being'.

Beekeeping

In addition to these benefits derived through crop pollination, certain bees also produce valuable products such as honey and beeswax which can generate a steady and significant source of income for rural communities, requiring few financial inputs. Income generated from beekeeping can have a number of important economic spin-off effects. Research has shown that extra money derived from beekeeping is often used to invest in new agricultural products or technologies, educate children or expand an existing business, helping to lift people out of the 'poverty trap' (J. Lowore 2018, personal communication, 29 March). In this sense, the development impacts may reach far beyond a bit of extra income. Beekeeping can also have important cultural benefits such as the empowerment of women, youth employment and creating social structures such as beekeeper associations (IPBES 2016). Keeping bees in orchards has also been shown to increase crop yields and quality, for example cashew orchards in Ghana benefitted from a two-fold increase in yield as well as a two-fold increase in quality when beehives were placed in the fields. This resulted in a 320% increase in the farmer's annual income, when income from honey production was also taken into account (Aidoo 2014).

Indirect benefits

Less tangible, but no less important is the cultural significance of pollinators in many parts of the world (Potts *et al.* 2016). Local knowledge and traditions relating to pollinators can be extensive (Lyver *et al.* 2015) - something that should be taken into account and perhaps utilised when studying pollinators in these countries. And because up to 90% of wild plants are at least partially dependent on animal pollination (Ollerton *et al.* 2011), many important medicines, foods, building materials and fibres derived from wild plants are also at threat from pollinator declines (IPBES 2016).

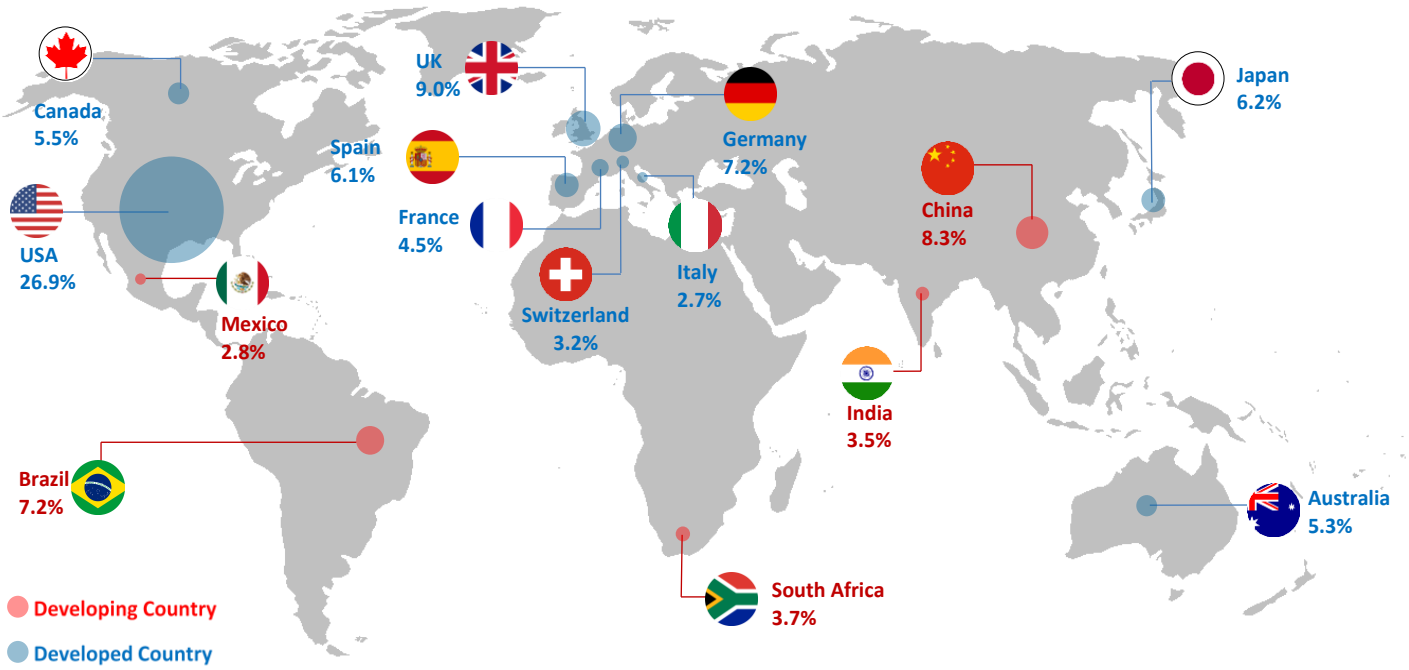


Figure 1. World map showing the top 15 countries contributing to pollination science papers between 1998 and 2018 (measured as number of papers co-authored by academics within each country). Note the imbalance between the 'Global North and South'. Source: Web of Science 2018

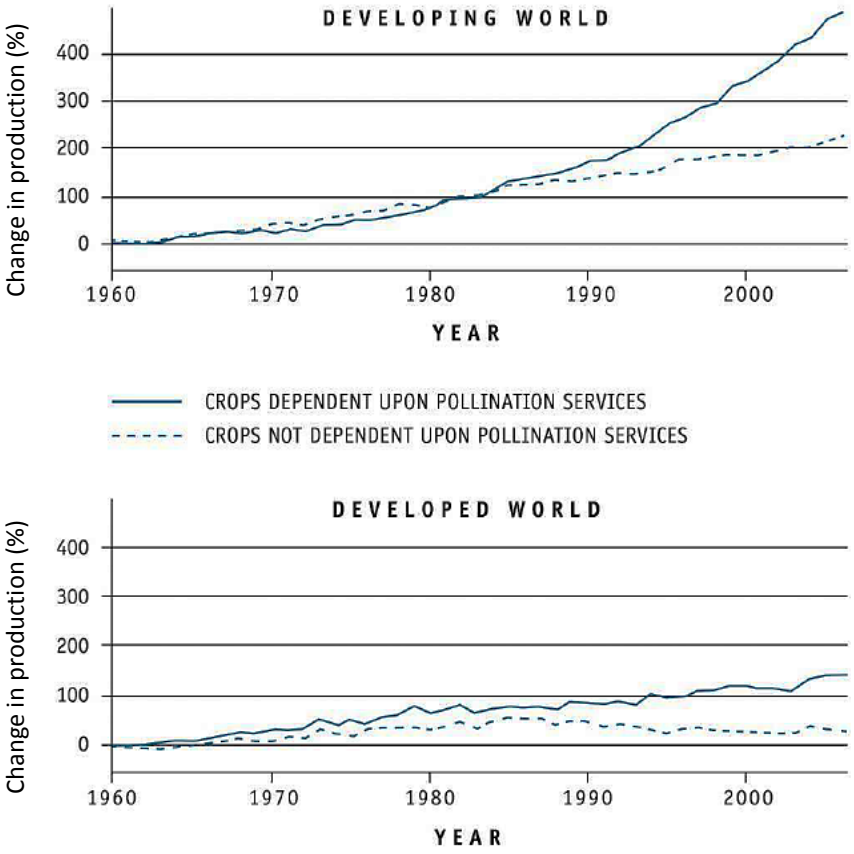


Figure 2. Temporal trends in pollinator and non-pollinator-dependent crop production in the developing world (top) and developed world (bottom) between 1961 and 2006. Production of pollinator-dependent crops in the developing world increased c. 5-fold over this period, compared with just a 1.5-fold increase in the developed world. This highlights the vulnerability of developing countries to pollinator declines. Figure from (Gemmill-Herren *et al.* 2014)

Should we be worried?

While the importance of pollinators in the developing world is clear, it is difficult to assess whether population declines are occurring in these regions. A lack of baseline data or systematic monitoring programmes on pollinator abundance and distribution in the developing world makes it difficult to determine their population trends. However from various studies showing local declines (IPBES 2016) and trends seen in parts of the developed world where many of the same threats exist, it would be sensible to assume that pollinators are also declining across other regions.

Agricultural intensification

Although agriculture is generally less intensive in the developing world (particularly Africa), with smaller fields and lower inputs of fertilizer, pesticide and mechanisation (Binswanger-Mkhize & Savastano 2017), this is likely to change. With rapidly-growing human populations and rising per-capita demands, agriculture will have to intensify, particularly in the developing world (Green *et al.* 2005). Removal of natural habitat - particularly forest which appears to be more important for pollinators in the tropics than in temperate areas – is a rapidly growing threat in these regions. In developing countries, a further 120 million hectares of natural habitat is predicted to be converted to farmland by 2050 (FAO 2009). Understanding the nature of agricultural changes and how these will effect pollinators may help mitigate some of the negative effects.

Image 1. Deforestation in Para, Brazil.
Image: Andre Penner

Pesticides and disease

The use of poor-quality generic pesticides is rapidly increasing across the developing world, particularly in sub-Saharan Africa (Popp *et al.* 2013). When coupled with limited formal regulation and training (Popp et al. 2013), this could pose a growing threat to pollinator populations in these regions. In South Africa for example, pesticide use was found to be associated with declines in floral visitors to mango plantations and a resulting decrease in fruit production (Carvalheiro *et al.* 2010; Carvalheiro *et al.* 2012).

The mass breeding and movement of managed pollinators – primarily honeybees, but also some bumblebees – around the world, has resulted in the geographic spread of disease to local pollinators, both managed and wild (Graystock *et al.* 2016). The effect that this may have on honey production and the provision of pollination services in developing countries remains unknown. While we can speculate on the threats that are likely to face pollinators in the developing world, these assumptions should be treated with caution. Threats and pollinator responses to these threats tend to be regionally dependent, making extrapolation from studies in other parts of the world difficult (De Palma *et al.* 2016). However, the high reliance on pollinator-dependent crops across the developing world suggests that many farmers and communities are vulnerable to negative impacts.

International Initiatives

There have been two major international initiatives which transcend national or regional efforts and aim to bring all the pollination research, expertise and practical efforts together in one coherent framework or report. The first is the International Initiative for the Conservation and Sustainable Use of Pollinators (also known as the International Pollinators Initiative - IPI), established in 2000 by the Convention on Biological Diversity to build greater understanding, management and conservation of pollinators around the world (see Box 1 for more details). More recently the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) delivered the comprehensive *Thematic Assessment of Pollinators, Pollination and Food Production* as its first thematic deliverable, bringing together an extensive body of research and evidence from around the world.

International Pollinator Initiative

- Established by the Convention on Biological Diversity (CBD) in 2000
- Coordinated by the FAO but with close co-operation with other relevant organisations
- Delivered a Global Pollination Project across 7 developing countries
- The IPI aims to:
  - *Monitor pollinator decline, its causes and impact on pollination services*
  - *Address the lack of taxonomic information on pollinators*
  - *Assess the economic value of pollination and the economic impact of the decline of pollination services*
  - *Promote the conservation, restoration and sustainable use of pollinator diversity in agriculture and related ecosystems*
- The CBD has recently mandated the FAO to revise and update the IPI – work which is still underway.

IPBES Pollination Assessment

- Comprehensive assessment of our state of pollination knowledge, based upon a wide body of science, as well as indigenous and local knowledge systems
- Published in 2016 after 2 years of work by 76 international experts
- Served as the first 'thematic deliverable' for IPBES
- Aims to provide policy relevant knowledge to inform decision-making
- Complements and builds upon the work of the FAO
- Focuses primarily on the relevance of pollination to food systems and human livelihoods, providing clear links to the UN's Sustainable Development Goals

The report's key findings were incorporated into the CBD at the 2016 Convention of the Parties in Cancun, Mexico, putting them into a policy-relevant framework for the 196 signatory countries.

Box 1. Summary of the two major global pollination initiatives/platforms

Generating international attention and momentum

These two major global initiatives with their substantial intellectual and political weight have generated a great deal of scientific and media attention, spring-boarding pollination into the public and political spotlight. The momentum they have generated – particularly since the publication of the IPBES report in 2016 – has led many governments to increase their engagement with these issues. National or regional pollinator initiatives have been established by a number of countries, including the developing nations of Brazil, Argentina, Colombia, South Africa and India. Building upon this momentum, a BES-Net Pollination Trialogue was held in Eastern Europe in October 2017, bringing together researchers, policy-makers and practitioners from Albania, Bosnia and Herzegovina, Georgia, Moldova and Montenegro. By engaging these diverse stakeholders in discussion, hearing their opinions and the challenges they face, these countries become far more likely to engage with the international initiatives and take action. There is scope to pilot similar trialogues in other regions such as Sub-Saharan Africa.

Reaching beyond the research sector

One of the strengths of the International Pollinator Initiative is that it is coordinated by the Food and Agriculture Organization of the United Nations (FAO). As an intergovernmental agricultural organisation, the FAO has long-standing relationships with agricultural research and training institutes, politicians and farmers across the world. This allows the IPI to include the agricultural sector and high-level decision-makers in its projects and discussions. In this way, pollination and other agro-ecological principles can be brought to more traditional audiences who have the greatest potential to deliver changes on a large scale. Many of the outputs from the IPI have reflected this, focusing on practical agricultural aspects of pollination, for example a manual on apple pollination, a risk assessment of pesticides to pollinators and a handbook for detecting crop pollination deficits.

Expanding research to an international scale

An important role of the IPI is to coordinate and galvanise funding for large international projects which go a step beyond isolated local studies. With such a scaled-up and joined-up approach, meaningful comparisons between different regions and crop types become possible and one can start identifying some universal patterns. By putting local results in a global context, such studies can deliver powerful recommendations to policy-makers and practitioners. An example of this was the GEF-funded Global Pollination Project coordinated by the FAO. The project developed a protocol to monitor pollinators and their role in crop production at regional, national, or international scales. By assisting partner organizations in South Africa, Nepal, Pakistan, Kenya and Ghana to apply the protocol, and analyse their results, the study generated large-scale, inter-comparable findings. This led to a range of high-impact publications e.g. Garibaldi *et al.* (2016) and practical documents which may not have been possible for each of the partners working alone.

The future

The various outcomes of this Global Environment Facility (GEF)-funded project and the publication of the IPBES Pollination report have brought about a renewed interest in pollination. This has led the Convention on Biological Diversity to call for a new plan of action for the IPI which will be presented for approval at the meeting of the Subsidiary Body on Scientific, Technical and Technological Advice in July 2018. The new plan is likely to move beyond knowledge generation, focusing more closely on the management and implementation of pollinator-friendly practices and incorporating knowledge and recommendations into a policy-relevant framework. Because neither farmers nor policy-makers manage for pollinators in isolation, the updated IPI is likely to take a more holistic view of pollination. One in which pollination is viewed as just one important part of a broader suite of agro-ecological principles which need to be addressed together. It is will also expand its focus beyond agricultural settlings and food production to include the value of pollination in natural ecosystems.

Development research opportunities

There are a number of important contextual differences between pollination and agriculture in the developed and developing worlds. This makes it difficult to apply what has been learnt from studies in Europe and North America to the rest of the world, but also provides a number of research opportunities to discover what works in Low and Middle Income Countries (LMIC).

Firstly, farming differs greatly in terms of style and scale. More than 2 billion people in developing countries are smallholders (farming areas <2ha in size), representing 83% of the global agricultural population (Lowder *et al.* 2014; Steward *et al.* 2014). This scale of farming is largely neglected in the pollination literature (Steward *et al.* 2014), despite being relied upon by a majority of people in

developing countries and producing around half of the world's food (Herrero *et al.* 2010). The yield gaps (unfulfilled potential for yield increases) in these smallholder farming systems are generally large, as a result of few agricultural inputs and limited education. This provides a lot of scope for ecological intensification (Gemmill-Herren *et al.* 2014) (Box 2).

Box 2. Ecological intensification

This is the process of increasing crop yields and farmers' livelihoods through optimal management of natural ecological functions and biodiversity, rather than chemical and technological inputs.

It involves understanding and managing processes such as pollination, nutrient cycling and biological pest control to improve agricultural performance. Unlike traditional intensification, ecological intensification doesn't require large financial investment and is therefore accessible to smallholder farmers. It simply requires the education of farmers, allowing them to understand and manage the ecological processes operating on their farms. There is evidence that this form of intensification can be effective in certain farming systems.

A large scale study examining a range of crop types across 11 countries found that on smallholder farms (<2ha), an increased pollinator density could result in 24% higher yields for pollinator-dependent crops (Garibaldi *et al.* 2016). Another study found that in Burkina Faso, pollination by wild bees and honey bees increased yields of the important cash crops cotton and sesame by 62% (Stein *et al.* 2017).

It is worth noting however that while pollination is an important process to manage, it is just one component of a broader suite of agricultural approaches. These include practices such as integrated pest management, nutrient cycling, precision farming and plant breeding which should all be tackled together to have optimal benefits for crop yields and farmer livelihoods. It is important that researchers and practitioners engage with the complexity of opportunities and challenges in-country if they are to influence mainstream agricultural thinking so that pollinator management is successful and sustainable.

Research into sustainable beekeeping practices, honey and wax production and markets for these products may also offer a range of development opportunities. Particularly as beekeeping becomes an increasingly common component of sustainable development programmes. In these programmes, free natural resources such as wild flowers and native bees can be utilised to generate income and livelihoods with minimal infrastructure or investment. Organisations such as Bees Abroad and Bees for Development UK disseminate relevant beekeeping research through education programmes, training manuals and a dedicated journal. Establishing this link between academic research and practical development programmes is an important way of ensuring research is having optimal development outcomes.

Knowledge Gap Priorities

Gaps in our understanding of pollinators, pollination and the ways in which we can conserve them provide a fundamental barrier to ensuring they can provide the maximum benefit to developing communities. Filling these knowledge gaps will therefore provide some progress towards addressing the UN Sustainable Development Goals.

In response to a request by the Convention on Biological Diversity, a Global Pollination Workshop was held at Reading University in November 2017 to assess global risks to pollinators. Led by Simon Potts, this brought together a regionally-balanced selection of pollination researchers from around the world to discuss knowledge gaps and quantify expert opinion at a regional scale. The primary objectives were to: assess the role of pollinators in natural ecosystems and their services beyond food production; assess the status and trends of pollinators around the world and drivers of change; and identify knowledge gaps across all these areas. The outputs were a global risk assessment for pollinator loss (to be published in late 2018) and a report on "Pollinators beyond agriculture" for the CBD. Work such as this highlights areas which are in urgent need of more information and goes some way towards describing regional variation in results and knowledge.

Below are a series of primary knowledge gaps identified from the literature and from talking to experts in the field. These are fundamental gaps in our knowledge which require further research, monitoring or capacity building to address. Many of them will take at least 5-10 years to achieve, so it would be beneficial to deliver some shorter-term solutions to start tackling the issues immediately. This could include taking lessons from existing research to identify universal patterns and shortcuts to pollinator research, conservation and management. The longer-term bottom-up approach of knowledge generation and capacity building could be run alongside the top-down approach of using existing work to directly inform policy and management. Ideally the outcomes from both processes would feed into each other, influencing each other's direction. Figure 3 on page 15 is a schematic diagram showing the inter-dependent pathway of knowledge generation in this field and some of the shortcuts that could be taken.

Pollinator taxonomy

One of the areas in which knowledge and capacity is most urgently needed is the taxonomy of wild pollinators (e.g. bees, moths, flies etc.) in the developing world, particularly Africa. Good taxonomy underlies most pollination science studies and therefore a lack of capacity in this field provides a fundamental barrier to progress. In theory it is possible to partially circumvent this issue in research studies by classifying flower visitors into broad functional groups such as bees, flies and moths. However, this makes it difficult to compare study results between regions and deliver targeted management recommendations. Not all species within a functional group act in the same way, many only visit certain crop types and some are not even pollinators.

Image 2. Museum specimens showing remarkable diversity of the world's bees. Image: Oxford Natural History Museum

It is important that pollinator taxonomists in developing regions of the world are provided with a framework in which to pass on their knowledge to individuals in these regions. Successful work on this has been done in Kenya where a number of pollinator taxonomists and parataxonomists were trained by specialist taxonomists through a series of courses and workshops. This was joint initiative by the National Museums of Kenya, the International Centre of Insect Physiology and Ecology (ICIPE) and The Royal Museum for Central Africa, Belgium. Building widespread capacity in taxonomy raises the scientific value of institutions hosting this expertise, as well as benefitting the individuals involved. One Kenyan student trained in pollinator taxonomy through the Belgian Global Taxonomy Initiative has since completed a PhD and gone on to successfully educate Kenyan farmers in sustainable farming practises through social media platforms.

Research question examples:

- How can molecular techniques such as DNA barcoding be used to aid the identification of pollinator taxa in understudied regions? And what traditional taxonomy work remains to be done before these techniques become effective?
- Prior to this, how can we balance detailed taxonomic knowledge with affordable methods such as functional group classification, to understand pollination services and how to maximise them?

Baseline data on abundance, distribution and ecology of pollinator species

Across most of the developing world, there is limited formal knowledge of the distribution and abundance of important crop pollinators and little historical monitoring. This makes it difficult to assess population trends and forces us to draw extrapolations from trends in a handful of developed countries. Establishing a globally-coordinated and regionally-balanced monitoring programme for key pollinator groups would be beneficial, though it will take at least a few years for trends to become apparent. Understanding the basic biology of pollinators in these regions will provide an important starting point for designing schemes to conserve them and manage their services. This may include the plants they interact with, the nesting resources they require and which periods of the year they are active. The JRS Foundation in the US fund a number of projects focusing on topics such as these, through their annual funding calls for research on Pollinator Biodiversity & Services in Africa.

Research question examples:

- What is the abundance, distribution and basic life history of dominant crop pollinators in less-studied regions such as Africa?
- What options are available for assessing pollinator trends in the absence of baseline datasets or monitoring programmes? For example, utilising records from amateur entomologists or museum collections. Or using proxies for biomass changes such as the 'windshield phenomenon'.
- How can monitoring programmes be designed to assess pollinator population trends in the shortest possible time, while remaining cost effective?
- What is the scope for using citizen science to assess pollination in developing countries?

Threats facing pollinators in the developing world

A pre-requisite to pollinator conservation is recognising the threats they are facing and how these can be minimised. Many of the major threats identified in Europe and North America, such as habitat loss, pesticide exposure and disease - largely driven by agricultural intensification - are also present across the developing world and likely to increase (Green *et al.* 2005). As such, further research into the nature of these threats and how they might be managed, would be beneficial.

Research question examples:

- How is the largely unregulated use of low quality pesticides (Popp *et al.* 2013) affecting pollinators in developing countries?
- Which habitats are being lost most rapidly across the developing world and how important are these to pollinators?
- Are the diseases which have harmed wild and managed pollinators across much of the developed world also a threat in the developing world?

Pollinator dependence of different crops

It is well established that many important crops grown in the developing world are pollinator dependent, for example coffee, cocoa, cashews, mangoes, apples etc. Comprehensive bodies of information such as the Pollination Directory for World Crops (Crane & Walker 1984) list the mechanism and agents of pollination for a number of world crops, as well as recommendations for ensuring adequate pollination. However, the extent of pollinator reliance – i.e. the degree to which yield or quality reduces in the absence of pollination – is often not clear. It is also likely to vary between cultivars, regions and agricultural conditions. A number of lesser-known but highly important crop types may not have been assessed for their pollinator dependence. Establishing the economic value of pollination services under different scenarios would allow farmers to make more informed decisions about how they manage pollination.

Research question examples:

- Which crops are most vulnerable to pollinator declines and how does this vary between regions and cultivars?
- What is the economic value of the service provided by pollinators to different crops and how does it compare with the cost of managing for the service?
- Are there trade-offs between managing farmland for maximum productivity and managing for pollination services? And if so, how can this be most effectively balanced by farmers?
- What are the most effective strategies for communicating to farmers the importance of pollination and how to balance this with other agricultural demands?

Extent of pollination deficits and their causes

Significant pollination deficits (loss of yield or quality as a result of inadequate pollination) have been recorded in a few parts of the developing world, across a handful of crop types e.g. Garibaldi *et al.* (2016) and Samnegard *et al.* (2016). However, it is still not clear how widespread these deficits are, or often what is causing them. It is also not clear whether insufficient pollination fundamentally changes the nutrient content of a crop, which might have further implications for human health.

Research question examples:

- How widespread are pollination deficits across different crops and regions?
- What are the primary factors driving pollination deficits? For example, is it a lack of any pollinators, is it a lack of the most appropriate pollinators, or are the pollinators present but simply not visiting the focal crop?
- Are there cost-effective agricultural practices (e.g. hand fertilisation, plant-breeding) which could be employed to reduce pollination deficits?
- Can inadequate pollination change the nutritional quality of a crop product, for example reducing its micronutrient content as well as its yield?

Image 3. Insufficient pollination by insects can result in loss of yield and quality in crops such as strawberries

Managing for wild pollinator service provisioning

Whilst the importance of wild pollinator services has been well-established, specific agricultural management practises for maximising these services have yet to be explored and implemented in many parts of the world. A number of ecologically-informed management options for sustaining and enhancing pollination services in agroecosystems are presented in a comprehensive book entitled 'Pollination Services to Agriculture' (Gemmill-Herren 2016). However, because management strategies may vary depending on crop type, ecological setting and agricultural practises, we suggest this work be done on a region-by-region and crop-by-crop basis. Particularly in the developing world, where there may be more scope for ecological intensification.

Research question examples:

- What role do natural and semi-natural habitats play in maintaining pollination services?
- Which local flower and nesting resources can best support wild pollinators?
- What management practices can be employed to attract wild pollinators to a focal crop?
- How can farmers ensure better synchrony between crop flowering times and peaks of local pollinator abundance?
- Which general principles can we draw from studies in other regions of the world and apply universally? For example that diversified farming systems host larger pollinator populations (Kennedy *et al.* 2013) or that pollination services increase with proximity to natural habitat (Ricketts *et al.* 2008).
- From a development perspective, what works to support and train farmers to understand and manage pollination services?

Using managed pollinators

Managed pollinators can be used to supplement natural crop pollination and increase yields. Certain species can also be used to generate income through beekeeping. In many cases, the traditions surrounding beekeeping and honey-hunting have important cultural significance for local communities. Targeted academic research in these areas may be valuable in informing education and development programmes. This should include understanding and learning from existing local knowledge which can be extensive in many cases (Lyver *et al.* 2015).

Research question examples:

- How can beekeeping practices be optimised to deliver the dual benefits of honey production and effective crop pollination?
- Which managed pollinators (e.g. honey bees, bumblebees, and stingless bees) are most effective and productive in different regions and agricultural scenarios?
- When can native bees be used in place of domestic species and what are the advantages of this?
- What local management practices support the productivity of managed beehives?
- What low-cost and locally-available options are available for managing and treating disease in managed colonies?
- What management and marketing practices for beekeeping products can improve access to markets for rural communities in developing countries?
- How can existing local knowledge and cultural practices surrounding pollination and beekeeping be integrated with more modern, scientifically-informed approaches?

Regional dietary information

Human nutrient intake data is currently only available at a fairly coarse scale, often averaged out at a national level and lacking specific nutritional information on many important foods (Smith *et al.* 2015). This may conceal important local variation in human diets. In order to better understand the

effects that pollinator declines will have on human health and livelihoods, it is necessary to understand human nutrient intake at a local level. We also need to know exactly which foods these nutrients are coming from. Only then will researchers be able to accurately predict the local dietary changes that communities will experience and propose how to minimise any negative effects.

Research question examples:

- How can data on food consumption be gathered most effectively at a local scale? And how can this be used to model nutrient intake at a high resolution?
- How can we predict the changes in local diets that are likely to occur as a result of rising wealth and agricultural intensification in many developing countries?
- Which crops will bring about the greatest changes in human nutrient intake under the scenario of pollination declines?
- How much local variation will there be in human dietary changes as a result of pollination declines?

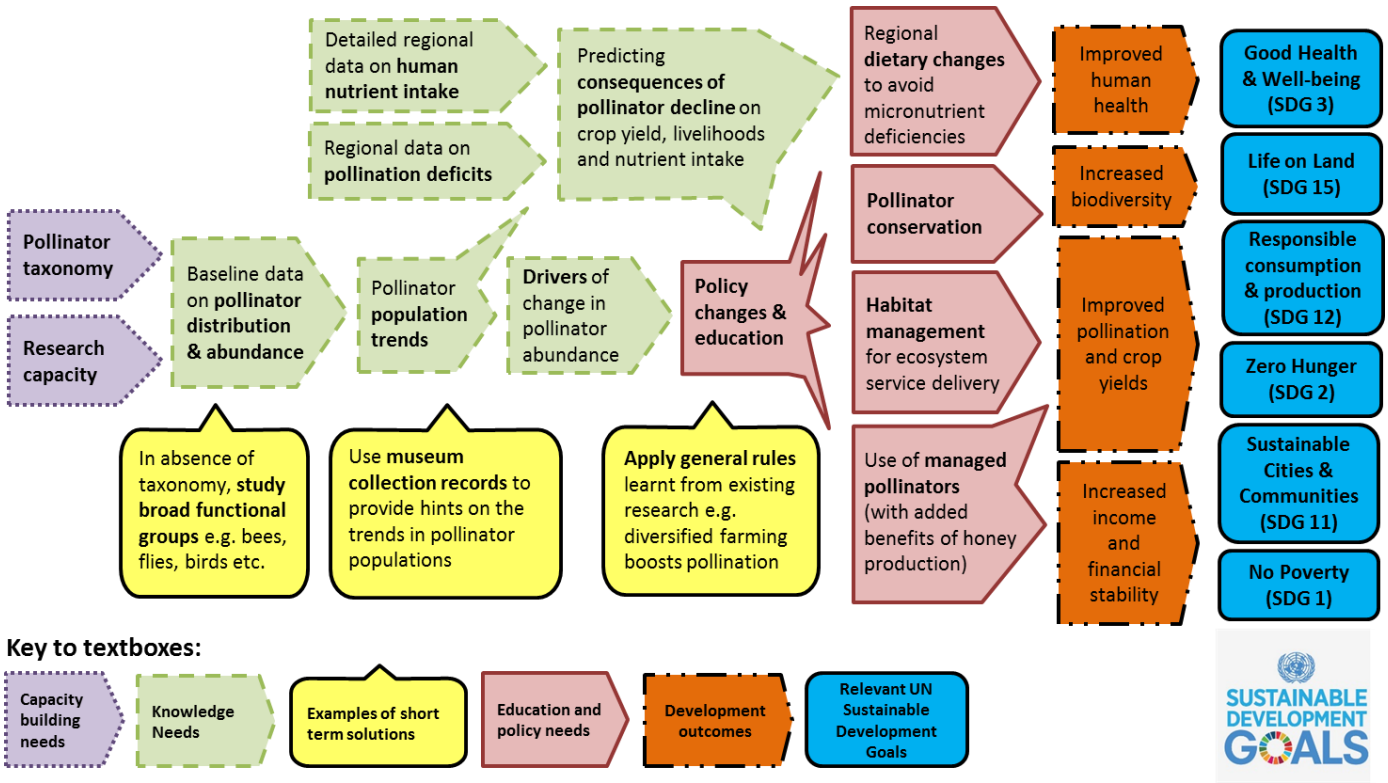


Figure 3: Schematic diagram of key knowledge and capacity needs in pollination research and the process by which addressing these can lead to improved development outcomes. This includes progress towards the UN Sustainable Development Goals (shown in blue).

Building and Strengthening Capacity

Institutional Capacity

A consistent issue raised by consultees as a barrier to research or delivery of pollination science in developing countries is limited institutional capacity. Without strong, well-resourced in-country institutions, it is difficult to attract funding and establish projects or collaborations with successful scientific and practical outcomes. In-country institutions are particularly important in delivering longer term outputs such as education, conservation and community engagement which ensure the legacy of the project.

Long-term core funding from countries such as the UK may help strengthen capacity, ensuring institutions are able to transcend short-term project funding. This may help retain human capacity and deliver longer-term outputs. Strong research partnerships, including 'North-South partnerships' (between developed and developing countries), can also strengthen capacity. However, it is important that these are long-term and equitable. The agenda should be driven by both parties, with complementary skills and knowledge identified and valued, and the outcomes benefitting both. A UKCDS report published in 2017 outlines a number of ways in which academics and funders can help ensure fair partnerships.

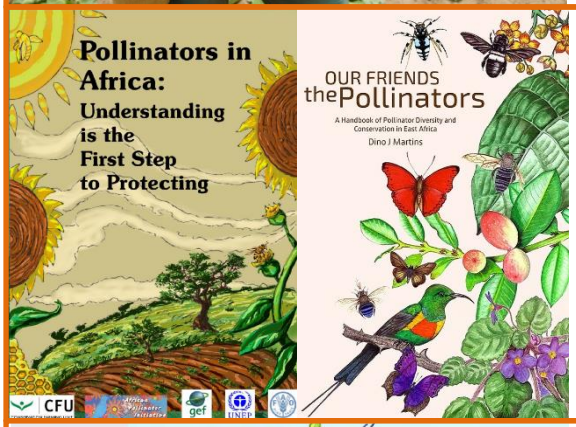
Individual Capacity – farmers and the general public

In order to understand and manage pollination more effectively, human capacity can be strengthened at various different levels, including farmers, extension workers, researchers and the general public.

Understanding of the process of pollination amongst farmers in developing countries is variable but generally low, with many farmers perceiving all insects as pests (M. Lattorff 2017, personal communication, 16 November). As long as this is the case, any policy requiring farmers to manage their land to support insects – for example by reducing pesticide application or leaving areas of wildflowers – is likely to be ineffectual. Given the reliance of many farmers upon successful pollination, basic education on the process of pollination and how to manage for increased pollination services, would be beneficial. Across the world, most agricultural institutions and training schemes prioritise traditional high-input agronomic practices over agro-ecological processes such as pollination, nutrient cycling and biological pest control. While these alternative approaches may not be effective or optimal in all cases, considering them alongside high-input practices may provide a number of benefits to farmers. To get these topics incorporated into mainstream agricultural training and policy may require pollination and agro-ecological researchers to work more closely alongside the traditional agricultural sector.

This represents an opportunity for the International Pollinator Initiative (IPI) in their next phase of work, to focus more heavily on mainstreaming the concept of ecological intensification. There is already a fair amount of existing knowledge and expertise in agro-ecological techniques which is likely to increase in the future. If this could be incorporated into the training of farmers, extension workers and the general public, individuals could make informed decisions about when to utilise these techniques. This process of public engagement can take place in a variety of ways (Box 3). For all of this to be effective however, initiatives such as the IPI will need to engage the agricultural sector (e.g. agri-business, agri-development NGOs and national training institutes), as well as researchers. Bodies such as the FAO may be able to put some of these agro-ecological principles at the heart of their extension work. There may also be scope to work alongside large charitable organisations such as Alliance for a Green Revolution in Africa (AGRA) which aim to tackle food insecurity and move countries towards sustainable and climate-friendly green agriculture.

The Farmer Field School (FFS) approach, first developed by the FAO, provides a successful model for teaching farmers about agroecological techniques. Local extension workers, farmers or NGO workers are trained up as FFS facilitators to run basic agro-ecological field trials with the local farming community. In this way, farmers can experiment with new methods in a risk-free environment and learn alternative farming techniques.
Image: FAO/ Olivier Asselin



Colourful and accessible published resources such as 'Pollinators in Africa' (Mayes 2011) and 'Our Friends the Pollinators' (Martins 2014) (downloaded over 7000 times and used by 150 000 farmers) provide an effective way of raising awareness amongst farmers and the general public.
With so few farmers in the developing world understanding the process of pollination, these can provide a very good starting point for learning the value of pollinators

With growing access to smart phones and internet, even in rural areas, online platforms such as Mkulima Young in Kenya can provide an effective way of instantly engaging rural farmers and sharing successful techniques. These sorts of channels can effectively complement the more top-down approach of organisations such as AGRA and FAO.

Box 3. A selection of different channels for engaging and educating farmers and the general public. These range from more traditional training programmes all the way through to social media platforms

Individual Capacity – researchers

In order to deliver education programmes to farmers and the general public, it is important that the information underlying these programmes is based on rigorous and locally-relevant science. This requires strong local researcher capacity. To have optimal development outcomes, it is also important that some pollination researchers are working within agricultural departments or institutes (rather than purely ecological ones). This will ensure their work is as relevant as possible to agriculture and is reaching the ultimate end users – farmers, extension workers and agricultural policy-makers.

Dedicated PhD or masters funding streams which target students from priority regions can go some way to building this much-needed capacity. For example ICIPE in Kenya, in association with the German Academic Exchange Service, is currently advertising 12 fully funded PhD projects in insect-related sciences for development (including 3 in pollination). These target students from relevant parts of Sub-Saharan Africa, providing them with the skills to compete in the international research

environment as well as generating useful science. One caveat with this approach is that individuals who develop appropriate technical expertise, for example through a PhD, are often quickly promoted out of these technical roles, losing the ability to utilise these skills. A similar issue occurs when highly qualified individuals move to better paid, but often less relevant positions in other regions where they may no longer contribute technical expertise to their country of origin.

Building networks

Promoting strong international networks between researchers across the globe may reduce the effects of 'human capital flight'. In particular, North-South partnerships can provide developing country researchers with increased exposure to funding sources, international literature and expertise. With improved access to foreign funding and scientific networks, researchers are better able to conduct world-class research, including for the benefit of their own country. An example of an international collaboration giving rise to world-class research and building valuable capacity is shown in box 4.

Regional networks involving a range of individuals and institutions are also beneficial for consolidating knowledge and making links between sectors with mutual interests. For example bee-keepers, farmers, researchers and policy-makers. The International Pollinator Initiative has gone some way towards achieving this by creating regional networks such as the African Pollinator

Box 4: Case Study – building capacity through a global pollination study

Measuring the importance of crop pollination in a standardised way is no easy task. However, the FAO and Institut National de la Agronomique in France have worked together with the Norwegian Directorate of Nature Management to develop a simple protocol to identify and assess pollination deficits (loss of yield as a result of inadequate pollination) (Vaissière *et al.* 2010). National research partners from various developing countries were trained in these protocols and applied them across 11 developing countries on 33 pollinator-dependent crop systems.

Drawing general conclusions from these local studies is difficult, but a 'working workshop' held in São Paulo, Brazil in 2013 brought together researchers from various developing countries involved in this study, to train them in analytical techniques and work together on meta-analysing the datasets.

The Results?

- Yield gaps as a result of pollination deficits are large and widespread across different continents and crop types.
- The benefits of pollinator density to crop yields are greater for smaller than for larger farms
- On smallholder farms (<2ha), higher pollinator densities could close yield gaps by 24%. But on larger farms, these benefits only occurred at higher pollinator richness.

The outputs?

- **A high-profile paper published in *Science* *(Garibaldi et al. 2016)***
- **Valuable capacity building in fieldwork protocols and analytical techniques**
- **International collaborations formed.**

Participants in the FAO-sponsored expert workshop on *Assessing Pollination Deficits in Crops*

Initiative and the Oceania Pollinator Initiative. These bring local researchers and practitioners together, helping to coordinate regional activities. A recent BES-Net trialogue event in Sarajevo went a step further by bringing together 60 policy-makers, scientists and practitioners from five developing eastern European countries to discuss Pollinators, Food Security and Rural Development. These networks only function however when all individuals stand to benefit from them and often require active interventions to drive them forward (P. Heylings 2018, personal communication, 26 January).

Policy-making Capacity

In many countries, a consistent policy framework for translating the wide body of research and management recommendations into national policy is lacking. Although a number of countries have contributed to the IPBES pollination assessment and are signatories to the CBD, both are non-policy-prescriptive, meaning that national governments have to devise specific policy themselves. Eleven countries around the world have developed a national pollinator strategy, with five more in development. These include a handful of developing countries: Brazil, Argentina, Colombia, South Africa and India. A follow-up paper from the 2016 IPBES Pollination Assessment lists ten simple policy recommendations for safeguarding pollination services (Box 5) which policy-makers can follow (Dicks *et al.* 2016).

Although it doesn't prescribe details on how each of these goals can be achieved, this sort of document provides a good framework into which local researchers and technical advisors can insert more locally-relevant recommendations. Of course political will is required to drive this forward, but this can evolve in a variety of ways, including through public awareness and pressure. In South Africa for example, a growing public interest in pollinators, through photography, social media and citizen science has increased civic and political engagement with these issues (C. Eardley 2018, personal communication, 26 January).

Box 5: Ten pollinator policies

From Dicks *et al.* (2016)

1. Raise pesticide regulatory standards.
2. Promote integrated pest management (IPM).
3. Include indirect and sublethal effects in GM crop risk assessments.
4. Regulate movement of managed pollinators.
5. Develop incentives, such as insurance schemes, to help farmers benefit from ecosystem services instead of agrochemicals.
6. Recognize pollination as an agricultural input in extension services.
7. Support diversified farming systems.
8. Conserve and restore "green infrastructure" (a network of habitats that pollinators can move between) in agricultural and urban landscapes.
9. Develop long-term monitoring of pollinators and pollination.
10. Fund participatory research on improving yields in organic, diversified, and ecologically intensified farming.

UK's Contribution

Through its role as a centre of excellence for pollination science and a leading funder of pollination research, the UK has a great deal to offer in this field. Here we outline some of the ways in which the UK contributes to this field and how these may be built upon. In particular, the ways in which pollination research can be made more relevant to addressing the UN's Sustainable Development Goals of 'No Poverty', 'Zero Hunger', 'Good Health and Well-Being', 'Sustainable Cities and Communities', 'Responsible Consumption and Production' and 'Life on Land'.

Delivery of high-quality scientific research

Researchers from the UK have contributed to 9% of all pollination publications from 1998-2018 (Web of Science, 2018), making it the second largest contributor after the United States, with 27%

(Figure 1). When we consider only highly cited pollination publications (top 1% most cited papers in this field), the UK contribution rises to 38%, demonstrating the high standard of this work.

Of all the pollination science papers with UK involvement, c.18% mention a developing country or region in their title or abstract; or have direct relevance to international development (Web of Science 1998-2018). This highlights an area in which the UK could potentially expand its focus. With targeted funding incentives, UK pollination science could be extended further in the developing world and made more relevant to addressing development challenges. For example the UK Centre for Ecology and Hydrology, in response to funding changes, is expanding their traditionally UK-focused research to various parts of the developing world through a programme known as SUNRISE (Sustainable Use of Natural Resources to Improve Human Health and Support Economic Development). Changes such as these may help reduce the geographic knowledge bias in pollination science and contribute to addressing the UN Sustainable Development Goals. To be effective and ethical however, this research should be conducted in close collaboration with, and for the benefit of, partners in developing countries.

Funding

The UK contributes 18% of the international funding for pollination science projects, the largest national contribution after the United States (Figure 4). Approximately 6% of this UK funding is estimated to involve work in developing countries or have direct relevance to international development (ÜberResearch 2018). With the recent changes in the UK's science funding landscape and a lot more funding directly available to universities through the Official Development Assistance (ODA) budget, this may change. There is a shift in emphasis towards research that directly contributes towards international development. Programmes such as the Global Challenges Research Fund (GCRF) and Newton Fund have both been recently established to fund UK research that tackles challenges faced by developing countries. With the relevance of pollination and agro-ecology to addressing the UN's Sustainable Development Goals, these topics may fit into this new funding landscape.

Collaboration and capacity building

The UK research community engages in a number of collaborative projects with researchers in developing countries. Such 'North-South' partnerships can benefit international science by addressing the regional imbalance in knowledge between the Global North and South and allowing researchers to work on new systems. They may deliver funding and expertise to countries historically lacking these, building valuable research capacity. The scientific outputs are also likely to be more relevant to international development. However, when it comes to pollination science, it would be beneficial if these partnerships include not only university researchers, but also agricultural institutes, development NGOs and the private sector who all have a stake in this field. Partners and institutions in developing countries must always stand to benefit from these collaborations.

Bureaucracy in both partner countries has been identified as an obstacle to progress by consultees of this project, often slowing down project delivery and wasting research funds. Long-standing collaborations built from personal relationships may reduce this issue by speeding up the bureaucratic navigation. This also helps ensure the most appropriate people from both countries are working together on a project. International researcher networks and events such as the BES-Net Trialogues and GCRF's Global Engagement Meetings can foster these links by bringing researchers from across the world together to showcase research and meet potential collaborators. An important component of such collaborations is an understanding by funders and researchers in both countries of what constitutes a fair research partnership.

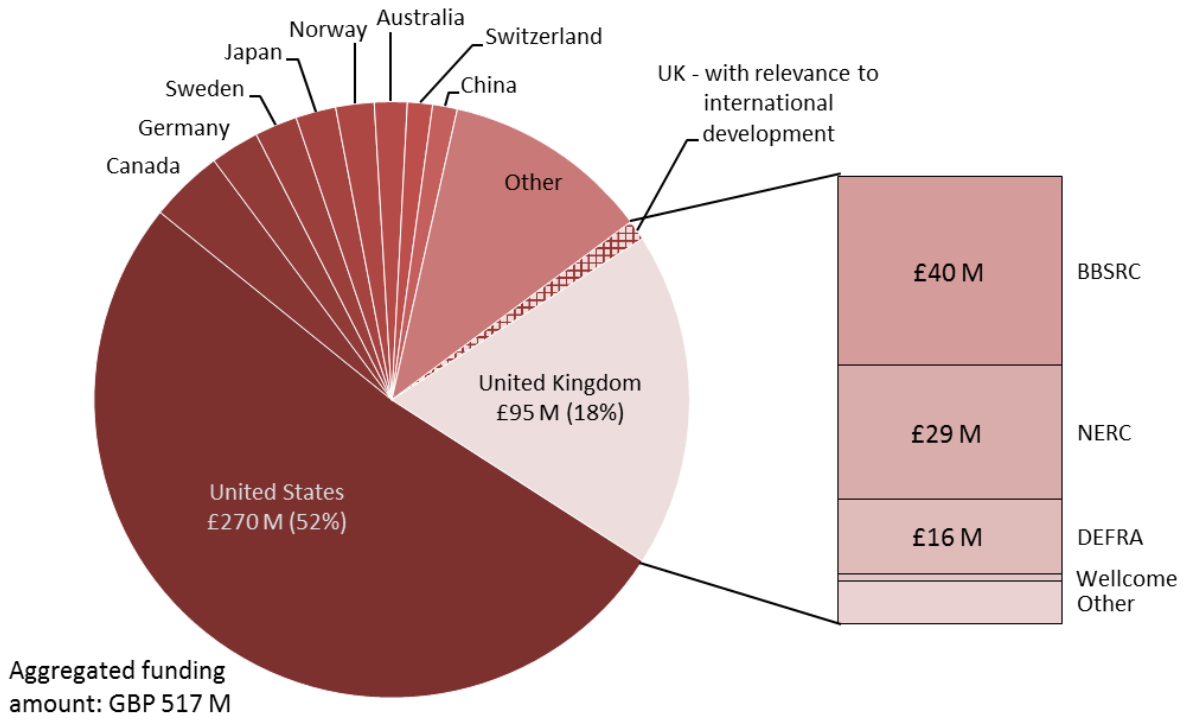


Figure 4. National funding contributions for global pollination research from 2008-2018. For the UK, contributions from individual funding bodies are shown, as well as the proportion of funding allocated to projects with relevance to international development. Source: ÜberResearch 2018. N.B. Some funding streams (e.g. those from DFID) are not included in the ÜberResearch database.

Conclusion

Pollinator declines have the potential to impact upon the food production, livelihoods, health and cultural traditions of communities in developing countries. However, pollination research from a range of disciplines may offer ways of mitigating some of these negative effects and providing a number of development opportunities. For this to be effective, there must be dialogue between researchers from different academic disciplines and regions, as well as with practitioners from the development, conservation, beekeeping and agricultural sectors. This will allow the relevant information to reach those who are able to apply it on the ground, while also ensuring the knowledge needs of practitioners are able to inform future research.

International bodies such as IPBES, CBD, FAO and BES-Net have engaged with many of these challenges and fostered a great deal of political, public and scientific interest in pollination. A number of opportunities are available to build upon this momentum and use academic research to inform on-the-ground initiatives such as farmer training and development projects. However, barriers to achieving this include a strong geographic knowledge bias in pollination research, a number of important knowledge gaps and limited research capacity across many regions. A key challenge for the UK research and development community will be to identify these knowledge and capacity needs and establish the most effective ways in which UK expertise, funding and institutions can contribute to addressing them. Effectively tackling these challenges can provide progress towards the UN Sustainable Development Goals of 'No Poverty', 'Zero Hunger', 'Good Health and Well-Being', 'Sustainable Cities and Communities', 'Responsible Consumption and Production' and 'Life on Land'.

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