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Item 17 of the provisional agenda*

REGIONAL REPORT FOR AFRICA ON POLLINATORS AND POLLINATION AND FOOD PRODUCTION

Note by the Executive Secretary

1. The Executive Secretary hereby provides, for the information of participants in the thirteenth meeting of the Conference of the Parties to the Convention on Biological Diversity, the Regional Report for Africa on Pollinators and Pollination and Food Production. The report was commissioned by the Executive Secretary in response to recommendation XX/9 of the Subsidiary Body on Scientific, Technical and Technological Advice, with contributions by experts from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, the Food and Agriculture Organization of the United Nations and the Secretariat of the Convention on Biological Diversity.

2. An earlier draft of the report was made available for peer review from 24 October to 13 November 2016. Review comments were received from Cameroon on behalf of a group of Central African countries, Oman, Zambia, the United States of America, the Universidad Nacional de Colombia, one independent environmental technical writer and researcher and Vera Fonseca, co-chair of the IPBES thematic assessment on pollinators, pollination and food production, as well as from several authors from Africa involved in the IPBES assessment: Colleen Seymour, Mary Gikungu, Connal Eardley and Thomas Aneni.

* UNEP/CBD/COP/13/1.

THE REGIONAL REPORT FOR AFRICA ON POLLINATORS, POLLINATION AND FOOD PRODUCTION

Executive Summary

This report, drawing on both the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) assessment and relevant work under the Food and Agriculture Organization of the United Nations (FAO)-coordinated International Pollinators Initiative from 2000 to the present, highlights the state of knowledge of animal pollination in the Africa region as a regulating service that underpins food production. It was prepared in response to the SBSTTA 20, Recommendation XX/9 paragraph 4, "to prepare a regional report for Africa on pollinators and pollination… and make the findings available for peer review prior to the thirteenth meeting of the Conference of the Parties."

The first three sections of the report follow the structure of the IPBES thematic assessment on pollinators, pollination and food production (i.e. (1) Values of pollinators and pollination in Africa; (2) Status and trends in pollinators and pollination in Africa and (3) Drivers of change, risks and opportunities and policy and management options. A fourth section, on Knowledge gaps, priority capacity building and research areas for Africa, is provided as a contribution to the two subsequent requests of SBSTTA recommendation XX/9, paragraph 12, to address data gaps and capacity for monitoring the status and trends of pollinators and pollination in developing countries, in particular Africa; and to identify and develop proposals for strengthening capacity related to pollinators and pollination, and supplementary regional assessments, in particular for Africa.

Values of Pollinators and Pollination in Africa: The high dependence of natural ecosystems, and particularly tropical ecosystems is highlighted along with the dearth of knowledge on these dynamics from the African continent. The many unique pollination syndromes found throughout African ecosystems are featured, along with the counterintuitive aspects of pollination and pollinators in Africa. The substantial contribution of pollination services to production, food security and nutrition in Africa is profiled, including the importance of many indigenous and agroforestry crops that do not enter into global crop commodity databases, and are often pollinator-dependent. Global studies, drawing on observations made in Africa and elsewhere, have documented the strong contribution of wild pollinators in crop production, and point to the important role of diversity in crop pollinator assemblages. Economic valuation of pollination services in Africa point to critical values in several regions (particularly North and West Africa), while subnational assessments in Kenya indicate that up to 40% of annual value of crops under consideration represented the net returns derived from bee pollination, and 99% of this could be attributed to wild pollinators. Other values of pollinators are important within Africa, serving as a source of multiple benefits contributing to medicines, biofuels, fibres, construction materials, musical instruments, arts and crafts and as sources of inspiration for art, music, literature, religion, technology, and biodiversity conservation.

Status and Trends of pollinators and pollination in Africa: To date, there has been no comprehensive assessment of the status and trends of pollinators and pollination services in Africa. Studies on natural systems within South Africa have shown the negative effects of habitat fragmentation on plant–pollinator interactions within the agricultural matrix. Such detailed information on trends is largely missing for the remainder of the continent. Amongst wild pollinators, the availability of resources such as nectar plants have been shown to have significant impacts on bird pollinator species. While there are inherent difficulties in determining trends in the number of honey bee colonies within Africa, known

threats to managed pollinators in South Africa and Kenya are presented. Indigenous knowledge on the status and trends of stingless bees indicates declining trends as well. Historical records of pollination of an orchid in South Africa indicated that pollination rates one hundred years ago were many times higher than current rates from the same location. Such trends need to be placed in the context of a recognized greatly increased demand for crop pollinators in developing countries, including the continent of Africa.

Drivers and Response: Drivers for pollinator trends are not well documented within Africa, although land use change - including habitat fragmentation and habitat isolation - land management practices, agricultural pesticides, chemical fertilizers, tillage practices, and the pests of both wild and managed bees in an African context are discussed. Indirect drivers such as climate change and international trade may play important roles. Responses to these drivers include creating a more diversified agricultural landscape based on principles from sustainable agriculture, agroecology and organic farming management (i.e. intercropping, polyculture, crop rotations, cover-cropping, fallowing, agroforestry, insectary strips and hedgerows). Recognising and appreciating diverse knowledge systems, including science and indigenous and local knowledge within Africa, can contribute substantially to understanding pollinators and pollination and their effective management. Building capacity within Africa through both formal and informal education on topics such as managing for pollinators and natural enemies simultaneously, and developing alternative pollinators, is a priority response, as is increasing public awareness of the role of pollinators to livelihoods. Policy measures to support pollinator, - friendly farming have as yet been little articulated within Africa. The farming systems that are beneficial to pollinators - in particular, promoting diversity and minimizing pesticides - need to be supporting by enabling policy environments.

Knowledge gaps, priority capacity building and research areas for Africa: Priority knowledge gaps for capacity building and research in Africa are identified for multiple areas, including: the fundamental biology of pollination services in African ecosystems; pollination dynamics within African tropical forests; taxonomy of African pollinators; assessment of pollinator declines; crop pollination; identification of specific agricultural practices favorable to pollinators; development of alternative managed pollinators such as stingless bees; honey bee hive health in Africa; economic valuation of pollination services and tools to asses this; pollination and climate change in Africa; recognition and appreciation of local and traditional knowledge; capacity building needs in formal and farmer education; building public awareness; and creating policy environments and markets for farming systems that are beneficial for pollinators.

Introduction

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has completed its first thematic assessment on pollinators, pollination and food production; this assessment was adopted in the fourth session of the Platform's Plenary, held from 22 to 28 February 2016, in Kuala Lumpur, Malaysia. The implications of the assessment were considered by the Convention on Biological Diversity Subsidiary Body on Scientific, Technical and Technological Advice (CBD-SBSTTA 20). Among the recommendations made by SBSTTA 20, Recommendation XX/9 paragraph 4 requests,

> "the Executive Secretary, in cooperation with Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services and Food and Agriculture Organization of the United

> Nations to prepare a regional report for Africa on pollinators and pollination, drawing upon the Assessment and relevant work under the International Pollinators Initiative, and make the findings available for peer review prior to the thirteenth meeting of the Conference of the Parties."

SBSTTA 20 also requested the Executive Secretary, in cooperation with the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, the Food and Agriculture Organization of the United Nations, and other relevant organizations, subject to the availability of resources and avoiding duplication of efforts:

> (a) To promote, as a priority, efforts to address data gaps and capacity for monitoring the status and trends of pollinators and pollination in developing countries, in particular Africa;
>
> (b) To identify and develop proposals for strengthening capacity related to pollinators and pollination, and supplementary regional assessments, in particular for Africa, to be integrated into the updated and streamlined plan of action of the International Initiative on the Conservation and Sustainable Use of Pollinators referred to in paragraph (9) above;

This report, drawing on both IPBES assessment and relevant work under the International Pollinators Initiative from 2000 to the present, highlights the state of knowledge of animal pollination in the Africa region as a regulating service that underpins food production. It also focuses on the contribution of pollination services to gene flow, biodiversity-related plant-pollinator interactions and the restoration of ecosystems in Africa. Where possible, significant needs in the region in terms of monitoring pollination services, and building appropriate capacity are flagged, as an initial contribution to the two additional requests of SBSTTA recommendation XX/9, paragraph 12.

The format of this report is divided into four sections:

1. Values of pollinators and pollination in Africa
2. Status and trends in pollinators and pollination in Africa
3. Drivers of change, risks and opportunities and policy and management options
4. Knowledge gaps, priority capacity building and research areas for Africa

The first three correspond to the structure of the IPBES assessment, while the fourth has been written an initial response to the requests of SBSTTA recommendation XX/9, paragraph 12 (a and b above).

Preparation for the report was led by Barbara Gemmill-Herren and Hien Ngo. It draws upon relevant information from the first thematic assessment on pollinators, pollination and food production of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), as well as relevant work of FAO, in its role of facilitating and coordinating the International Pollinators Initiative, and carrying out focused activities in Africa in the context of the Global Pollination Project. The revision of this report has greatly benefited from the reviews received from the governments of Oman, Zambia, Cameroon, the United States of America, the Universidad Nacional de Colombia, one independent environmental technical writer and researcher and Vera Fonseca, as well as several authors from Africa involved in the IPBES pollination assessment: Colleen Seymour, Mary Gikungu, Connal Eardley and Thomas Aneni.

Values of pollinators and pollination in Africa

Pollinators and the ecosystem service they provide

Pollination is an ecological process that is fundamental to the reproduction and persistence of flowering plants. It occurs when viable pollen grains are moved from anthers (the male part of a flower) to receptive and compatible stigmas (the female part of a flower) of flowering plants and, when followed by fertilization, which usually results in fruit and seed production. Pollination is thus the main mechanism for sexual reproduction in flowering plants. As many plants do not self-pollinate, or do so only to a certain degree to ensure seed production, most flowering plants depend on pollen vectors for pollination such as animal pollinators, wind, or water (Proctor et al., 1996). As a precursor to fruit and seed production, pollination is crucial for the continued reproduction, evolution of flowering plants, and production of food for wild animals, microorganisms and people. Animal pollination has a particularly strong and unique role. In the fossil record, the appearance and spectacular diversification of flowering plants coincides with the evolution of many key animal pollinators, such as bees (Hu et al., 2008). Thus, animal pollinators, permitting sedentary plants to intermix genetic material over distances, have been a key mechanism of genetic diversity (Darwin, 1876). The proportion of species (both wild and crop taxa) that rely on animal pollination has been estimated at 78% of all species in temperate zones, and 94% in tropical zones (Ollerton et al., 2011). Across the heterogeneous landscapes and ecosystems of Africa, the contribution of animal pollinators to biological diversity is immeasurable.

Plants lure pollinators to their flowers with various rewards (Proctor et al., 1996). These rewards include nectar (consumed by insects, bats, birds, non-flying mammals) as a source of carbohydrates; pollen (used mostly by bees that collect it for provisioning their larval cells, and beetles, flies, birds, and some bats and non-flying mammals that eat it) for protein, vitamins, fatty acids and minerals; oils (collected by oil-collecting bees for provisioning their larval cells), and resins collected by various bees for use in nest construction and for sealing gaps in their hives, and a range of other materials as mentioned below.

Dependence on pollinators and pollination within natural ecosystems

Of the world's wild flowering plants, it has been estimated that 87.5% (approximately 308,000 species) are pollinated by insects and other animals and most of the remainder use abiotic pollen vectors, mainly wind (Ollerton et al. 2011). This degree of dependence is thought to be even higher in tropical zones, where it is estimated that more than 98 per cent of plants depend on animals for pollination (Bawa 1990). However, most of these observations have been made in Latin American and Asian tropical lowland rainforests, and the degree of dependence on animal pollination in African tropical forests does not appear to be well documented. Indeed, the region of Africa that includes tropical forests (Figure 1) has been the subject of very few pollination studies (Figure 2; Gemmill-Herren et al. 2014).

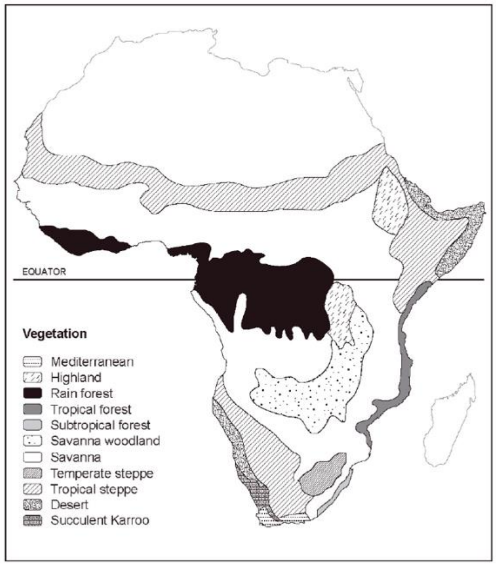


Figure 1. Map of Sub-Saharan Africa showing broad distribution of vegetation types (from Eardley 2009, as adapted from the NASA Scientific Visualization Studio maps (http://svs.gsfc.nasa.gov/ vis/) and the University of Chicago Fathom Archive African map series (http://fathom.lib.uchicago.edu/).

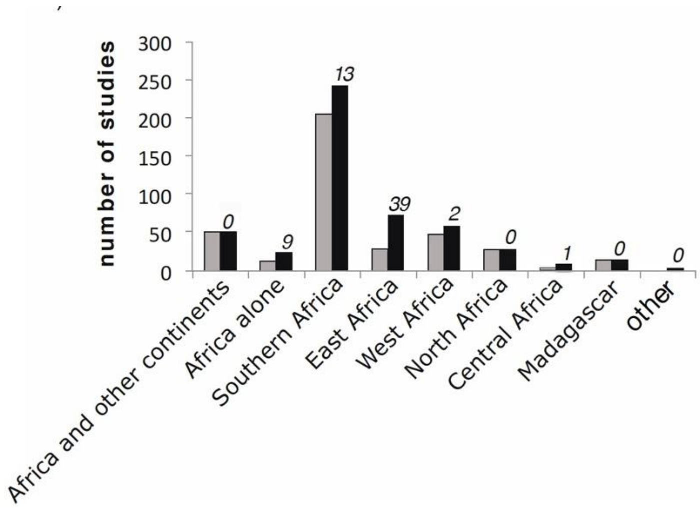


Figure 2. Location of pollination studies carried out in Africa as identified in 2003 (grey bars), and in 2013 (black bars), with numbers of additional studies in the decade interval indicated above the black bar. From Gemmill-Herren et al. 2014, p. 46.

Diversity of pollinators in Africa, and unique attributes of pollination systems

Wild pollination systems involve a wide diversity of pollinators. Important pollinating species including many insect taxa, including bees, moths (known to be important for orchids, papaya, and many other night-blooming flowering plants), flies, wasps, beetles and butterflies. Most invertebrates in the region remain undescribed. Even bees, for which 2600 species have been described from the continent (Eardley et al. 2009, http://www.gbif.org/dataset/da38f103-4410-43d1-b716-ea6b1b92bbac) likely include many species yet to be recognized. Yet most of these bee species – described or not -are effective pollinators, with the exception of parasitic bee taxa. Vertebrate pollinators known from Africa include bats, non-flying mammals such as rodents, lemurs and birds, particularly sunbirds and whiteeyes, throughout the continent.

There are many aspects of pollination and pollinators that are counterintuitive. Three aspects that could apply to Africa are detailed below.

Unlike many other aspects of diversity, arid regions tend to be particularly rich in bee diversity; for example, the Western US, the Chaco region of Argentina, the Mediterranean, the Middle East, the dry interior plains of China, and arid regions of Australia are all centers of high bee diversity (Michener 2000). South Africa is also considered one of these centers of high bee biodiversity, yet the patterns of bee diversity in South Africa have been shown to be quite nuanced (Kuhlmann et al. 2007) with a bipolar pattern of highest species diversity both in the arid west of the country and the moister east.

Another counterintuitive feature of pollination is that in natural ecosystems, pollen limitation becomes more severe in biodiversity hotspots. Thus, plants located in more species-rich areas use, or are visited, by fewer pollinating species. This has been demonstrated for floristic regions in South Africa that exhibit severe pollination limitation effects (Vamosi et al 2006) (Figure 3). The fact that other such sites of pollination limitation cannot, at this time, be identified in Africa is probably due more to the lack of studies than of actual evidence.

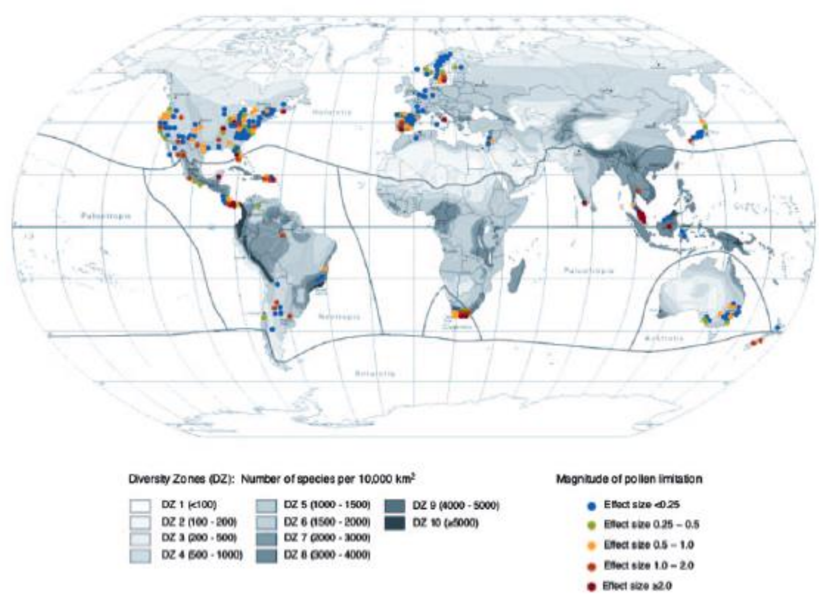


Fig. 3. Summary of the meta-analysis of fruit-set effect sizes of pollen-supplementation experiments conducted on 241 species in different biodiversity zones of the world. (from Vamosi et al. 2006), p. 957.

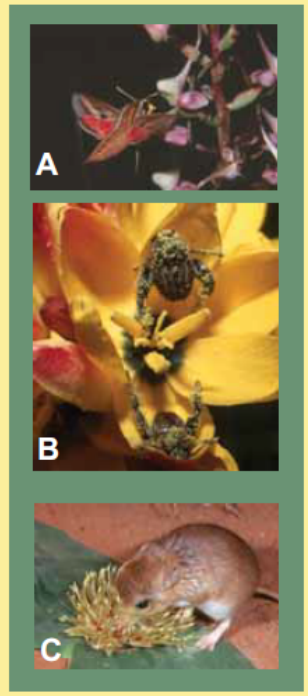
Finally, while ecologists (including many in Africa) have focused and documented the role of large mammals as “bulldozer herbivores” or “ecosystem architects” - rearranging and consuming vast quantities of low energy material (Kohi 2013), bees and other pollinators may have far greater roles than expected or understood in ecosystem architecture. As thoroughly documented by Roubik (1994) (but with all evidence from non-African regions), bees are high-end “recycling centers”. Considering that pollen is high in protein and nectar is high in energy, the ability of bees to redistribute high-value material within ecosystems is considerable. Roubik (1994) estimated that stingless bees alone redistribute 10% of the total annual energy production from primary production in a given square kilometer of tropical forest annually, into their hives, from evidence in Central America. The waste products from stingless bee hives, itself quite rich in nutrients, amounts to about 1,800 kg/year/square hectares. Resources used by bees include gums, resins, rotten wood, bark, fruit juices, seeds, leaves, plant hairs or trichomes, fragrances, pollen, nectar, oils, spores, sap, honeydew from homopteran bugs, animal feces, carrion, urine, animal hairs, mud, sand, and water. Again, this role of pollinators as ecosystem architects has not been documented in Africa.

Diversity of pollination syndromes in Africa

The continent of Africa is graced with a wealth of highly unique pollinator syndromes in its natural ecosystems. A few of these from Southern Africa are featured in Figure 4 below. Others, mostly from other regions, include the ancient system of beetle pollination of cycads, the unique pollination syndrome of *Ceropegia* flowers and their imprisoned flies (see Figure 5), sunbirds visiting aloes, bats hanging from robust *Parkia* flowers, evolved to support their weight, and deceptive flowers that do not give a rewards.

*Focus on...*Unique Pollination Systems of Southern Africa

Southern Africa, with a tenth of the world's plant species, has the richest flora of any region of equivalent size in the world. This diversity is matched by a remarkable range of pollination systems, many of which have been discovered only in the past few decades. Some of these are described below.



Flies: Long-tongued flies (Nemestrinidae, Tabanidae, Bombyliidae) are known to be flower specialists and feed mostly on nectar (Fig. A). Particularly long probosces have evolved in the Nemestrinidae and Tabanidae, with the nemestrinid *Moegistorhynchus longirostris* having the longest proboscis (6–10 cm) of any fly worldwide. The long proboscis of these flies serves to extract nectar from deep tubular flowers, and research in the past decade has shown that dozens, if not hundreds, of plant species in southern Africa rely exclusively on these flies for pollination. Within any particular geographical region, there are guilds of plants that, in some cases, rely on a single long-tongued fly species for pollination. Such specialization by plants is rare worldwide and was hitherto known only in plants such as figs and yuccas that offer specific brood sites for pollinators.

Moths: Moth pollination is well developed in the African flora. Some 50% of African orchids, for example, are pollinated by moths. Data on moth pollination are hard to acquire because of the difficulty in making nocturnal observations. However, in the past decade several studies have been made of pollination by both settling moths (Noctuidae and Geometridae) and hawk moths (Sphingidae). Interestingly, moth pollination is rare in the Cape floral region where nutrient-poor soils render vegetation unpalatable to most moth larvae, but it is relatively common in the summer rainfall region.

Beetles: The classical beetle-pollinated flower has long been characterized as bowl shaped and pale in colour, with a strong fruity odour. This description applies mainly to plants pollinated by fruit-chafer beetles (Cetoniinae). In South Africa, most documented beetle-pollination systems involve plants with bright (red, orange or yellow) odourless flowers visited by monkey beetles (Scarabaeidae: Rutelinae: Hopliini) (Fig. B).

Pollen wasps: Southern Africa has the richest fauna of masarid wasps worldwide. These wasps feed their larvae on pollen and nectar, like bees, and not on insects and arachnids like other wasps. They appear to play a particularly important role in pollinating plants in the semi-arid Karoo region. Sexual deception of male wasps by Cape *Disa* orchids has recently been recorded.

Vertebrates: Bird pollination is well known in Africa, with sunbirds, sugarbirds and several other bird species visiting flowers regularly. But there are other vertebrate pollinators, as well, some of which are known only on the continent to serve this function. Pollination by rodents is an oddity that was first discovered in Cape proteas in the 1970s and later found to occur also in Cape lilies (Fig. C). Flowers adapted for rodent pollination blossom close to the ground, are dull coloured and produce a yeasty scent during the evening, timed in tune with the nocturnal activities of rodents. Flowering usually occurs in winter when rodents are short of food and alternative pollinators, such as insects, are less active. Bats are also pollinators—the baobab tree, which provides shelter and food for an abundance of animals, is bat pollinated.

adapted from Johnson 2004

Figure 4. Unique Pollination Syndromes of Southern Africa, from Johnson 2004

Figure 5. The diverse genus *Ceropegia*, with over 160 species distributed throughout the old world tropics, is well represented in Africa. Members of the milkweed family, *Ceropegias* are mostly climbing, succulent herbs, with unique and distinctive flowers. The complex flowers are highly variable, but consist of a chamber with limited access, a fringe of hairs to the corolla (typical trait of many fly-pollinated succulents) and a complex pollination mechanism. Flies, drawn to the fetid colour and smells of the *Ceropegia* blossom, led through gaps and folds, are tricked into entering the chamber. Here they are duly trapped and find themselves drawn once again to the flower's reproductive structures. By means of clips, the pollinia are then attached to the hapless fly's proboscis or body. The fly is released as the flower wilts. Loaded with the very securely attached pollinia, the fly eventually visits another blossom. From Masinde, 2004.

The distinctiveness of pollination syndromes in Africa must be stressed. African studies have contributed to the recognition of bats (e.g. Baker and Harris, 1959; Ayensu, 1974), in tropical ecosystems, and birds (e.g. Arroyo, 1981; Rebelo, 1987b) as important pollinators. Unique pollination systems involving oil-collecting bees (Steiner and Whitehead, 1996; Steiner, 1999), long proboscid flies (Goldblatt and Manning, 1999; Manning and Goldblatt, 1997) and monkey beetles (Picker and Midgley, 1996; Goldblatt et al., 2000, etc.) are known from South Africa. Monkey beetle pollination differs from the general beetle pollination syndrome (Proctor et al., 1996a) in that visual attraction seems more important than odour; the beetles are particularly hairy and many species do little damage to the flowers. Ecologists in Africa have been able to document shifts in pollination syndromes with consequent impacts on the evolution of flower traits (Kiepiel and Johnson 2014).

Pollination services to agriculture and livelihoods in Africa: Overview

Pollination is one of 15 ecosystem services identified as declining by the Millennium Ecosystem Assessment (2005). The importance of this trend is that crops that are animal pollinated are vital to human health. Animal-pollinated crops (for example, the globally important components of human diets such peppers, tomatoes, apples and almonds) provide critical nutrients in human diets, and are responsible for 90% of vitamin C, and the majority of carotenoids, including vitamin A (Eilers et al., 2011). As noted by Smith et al., (2015) the complete removal of pollinators would result in 71 million people in low-income countries becoming newly deficient in vitamin A, and an additional 2·2 billion already consuming below the average requirement experiencing further declines in vitamin A supplies. Globally, there is a growing demand for a diverse, nutritious diet (Klein et al. 2007; Eilers et al. 2011) and is resulting in more land being cultivated to satisfy global needs for food (Foley et al. 2011; Tilman et al. 2011). That, in turn, is increasing concern over security of food and other agricultural commodities (Gregory and George 2011; Tilman et al. 2011; Breeze et al. 2014). An estimated 98% of farms in Africa are family farms, holding on average 67% of the land and producing the majority of food within each country (Graueb et al., 2015). Smallholders and family farmers in Africa are thus key to local food security, and to the maintenance of landscapes that host pollinators. Women farmers, who are known to be stewards of local agricultural biodiversity and food cultures, often cultivate or promote local fruits and vegetables of importance to the food security for children and families, many of which are pollinator-dependent. These continued relationships, between women, local communities, and landscapes that promote pollinators, are an important nexus toward attaining the Sustainable Development Goals related to food security, and others. A key message to policymakers has been articulated in the scientific literature from Africa and beyond, that the support and contribution of smallholder farmers is key to fostering sustainability (Steward 2014).

The level of dependence of crops and wild flowers on pollination is highly variable. Of 115 global crop types most widely consumed by human beings the fruit, vegetable or seed production from 87 species rely to different degrees upon animal pollination, while 28 do not require animal pollination. In terms of global production amounts, 60% of annual crop production does not depend on animal pollination (e.g. cereals and root crops), while 35% does depend on pollinators and 5% have not been evaluated (Figure 6). Considering crop types traded on the global market, pollinators are essential for 13 crop types, production is highly pollinator-dependent for 30, moderately so for 27, slightly dependent for 21, no increase for 7 and 9 are of unknown significance (Klein et al. 2007). Overall, approximately seventy-five per cent of global food crop types benefit from animal pollination (Klein et al., 2007).

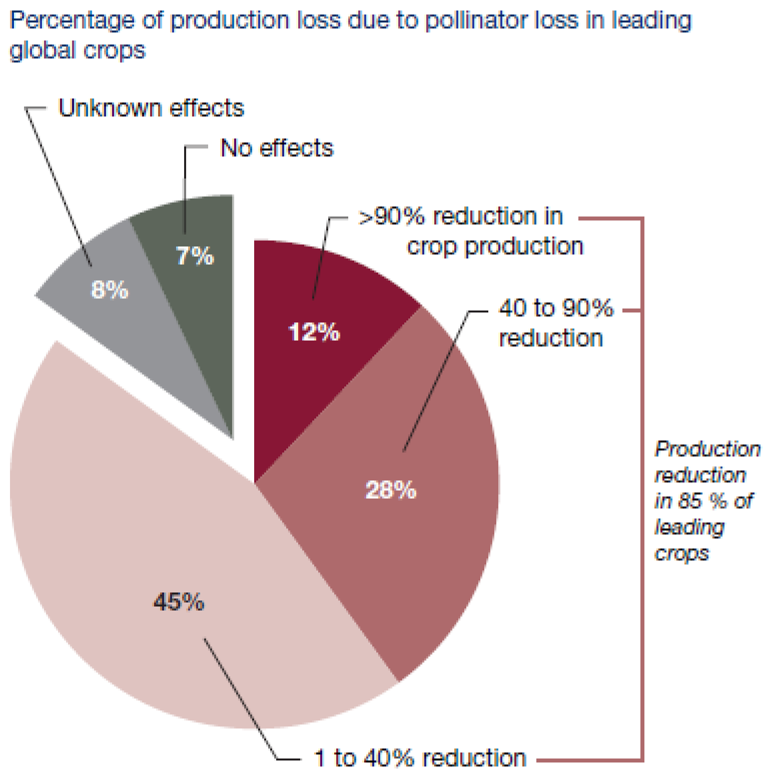


Figure 6. Percentage of production loss due to pollinator loss in leading global crops (Gallai et al., 2009)

Contribution to food and nutrition security in Africa

Because the degree of yield dependency on pollinators varies greatly among crops, pollinators are directly responsible for a relatively small proportion (5-8%) of total agricultural production volume

(IPBES 2016). However, pollinators are also responsible for many indirect contributions, such as the production of many crop seeds for sowing but not consumption. Animal pollination is directly responsible for the crop market outputs and yields of foods that are critical to both food and nutrition security. The food types that are pollinator-dependent in particular supply major proportions of micronutrients, such as vitamin A, iron and folate, in global human diets (Eiders et al. 2011; Chaplin-Kramer et al. 2014; Smith et al. 2015), even though some may comprise a small component of human diets. Human deficiency of one or more of these micronutrients is most severe in those regions of the developing world where the production of crops providing such nutrients depends heavily on pollinators (Ellis et al., 2015; Chaplin-Kramer et al., 2014). (Figure 7)

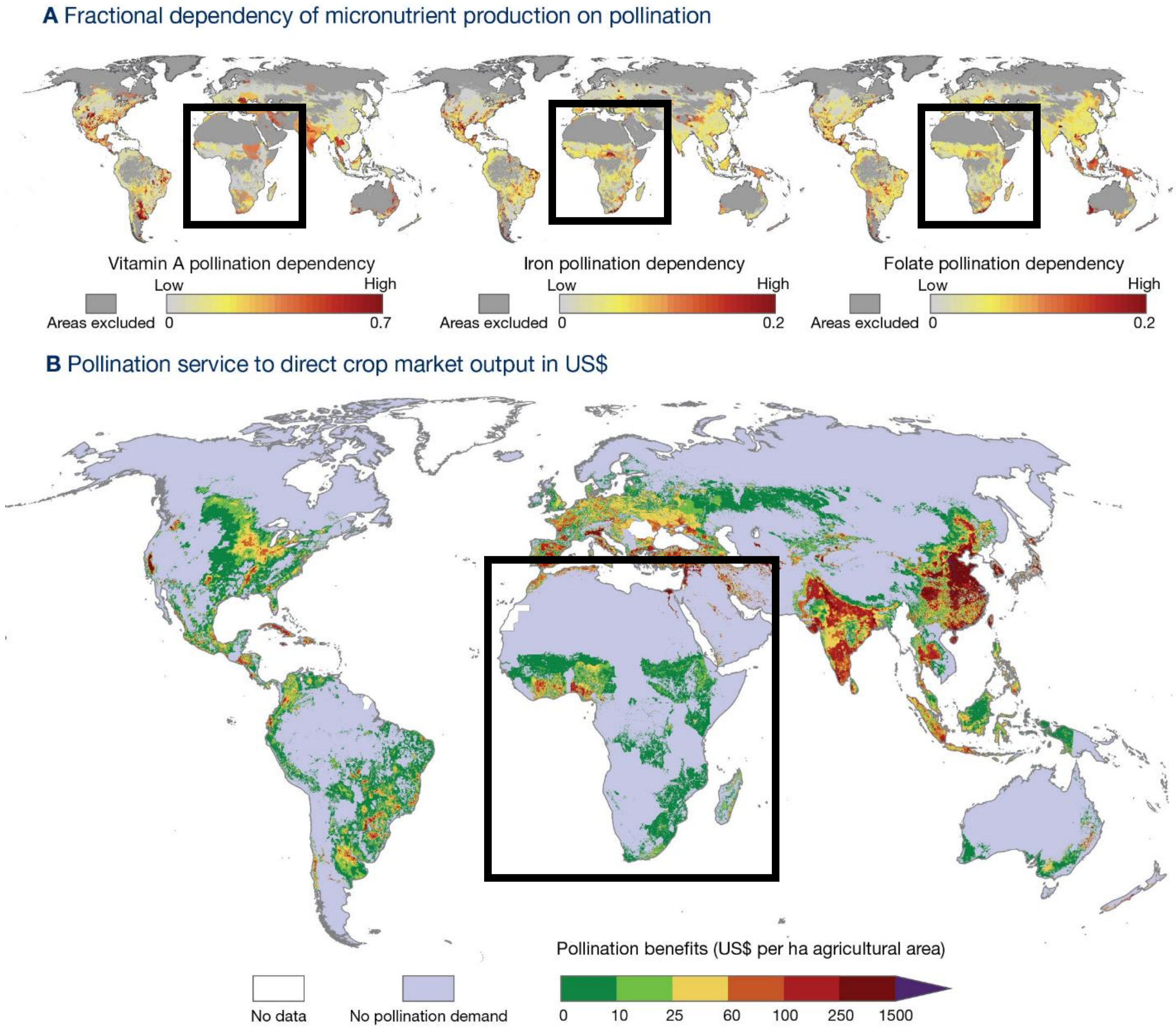
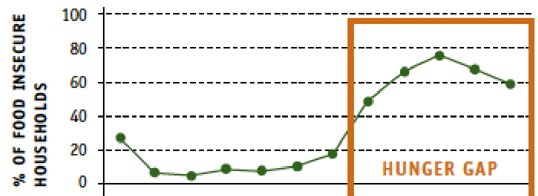


Figure 7. Fractional dependency of micronutrient production on pollination (A) and pollination service to direct market output (B). From Ellis et al., 2015 and Chaplin-Kramer et al., 2014

In Africa, there are many indigenous crops that are pollinator-dependent. These are not included in the lists of calculations of "leading global crops"; yet they are highly important for food and nutrition security. These include seed for indigenous vegetables, for example: African nightshades (*Solanum scab rum*), amaranths (*Amaranthus blitum*), spiderplant (*Cleome gynandra*), slenderleaf (*Crotalaria ochroleuca* and *Crotalaria brevidens*), African kale (*Brassica carinata*), jute mallow (*Corchorus olitorius*), African eggplant (*Solanum macrocarpon* and *Solanum gilo*) (Abukutsa-Onyango et al., 2010; Gemmill-Herren et al., 2014), and many of the agroforestry fruit trees that provide needed foodstuffs in the "hungry season" (Figure 8, from Prabhu et al. 2015), or trees that provide fruit for multiple purposes such as Marula (*Sclerocarya birrea*) in southern Africa.

Food security levels of 300 surveyed households in Machakos County, Kenya, and harvest periods of the most important exotic and indigenous fruit species according to respondents



ENGLISH NAME	SPECIES NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	VIT C	VIT A
Pawpaw	**Carica papaya**	▓	▓	▓	▓	▓	▓				▓	▓	▓	+	+++
Mango	**Mangifera indica**	▓	▓	▓									▓	+	+++
Banana	Musa x paradisiaca	░	░			░					░				
Loquat	**Eriobotrya japonica**		▓												+++
Mulberry	**Morus alba**		▓	▓										(+)	
Tamarind	*Tamarindus indica*		░	░											
Waterberry	**Syzygium spp.**			▓					▓	▓					+++
Custard apple	**Annona reticulata**			▓	▓									(+)	
Guava	**Psidium guajava**			▓	▓	▓	▓							+++	+
Pomegranate	Punica granatum				░										
White sapote	**Casimiroa edulis**				▓					▓				(+)	
Wild medlar	*Vangueria madagascariensis*				░	░	░								
Lemon	**Citrus limon**					▓	▓	▓						+	
Orange	**Citrus sinensis**					▓	▓	▓						+	
Chocolate berry	***Vitex payos***					▓	▓	▓							+++
Avocado	Persea americana					░	░	░	░	░	░				
Passionfruit	**Passiflora edulis**							▓				▓			+
Jacket plum	*Pappea capensis*								░	░					
Desert date	***Balanites aegyptiaca***								▓	▓				(+)	
Bush plum	*Carissa edulis*												░		
NUMBER OF VITAMIN-RICH SPECIES AVAILABLE		2	4	6	4	4	5	4	2	3	1	2	2		

Indigenous fruit species are in italics. The ratings of vitamin C and beta carotene (vitamin A) contents are given as: +++ – very high; + – intermediate; and (+) – moderate. The harvest periods of fruits rich in vitamin C and A are indicated by dark green boxes and their species names are in bold.

Fig. 8. Food security levels harvest periods of the most important exotic and indigenous fruit species of 300 surveyed households in Machakos County, Kenya. From Prabhu et al. 2015, p. 213.

The availability of pollinators and their pollination services not only affects crop production in terms of quantity but also quality. For example, a study on strawberry production which compared the pollination efficiency of three stingless bee species and the honey bee, *Apis mellifera scutellata,* on two strawberry varieties found that strawberries require different honey bee and stingless bee species for optimal pollination. Increased insect pollination/visitation by a diversity of pollinators which included stingless and honey bees resulted in more uniform and marketable strawberries and the resulting recommendation was to cultivate strawberries that use both or any bee species best adapted to the climatic condition for their pollination requirement (Asiko, 2012). Similarly, near Nanyuki, Kenya, export-grade runner beans (*Phaseolus coccineus* L.) that do not receive adequate pollination produce distorted, sickle-shaped pods resulting in beans that are not of export market quality (Vaissière et al. 2010)

Additionally, insect pollination, specifically *Hypotrigona gribodoi* (stingless bee) pollination, improves green pepper (*Capsicum annum*) fruit marketability, producing the heaviest fruits with the highest seed numbers (Nkoba et al., 2014); this study concluded that *H. gribodoi* is an efficient pollinator of green pepper in the tropical region of East Africa. Insect pollination can also affect ripening speed for capsicums (chili peppers) (Bruijn and Ravestijn, 1990); farmers are able to secure higher off-season, prices for their crop through increased pollination services to the target crop.

Diversity of crop pollinators in Africa

Honey bees, *Apis mellifera* L., native to Africa and Eurasia (Michener 1974; Butz-Huryn 1997), have been moved by people around the globe (Moritz et al. 2005) and are the most prevalent managed pollinators and the dominant visitor to more than half of the world's animal-pollinated crops (Klein et al., 2007; Kleijn et al., 2015). It is well known that managed pollinators suffer from a large number of serious problems, such as diseases, parasites and environmental stresses (Goulson et al. 2015).

In a wide-ranging meta-analysis published in *Science* in 2013, the pollination of more than 40 crops in 600 fields across every populated continent was studied through a contribution of 46 scientists (Garibaldi et al. 2013). Wild pollinators were twice as effective as honeybees in producing seeds and fruit on crops including oilseed rape, coffee, onions, almonds, tomatoes and strawberries. Furthermore, bringing in managed honeybee hives did not replace wild pollination when that was lost, but only supplemented the pollination that had taken place. The meta-analysis included only one study in Kenya and two in South Africa; the least among all continents. More studies are needed in Africa to confirm these global findings for this continent.

Another species of pollinator used commercially, originating in West and Central Africa, that has made a major economic contribution to the world, is the oil palm weevil (*Elaeidobius kamerunicus*). This is a West and Central African species that was introduced into Malaysia and has now been introduced around the world (Greathead 1983). Certainly the sustainability of oil palm cultivation is a matter of considerable scrutiny and discussion; the stability of its production due to understanding the pollination needs is one factor that is central to developing sustainable oil palm production systems (Figure 9).

Focus on…..West and Central African oil palm pollination

Consider the oil palm plantations of Malaysia and how an African pollinator has benefited them. Oil palm trees, native to West and Central Africa, were taken to Southeast Asia and planted in vast plantations to satisfy the global demand for cheap, versatile palm oil. Production was disappointing until the plantation managers realized that it could be enhanced by hand pollinating the palm flowers. Yet hand pollination was laborious and inefficient. Plantation owners began to ask how the oil palm got itself pollinated in its native habitat of West and Central Africa's forests. Researchers studied the oil palm in Cameroon, where they found that a tiny weevil, *Elaeidobius kamerunicus*, travels from male to female flower parts and pollinates the flowers effectively while feeding on the pollen. Start-up stocks of the weevil were taken back to Malaysia, where they were released into the plantations. (There was no problem of ecological complications with other species, since the weevil confined its attentions to the oil palm). The weevil now accomplishes all the pollination, bringing savings that were amounting to $150 million per year already by the early 1980s (Greathead 1983). Figures such as these should help to convince policy-makers of the importance of pollinator conservation.

Figure 9. An example of the commercial value of pollination services of a West and Central African palm oil pollinator

Relatively little work has been conducted on comprehensive assessments of the impact of pollinator diversity and pollinator assemblages on crops in Africa. Exceptions, where some work has been done, include South Africa and Kenya. A recent review conducted in South Africa assessed the importance of different pollinators for crop production (Melin et al., 2014). The specific contribution and importance of pollinator diversity and floral visitation to fruit or seed set has been examined in South Africa with respect to sunflower seeds (Carvalheiro et al., 2011), mango (Carvalheiro et al., 2010) and rooibos seeds (Gess and Gess, 1994) in South Africa. In Kenya, the contribution of pollinator diversity has been documented for watermelon (Ngoroge et al. 2005), eggplant (Gemmill-Herren and Ochieng 2008) and strawberry (Asiko 2012). Further assessments are needed to understand the importance of pollinator biodiversity in crop production in all regions of Africa.

Economic valuation of pollination services in Africa

The annual market value of the 5-8 per cent of production that is directly linked with pollination services (IPBES 2016) is estimated at $235 billion-$577 billion (in 2015 US$) worldwide (Gallai et al., 2009). On average, pollinator-dependent crops have higher prices than non-pollinator dependent crops. The accuracy of the economic methods used to estimate these values is limited by numerous data gaps, and because most studies focus on developed nations. Explicit estimation and consideration of economic benefits through tools such as cost-benefit analyses and multi-criteria analyses provide information to stakeholders and can help inform land-use choices with greater recognition of pollinator biodiversity and sustainability.

Many livelihoods rely heavily on pollinators for the benefits and products they provide within an ecosystem (see Table 1). Many of the world's most important cash crops are pollinator-dependent. These constitute leading export products in developing countries (e.g., coffee and cocoa) and developed countries (e.g., almonds); providing employment and a source of income for millions of people. Impacts of pollinator loss will therefore be different among regional economies, being higher for economies with a stronger reliance on pollinator-dependent crops (whether grown nationally or imported).

Economic Valuation of Pollination and the Vulnerability of Agriculture at regional, subregional and national scales in Africa

Applying a framework for assessing impacts of pollinator declines (Potts et al., 2012) on the region and subregions of Africa, using data from Gallai et al., 2009, it is possible to estimate economic values and vulnerabilities by subregion (Table 1).

Table 1. Geographical distribution of the economic value of insect pollination and crop vulnerability. Insect pollination economic value (IPEV) is the proportional contribution of biotic pollination to production multiplied by the total economic value (EV) of the 100 most important commodity crops, summed for all crops in a region. The ratio of IPEV to the EV indicates the economic vulnerability of crops to pollinator loss.

Geographical region (following FAO, http://www.fao.org)	Insect Pollination Economic Value (IPEV) in 10^9€	Vulnerability of region (IPEV/EV)
Africa	**11.9**	**8**
Central Africa	0.7	7
East Africa	0.9	5
North Africa	4.2	11
Southern Africa	1.1	6
West Africa	5.0	10

Methods for economic valuation of pollination services on a national scale has been developed, and applied to Ghana. The total contribution of pollination services to Ghana's national agricultural production is approximately 11.1% of the national agricultural production p.a. of $788 million (USD) (Gallai and Vassière, 2009) (Table 2).

TABLE 2. National impact of insect pollination on the 2005 agricultural production used directly for human food in Ghana (from Gallai and Vaissiere 2009a). From Gemmill-Herren et al., 2014

Crop category following FAO	Average value per metric ton in US$	Total value of crop (TVC) Price * Production in US$	Economic value of insect pollinators (EVIP) =TVC*%yield dependent on pollination (D) in US$
Cereals	422	821,267,900	0
Fruits	55	190,191,024	5,895,398
Oilcrops	141	400,822,900	30,717,694
Pulse	687	10,307,100	*not well known; while many pulses self-pollinate; the contribution of pollinators to higher yields is not well documented.*

Roots and Tubers	286	4,356,036,458	0
Spices	1940	138,127,909	6,142,868
Stimulant crops	994	756,426,216	710,888,934
Sugar crops	28	3,981,600	0
Treenuts	466	6,060,990	3,296,046
Vegetables	617	396,491,526	31,505,314
TOTAL		**7,079,713,622**	**788,446,253**

On a subnational level, the contributions of a diversity of pollinators to smallholder agriculture in western Kenya, and their economic benefits have been documented (Kasina et al. 2009a, b). The resulting analysis showed that bee pollination enhances the yield of most crops grown in the farmland and improves the quality of produce. Almost 40% of the annual value of crops under consideration represented the net returns derived from bee pollination. More than 99% of this benefit could be attributed to pollination by feral bees.

There have been a number of global studies that have focused on economic vulnerabilities and dependencies that could result from pollinator declines. In relation to the Africa region it has been noted that:

- In North Africa, production of pollinator-dependent crops greatly exceeds consumption, as many crops are sold as exported produce to Europe. A loss of pollinators could result in a deficit in which production would no longer be able to meet local consumption, much less export needs (Gallai et al. 2009).
- In regions that are highly specialized in the production of pollinator-dependent crops vulnerability to a loss of pollinators is particularly high. West Africa, in particular, with its specialized production of cocoa, has a very high vulnerability ratio of 90%. The consequences of a total pollinator loss on cocoa and other pollinator dependent crops from the region such as coffee could be considerable not only for the revenues that West Africa derives from these crops, but also on a global scale for the world production and resulting price structure of these stimulants (Gallai et al. 2009).
- Estimations have been made of the cost of replacing managed pollination services for the Western Cape deciduous fruit industry of South Africa. The estimations find that wild pollination services have been underestimated in the past, and that overall the valuation of both managed and wild pollination services is grossly undervalued. For managed services alone, the contribution of managed honeybee pollination is found to be between US$28.0–122.8 million, for which only US$1.8 million is presently being paid (Allsop et al 2008).
- Several crops that are both commercially important and important for nutrition security in Africa are strongly dependent upon pollinators (such as eggplants, tomatoes, peppers, papaya and passion fruit among others). For many of these crops, honey bees are not considered effective pollinators, yet alternative wild pollinators are not well understood (Rodgers et al. 2004). This represents a potential vulnerability from any threats to pollinators.

Globally, available data show that 81 million hives annually produce 65,000 tonnes of beeswax and 1.6 million tonnes of honey, of which an estimated 518,000 tonnes are traded. Many rural economies favour beekeeping and honey hunting, as minimal investment is required; diverse products can be sold;

diverse forms of ownership support access; family nutrition and medicinal benefits can be derived from it; the timing and location of activities are flexible; and numerous links exist with cultural and social institutions. Long-evolved mutualisms may exist between honey hungers and honeyguides (Spottiswoode et al., 2016). Beekeeping is also of growing importance as an ecologically-inspired lifestyle choice in many urban contexts. Significant unrealized potential exists for beekeeping as a sustainable livelihood activity in developing world contexts.

Honey production in Africa is estimated to be less than 10 percent of world production, and beeswax production is less than one quarter of world production. Large quantities of honey and beeswax production tends to come from only a very few countries (Table X), suggesting that there is considerable scope for increasing the production of these high-value products in similar ecologies.

Country	honey, tonnes	beeswax, tonnes
Algeria	6147	
Angola	23300	2300
Burundi	747	175
Cameroon	4300	300
Central African Republic	16200	775
Chad	1050	
Egypt	5100	175
Guinea	900	132
Côte d'Ivoire	650	
Kenya	12000	2500
Libya	815	
Madagascar	4400	405
Mali	190	70
Morocco	5300	100
Mozambique	545	80
Guinea-Bissau	130	100
Réunion	110	
Rwanda	50	41
Senegal	3150	300
Sierra Leone	840	130
South Africa	1080	
Sudan (former)	740	180
United Republic of Tanzania	30000	1870
Tunisia	5100	62
Uganda	712	1300
Ethiopia	45000	5000
Zambia	750	35

Table 3. Production of natural honey and beeswax in 2013, by country (FAOSTAT data).

Other values of pollinators

Pollinators are a source of multiple benefits to people well beyond food-provisioning, contributing directly to medicines, biofuels, fibres, construction materials, musical instruments, arts and crafts and as sources of inspiration for art, music, literature, religion, technology, and biodiversity conservation. For example, some anti-bacterial, anti-fungal and anti-diabetic agents are derived from honey; Jatropha oil (Negussie, et al., 2015), cotton and eucalyptus trees are examples of pollinator-dependent biofuel, fibre and timber sources respectively; beeswax can be used to protect and maintain fine musical instruments. Artistic, literary and religious inspiration from pollinators includes popular and classical music. In cultures throughout the world, social bees have been honoured through picture and song, appreciated for the production of honey, and amongst some cultures revered as magical or even divine. Rock art found in southern Africa attests to the significance of bees to ancient peoples (Figure 10).

Figure 10. Reproduction of rock art found in Zimbabwe, depicting herders and honey hunters (from: http://www.sarada.co.za)

A good quality of life for many people relies on the ongoing roles of pollinators in globally significant heritage as symbols of identity, as aesthetically significant landscapes, flowers, birds, bats and butterflies and in the social relations and governance interactions of indigenous peoples and local communities.

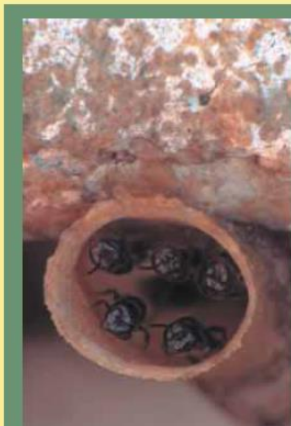
Livelihoods based on beekeeping and honey hunting are an anchor for many rural economies and are the source of multiple educational and recreational benefits in both rural and urban contexts. The centrality of bees to the forest-dwelling Ogiek in Kenya has been profiled by Samorai Lengoisa (Lyver et al. 2015), in which honey and bees are noted for having many roles: as food, medicine, alcoholic beverages, trade goods, and even as a means to secure a marriage. As bees migrated across the landscape with the season, so too did the Ogiek, in times past. In turn, the Ogiek protect certain trees that they know provide food to the bees. While many things have changed over time, bees and their honey remain.

Indigenous knowledge on bees and beekeeping is rich throughout many cultures in Africa, as documented in Crane (1999). Modern science and indigenous knowledge can be mutually reinforcing (Tengö et al. 2014). For example, there are parallels between folk taxonomy of Abayanda indigenous people living around Bwindi National Park in Uganda, and modern systematics (Byarugaba 2004; Figure 11).

***Focus on* ..Stingless bees of Bwindi Impenetrable Forest**

The Bwindi Impenetrable forest is located in western Uganda along the border with the Democratic Republic of Congo. The forest survives as an 'island' in the midst of dense agricultural settlement. Traditionally, local peoples including the Batwa (Abayanda) pygmies live in and use the forest. Batwa knowledge and exploitation of stingless bees is extensive and complex. Two genera occur in the forest: *Meliponula* and *Hypotrigona*.

Batwa peoples harvest stingless bee nests from the forest, using the honey and other hive products for a range of purposes including food and medicine. The Batwa classify the stingless bees of Bwindi into six distinct categories: maranga, obuganza, obugashu, obuhumbamba, obuzagali and obwiza. Characteristics such as body size and colouring are carefully observed in determining the kinds of stingless bee. The shape of the nests as well as the taste and qualities of the honey are also important factors. Batwa knowledge of forest ecology extends to recognizing ant associations with stingless bees; the bees engage in a mutualistic nesting within some ant colonies.



Stingless bees are important pollinators of a range of forest plants throughout the tropics. The six different types of stingless bee that the Batwa recognize are also scientifically classified as distinct species. Batwa names for the stingless bees reflect their various characteristics, such as 'obuhumbamba', meaning 'likes to nest in people's homes'. Traditional folk taxonomic systems are vital indicators of forest use, and they can be adapted to sustainable methods of harvesting, thus protecting local enterprise and conserving pollinators.

from Byarugaba 2004

Figure 11. Stingless bee knowledge among the Batwa people, Uganda

Honey bee hives more recently have been seen to have a role in reducing human-wildlife conflict, in that crop-raiding elephants may be deterred by honeybees so the hives can be placed around crop areas to deter the elephants (Ndlovu et al., 2016; Ngama et al., 2016).

Status and Trends of pollinators and pollination in Africa

Concern about pollinator decline is relatively recent (Kevan, 1999; Raw, 2001; Spira, 2001; Committee on the Status of Pollinators in North America, 2007; Williams, 1982), but there is a growing perception among both scientists and the general public that at least some populations and species are declining in at least some areas. Much of this concern comes from well-documented declines in managed honey bee (*A. mellifera*) populations in North America and Europe, as well as more recent reports of declines and even local or global extinctions of some native bees, such as bumble bees (*Bombus* species) (Bommarco et al., 2012; Bartomeus et al., 2013; Williams et al., 2009). The fact that almost half the studies on pollinator decline comes from only five countries (Australia, Brazil, Germany, Spain and the USA), with only 4% of the data from the continent of Africa (Archer et al., 2014), highlights the bias in information and the lack of data for some regions. To date, there has been no comprehensive assessment of the status and trends of pollinators and pollination services in Africa (Gemmill-Herren et al., 2014; Melin et al., 2014). We utilized the following information on global trends to analyze the relevant data and trends, when available, for the African region.

Trends in Wild Pollinators – known evidence for Africa

The current status of almost all wild pollinator populations is unclear and difficult to assess due to the lack of data. Even data on plant species in decline, due to suspected declines in pollinators, is not available for the African continent.

Studies on natural systems within South Africa have shown the negative effects of habitat fragmentation on plant–pollinator interactions within the agricultural matrix (Donaldson et al., 2002; Kehinde and Samways 2012) along with deterioration of specialist plant–pollinator networks on smaller conservation areas (reserves <385 ha); (Pauw 2007). Overgrazing has been documented to have deleterious impacts on pollinators in Southern Africa (Gess and Gess 1993; Mayer 2004, 2005; Mayer et al. 2006;)

Such detailed information on trends is largely missing for the remainder of the continent. At best, global patterns can be estimated while acknowledging the large gaps in data.

For example, two recent papers address the conservation status of vertebrate pollinators and the consequences of their loss. Despite data gaps, Aslan et al. (2013) estimated the threat posed by vertebrate extinctions to the global biodiversity of vertebrate-pollinated plants and further identified Africa, Asia, the Caribbean, and global oceanic islands as geographic regions at particular risk of disruption of pollination (and dispersal). Evidence would suggest that pollinator populations (diversity and abundance) can be maintained over long periods of time if habitat that provides nesting sites and food resources are conserved. General trends across studies indicate that the challenges posed by habitat loss or alteration, introduction of diseases, alien competitors, trampling by livestock, invasive plant species, and increasing pesticide use, are resulting in substantial shifts and often declines in pollinator populations that have prompted concern for their future. One important trend that can be extrapolated from comparative surveys between disturbed and undisturbed sites (e.g., Chacoff and Aizen, 2006; Quintero et al. 2010) is that substantial habitat disturbance could not only lead to impoverished pollinator faunas, but also to a spatial homogenization of bee communities (decreased beta diversity) (Carvalheiro et al., 2013). Below are a few examples of trends of wild pollinator taxa (wasps, moths, and bird respectively) in the African Region.

Nectar plants as resources can also affect the status of pollinator groups such as moths and birds. Moth species are important pollinators but there are few studies of their population dynamics outside of economically important pest species. Some moths have closely coevolved relationships with their nectar plants, with a close correspondence between proboscis length and corolla size (Nilsson, 1998). Others are routinely polyphagous. A study in Kenya found that, adult hawkmoths are routinely polyphagous and opportunistic, regardless of their proboscis length (Martins and Johnson, 2013).

The abundance of birds can also be affected by nectar plants as resources. Bird populations have been monitored in two large citizen science projects in South Africa, the first Southern African Bird Atlas Project (SABAP1: 1987–1991) and the second Southern African Bird Atlas Project (SABAP2: 2007-present). A recent comparison of these two data sets finds that the families Pycnonotidae and Ploceidae, which include nectar as a small component of their diet, have increased in abundance in 66%

and 61% of geographical grid cells respectively. Whereas the families Nectariniidae (Sunbirds) and Promeropidae (Sugarbirds), both of which include nectar as a major component of their diet, have increased in 52% and 33% of grid cells respectively. For the remainder (i.e., 67%) of gridcells, however, Promeridae declined (Loftie-Eaton, 2014). While these results are difficult to parse, the relative dependence of pollinating bird species on nectar seems to be a strong potential factor in their abundance.

Patterns observed in weather and climate can influence the status of wasp populations in Africa. Wasps are not common pollinators for very many plant species, but are involved in some interesting sexual deception pollination systems of orchids (e.g., Peakall and Beattie 1996, Schiestl et al. 2003). They are perhaps best known as obligate specialist pollinators of figs (*Ficus* spp.), which produce fruits that are important resources for many herbivores (Herre et al., 2008); an ancient symbiosis which was first identified around Lake Magadi in Kenya (Galil and Eisikowitch 1968). The susceptibility of the wasps to changes in flowering patterns induced by drought was documented in northern Borneo, when an El Niño Southern Oscillation (ENSO) event led to the local extinction of the pollinators because of a gap in the availability of flowers (Harrison 2000). Almost nothing is known about the size and variability of pollinating wasp populations in Africa, even though figs are a highly critical resource for a wide variety of animals throughout the continent.

Trends in Managed Pollinators – known evidence for Africa

Research in trends of managed pollinators, namely honey bees, is biased towards Europe and North America (Archer et al., 2013). Beekeeping is unique in Africa since it is the only region that has the presence of large populations of native honey bees still existing in the wild (Pirk et al., 2014). Africa has approximately 310 million honey bee colonies (Dietemann et al., 2009) and only a small proportion of those honey bee colonies are managed (Johannsmeier, 2001; reviewed in Dietemann et al., 2009)

The number of managed western honey bee hives is increasing at the global scale, although seasonal colony loss is high (IPBES 2016). FAO data show that the number of western honey bee hives has increased globally by about 50% over the last five decades, despite a temporary drop during the 1990s after the dissolution of the Soviet Union and Eastern-European Soviet Bloc. It is unknown whether this decline is an artefact of how data was collected and reported, or the result of a true decrease in honey bee hives that resulted from the political and economic disruption caused by the Soviet collapse. FAO data also show that national trends vary widely among countries, with contrasting trends (increases, decreases, no change) found between countries within continents. Within Africa, FAO data shows increasing growth in number of hives in northern and eastern Africa, and in Senegal and Central African Republic (Figure 12).

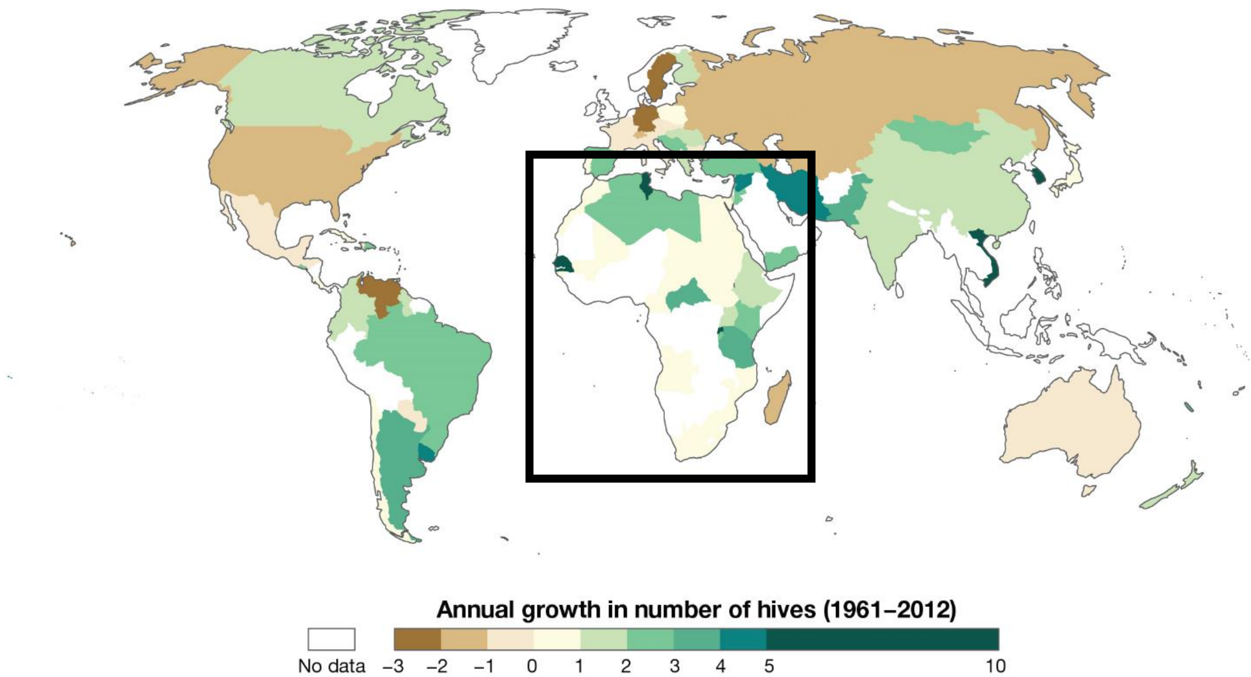


Figure 12. Honey bee colony densities and world map showing the annual growth rate (%/yr) in the number of honey bee colonies and honey production for countries reporting those data to FAO between 1961 and 2012 (FAOSTAT 2013). Data from the countries that were part of the former Soviet Union, the former Yugoslavia, or the former Czechoslovakia have been combined.

It should be noted that there are inherent difficulties in determining trends in the number of honey bee colonies for biological and sociological reasons, and these trends are often conflated with rates of colony mortality. Specifically, it is difficult to determine the number of honey bee colonies in a geographic locality in the Africa region for five reasons: 1) unlike other livestock, a honey bee colony can be divided by a beekeeper into two or more parts during the active season to multiply colony numbers and, conversely, colonies can be united into one in periods of flower dearth or cold temperatures; 2) an entire honey bee colony may depart (abscond) or be acquired as a passing swarm; 3) beekeeping is a labor-intensive activity and colonies are often not registered; 4) there are unknown numbers of wild honey bee colonies in Africa; and 5) there is variation across nations in how data on colony numbers are collected and interpreted. These factors compound to hamper reports on colony numbers (the total number of colonies at any one point in time) and annual rates of colony mortality (the proportion of colonies that die in one year).

Rates of colony mortality have recently been reported to be much higher than the usual rate of ca. 10%, and up to 30% or more since the winter of 2006-to-2007 in some parts of the temperate Northern Hemisphere (Oldroyd 2007), and may be equally high in South Africa (Pirk et al. 2014).

In the sections below, the trends in managed pollinators in South Africa and Kenya are focused upon, as two countries with some available data; it can be expected, though not confirmed, that trends are similar in nearby countries and similar ecosystems.

Honey bees in South Africa

In South Africa there are two subspecies of honey bees, the Cape honey bee, *Apis mellifera capensis*, and the African or Savannah bee, *Apis mellifera scutellata* (Hepburn and Radloff, 1998). Both of these honey bee species are managed and appear to be healthy despite presence of pests (e.g. *Varroa* mites) and diseases (e.g. American foulbrood) (Pirk et al., 2014). The data on the number of honey bee colonies in South Africa is outdated however, with the last census conducted in 1975 and not systematically conducted. Recently, Pirk et al. (2014) quantified honey bee colony loss in South Africa by conducting a beekeeper survey to assess the extent and the potential causes of colony losses in the country. Their study, based on 4-8% of the total population of beekeepers in South Africa, found colony losses (reported losses over two consecutive years, 2009–2010 and 2010–2011, of 29.6% and 46.2%, respectively) were higher than those considered acceptable in Europe or North America. The high rate of colony loss is not alarming to local/national beekeepers in South Africa since loss can be compensated by catching and rearing wild swarms rather than building colonies by replacing imported queens or breeding queens (Hepburn and Radloff, 1998; Johannsmeier, 2001; Dietemann et al., 2009).

A major factor of colony loss for *Apis mellifera scutellata* is attributed to the *Apis mellifera capensis*, a worker social parasite. This problem is unique to South Africa (Callis et al. 2005; Härtel 2006; Neumann and Hepburn, 2002;). Once *Apis mellifera capensis* honey bees gain entry to Apis mellifera scutellata colonies, Cape workers lay eggs and start reproducing parthenogenetic offspring that are females (Ruttner 1977). Their brood is necessarily nursed by African workers, which provide Cape larvae with more food than their own larvae (Calis et al. 2002, Allsopp et al. 2003). This results in the production of intermediates between workers and queens that are physically more adapted to reproductive behaviour (Calis et al. 2002, Allsopp et al. 2003). Due to the increasing number of laying Cape bees the social organisation in the colony disappears and the colony usually dies, but some Cape bees may spread to other colonies (Hepburn & Allsopp 1994). Subsequently, migratory beekeeping practices facilitates the spread of parasites and the loss of colonies as migratory beekeepers experience more colony loss, on average, than the stationary beekeepers.

Honey bees in Kenya

Honey bee health varies throughout the continent. A nationwide survey was carried out across Kenya in 2010 to evaluate the numbers and sizes of honey bee colonies, presence of parasites (*Varroa* mites and *Nosema* microsporidia) and viruses, to identify and quantify pesticide contaminants in hives, and to assay for levels of hygienic behavior (Muli et al. 2014). It was found that while *Varroa* infestation dramatically reduces honey bee colony survival in the US and Europe, in Kenya *Varroa* presence alone does not appear to impact colony size. *Nosema apis* was found at only three sites along the coast and one interior site. Only a small number of pesticides at low concentrations were found. The study suggests that parasites and viruses appear to be recently introduced into Kenya, but are not yet impacting bee populations.

Ultimately, the health of bees is affected by many factors. One of the possible contributing factors to the relative health of African honeybee populations may be their relatively smaller exposure to pesticides, as compared to populations in North America and Europe. Given equivalent levels of exposure, the impacts of specific pesticides on honey bee health and metabolic functions may not be different from that seen in other regions (Tosi et al., 2016).

Bumble bees and solitary bees

Bumble bees are not native to the sub-Saharan Africa, but as they are used as managed pollinators in intensive horticultural production in other parts of the world, experiences in the movement of bumblebees may inform the question of importing bumblebees. The movement of bees and the intentional introduction of bees for the purposes of crop pollination can result in unanticipated outcomes, as has been the experience with bumble bees (Dafni et al. 2010). At least four species of *Bombus* have been introduced to new countries to enhance crop production. For example, *B. hortorum*, *B. terrestris*, *B. subterraneus*, and *B. ruderatus* were introduced from the UK to New Zealand. *Bombus terrestris* has been also directly introduced from Europe to Israel, Chile, Asia, Central America, Northern Africa, and secondarily introduced from Israel to Chile, and from New Zealand to Japan and Tasmania. *Bombus ruderatus*, in turn, was introduced from the UK to New Zealand, and secondarily from New Zealand to Chile. Both *B. terrestris* and *B. ruderatus* spread secondarily from Chile to Argentina (Montalva et al. 2011) (Figure 13).

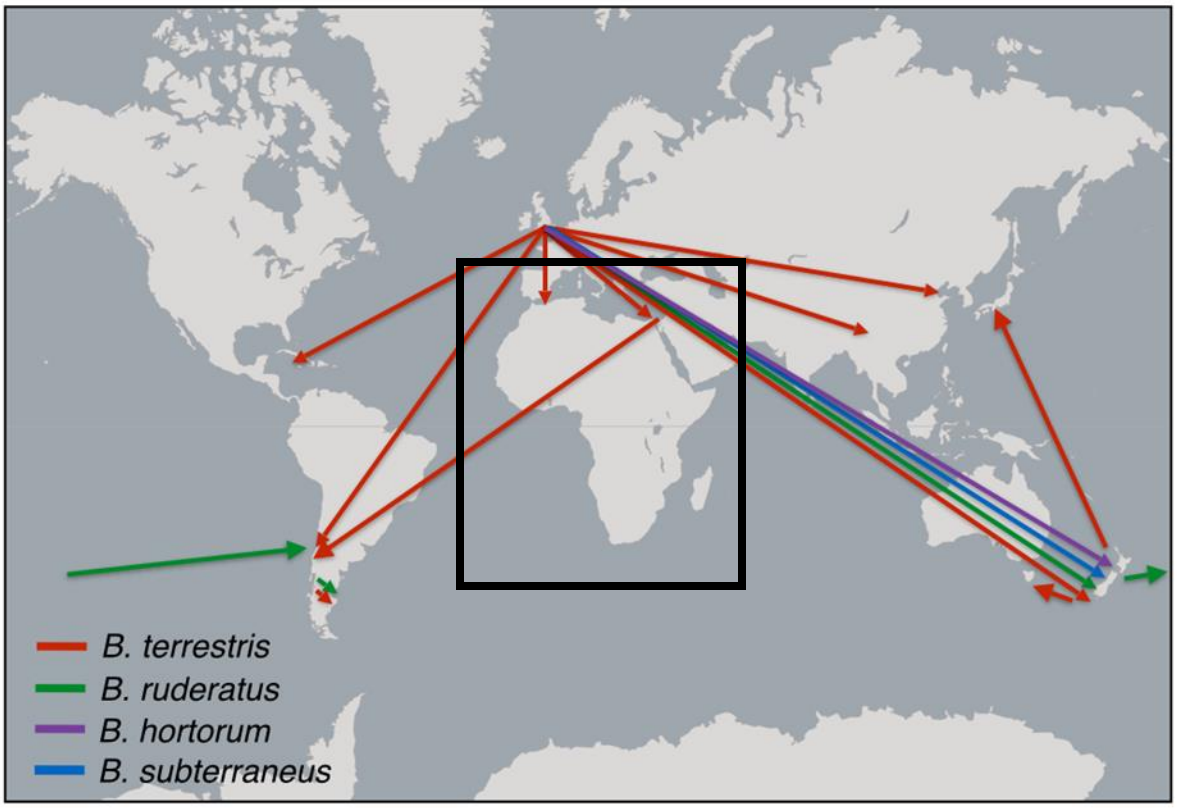


Figure 13. Global introductions of European bumble bees, *Bombus* spp. summarizes the main routes of invasion of *Bombus* species in the world. There is a clear primary source of invasion originating in Europe. A secondary source of invasion started in New Zealand. A conspicuous non-intentional spread has occurred from Chile to Argentina, with a subsequent spreading in the Argentinean territory, a process that is currently ongoing (Morales et al. 2013).

Conversely, aside from the honey bee, *Megachile concinna* Smith 1879 and *M. derelictula* Cockerell 1937 are leafcutter bees that were introduced to North America (including the Caribbean) most likely from Africa (Frankie et al. 1998, Gibbs and Sheffield 2009). *Megachile concinna* are known to pollinate alfalfa in the United States (Raw 2004) and *M. derelictula* was introduced to the Caribbean. There is a dearth of knowledge in understanding the implications of movement of bee taxa from one continent or region to another.

Trends in stingless bee keeping and wild honey bee colonies

Stingless bees, in the tribe Meliponini, are one of the groups of social bees that live in colonies, constructing hives that include production and storage of honey (Roubik, 1989). Stingless bees are widely distributed in the tropics and sub-tropics and have been widely managed/exploited in central and south America and Africa (Cortopassi et al., 2006; Quezada-Euán et al., 2001; Nates-Parra and Rosso-Londoño 2013; Kwapong et al. 2010). New insights into their nesting habits and ecology are emerging from Africa (Nkoba et al., 2014)

Knowledge of the rewards contained within stingless bee hives appears to be fairly ancient. In addition, many hunter-gatherer peoples, including the Hadzabe of Tanzania (Peterson, 2013; Marlowe et al., 2014) and the Abayanda of Western Uganda (Byarugaba, 2004) have folk taxonomic systems recognising distinct species of stingless bees and the different qualities of their honey. Wild harvesting of stingless bee honey is also widely practiced in Africa today (Kwapong et al. 2010). The bulk of stingless bee diversity is found in the Neotropics, with over 400 species described from Brazil alone where > 30 spp. are important for honey production. In the African dryland, savannah and forest habitats they can be among the most abundant bees seen at flowers (Martins, 2004).

Box A: Honey and Hadza hunter-gatherers in Tanzania (Marlowe et al., 2014)

The Hadza live near Lake Eyasi in northern Tanzania. As a source of energy, honey remains an important food for the Hadza peoples of Tanzania; honey is cited as one of their favorite foods and is collected from seven different species of bees. Both men and women are involved in collecting honey. Hadza women normally collect honey that is close to the ground or at eye level- often in holes in Commiphora trees- from stingless bees such as *Hypotrigona ruspolii*. This type of honey is referred to as Kanoa, and is collected more often than all other types of honey but it comes in smaller amounts than ba'alako, the honey made by honey bees, *Apis mellifera scutellata*. It is the men who climb baobab trees to collect ba'alako (honey) from *Apis meliifera scutellata* hives. Men will use honeyguides to lead them to these *Apis mellifera scutellata* hives. Honey accounts for a substantial proportion of the kilocalories in the Hadza diet, especially that of Hadza men.

Table 4 - Bee species used by the Hazda

Hazda name for honey	Type of bee	Latin species	Traits
Ba'alako	Stinging bee	*Apis mellifera scutellata*	Usually in baobab tree
Kanoa	Stingless sweat bees	*Hypotrigona ruspolii*	In Commiphora tree
Tsunako	Stingless sweat bees	*Hypotrigona gribodoi*	In Commiphora tree
Nateko	Stingless	*Meliponula ferruginea;*	In trees

Bambahau	Stingless	*Cleptotrigona cubiceps**	In trees
Mulangeko	Stingless	*Meliponula beccarii*	Underground
Lulindi	Stingless	*Plebeina hildebrandti*	Underground

**noted by Eardley (pers. comm.) to be a possible misidentification*

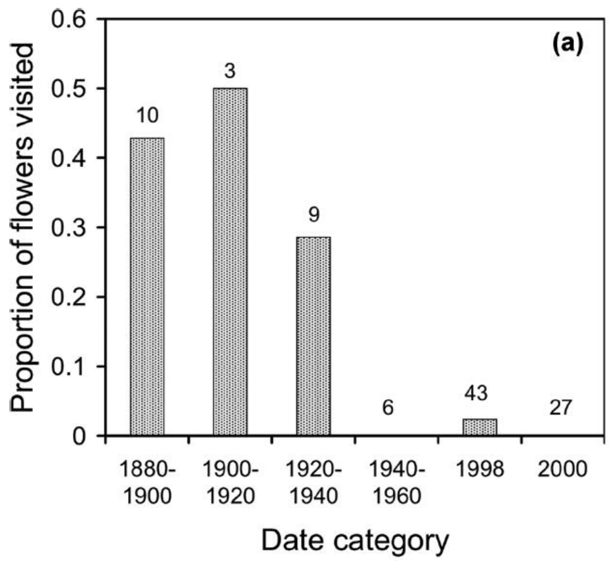
In Kenya, stingless beekeepers in Kakamega Forest recalled times when stingless bees and their products were a common part of the forest-edge households' livelihood and diet. However, the decline in abundance of stingless bees, due to habitat loss, has resulted in fewer keepers of stingless bees. Loss of stingless bees in Kenya appears to be driven by both loss of habitat as well as wild-harvesting of colonies (Martins, 2014). As more areas of tropical forest are lost, this trend is expected to continue both for stingless bees and other bees. This has been as widely echoed by the forest-dwelling Ogiek and other hunter-gatherer peoples in East Africa who have had to adapt cultural practices such as payment of dowry, - traditionally done with several large bags of honey - to a token amount of honey today due to the decline in availability of wild colonies for harvest. The scarcity of honey is attributed to destruction of forests, overharvesting, logging and charcoal production (Samorai Lengoisa, 2015). Agricultural intensification can also change the availability of wild honey, and this trend has been documented in Ethiopia (Verdeaux, 2011)

There is thought to be a decline in stingless bee husbandry in the Americas and Africa and changes in habitat management for wild honey bee species in Asia by local and indigenous communities. This is in part due to the loss of indigenous and local knowledge and sustainable bee management practices within local communities (Martins, 2014; Samorai Lengoisa, 2015). Shifts in social systems, cultural values, and accelerated loss of natural habitats have been associated with a decrease in the transfer of knowledge within and between generations. Whether there is a link between stingless bee husbandry decline and the loss of pollination of crops and wild flowering plants remains unknown.

Trends in pollinator abundance and diversity are linked to trends in plant reproduction

The life cycle of an animal-pollinated plant is a sequence of events starting with the arrival of the pollinator and ending with the flowering of the next generation. For pollinator decline to matter for plant population persistence, it must translate into changes in pollination rate, pollen receipt, fertilisation, seed set, the number of seedlings produced, and ultimately the rate of establishment of new plants. At any step in this procession, initial effects may fail to be transmitted and pollinator loss alone will then not cause a decline in plant abundance.

Direct comparisons with historical pollination rates are rare. In one study in South Africa, century-old herbarium specimens were rehydrated and examined for evidence of pollination. The historical pollination rates were found to be many times higher than current rates from the same location. There was a contemporaneous shift in plant community composition at the site due to the local extirpation of species that were unable to reproduce vegetatively, consistent with their greater dependence on seeds and pollination for population persistence (Pauw and Hawkins 2011) (Figure 14). While the ability of certain plant species to persist into the medium term without pollinators is good news, it can also be seen as a temporary relief, or an extinction debt, which we will pay in the long-term when the failure of seed production finally causes population decline, or the loss of genetic diversity. An essential point may be that as we lose pollinators or plant species from networks, others take up the role, although not always as efficiently (Brosi et al., 2013) Some evidence suggests that at a certain level of species loss, pollination networks may begin to collapse (Lever et al., 2014).



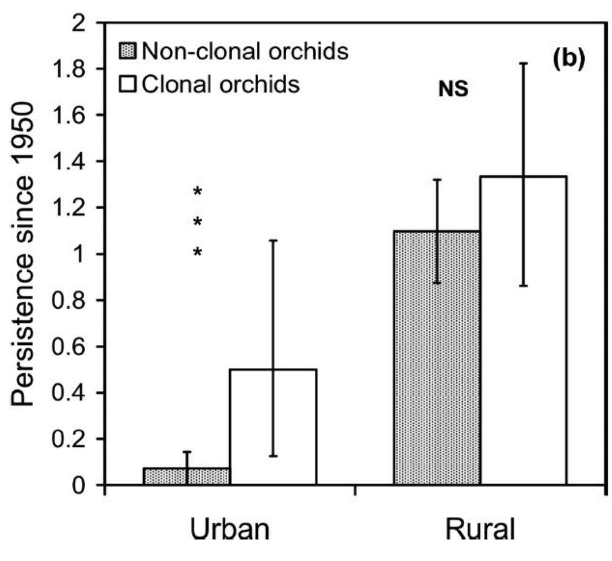


Figure 14. (a) Reconstruction of historical pollination rates from herbarium specimens of *Pterygodium catholicum* collected on Signal Hill, South Africa. Pressed herbarium specimens contain a record of past pollinator activity in the form of pollinarium removal rates. Sample sizes are above bars. (b) Following the human-caused loss of the pollinator, an oil-collecting bee, the orchid assemblages shifted in favour of greater representation by clonally reproducing species in urban areas, while no such shift occurred in rural areas where the pollinator still occurs. A "Persistence" value of 1 indicates that the number of pre- and post-1950 herbarium records is equal. Figure reproduced from Pauw and Hawkins (2011), with permission from John Wiley and Sons.

In most cases historical base-line data are lacking and researchers use space-for-time substitution, i.e. they compare human-altered areas with natural areas, assuming that the human-altered areas historically resembled the natural areas (Aizen and Feinsinger 1994, Murren 2002, Steffan-Dewenter et al. 2002, Pauw 2007). In these studies, it is important to account as far as possible for "natural" spatial variation.

Trends in demand for pollinators

Global agriculture is becoming increasingly pollinator-dependent. The proportional volume of agricultural production dependent on pollinators has increased by >300 % during the last five decades (Aizen et al. 2008; Aizen and Harder 2009). This increase in pollinator-dependency of agriculture has been steeper in developing countries in Africa, Asia and Latin America than in, (with some exceptions- e.g., Canada) developed countries in North America, Europe, Australia and New Zealand. In 2006, pollinator-dependent crops comprised 33% of developing country and 35% of developed country cropped land area (Aizen et al. 2008; Figure 15)

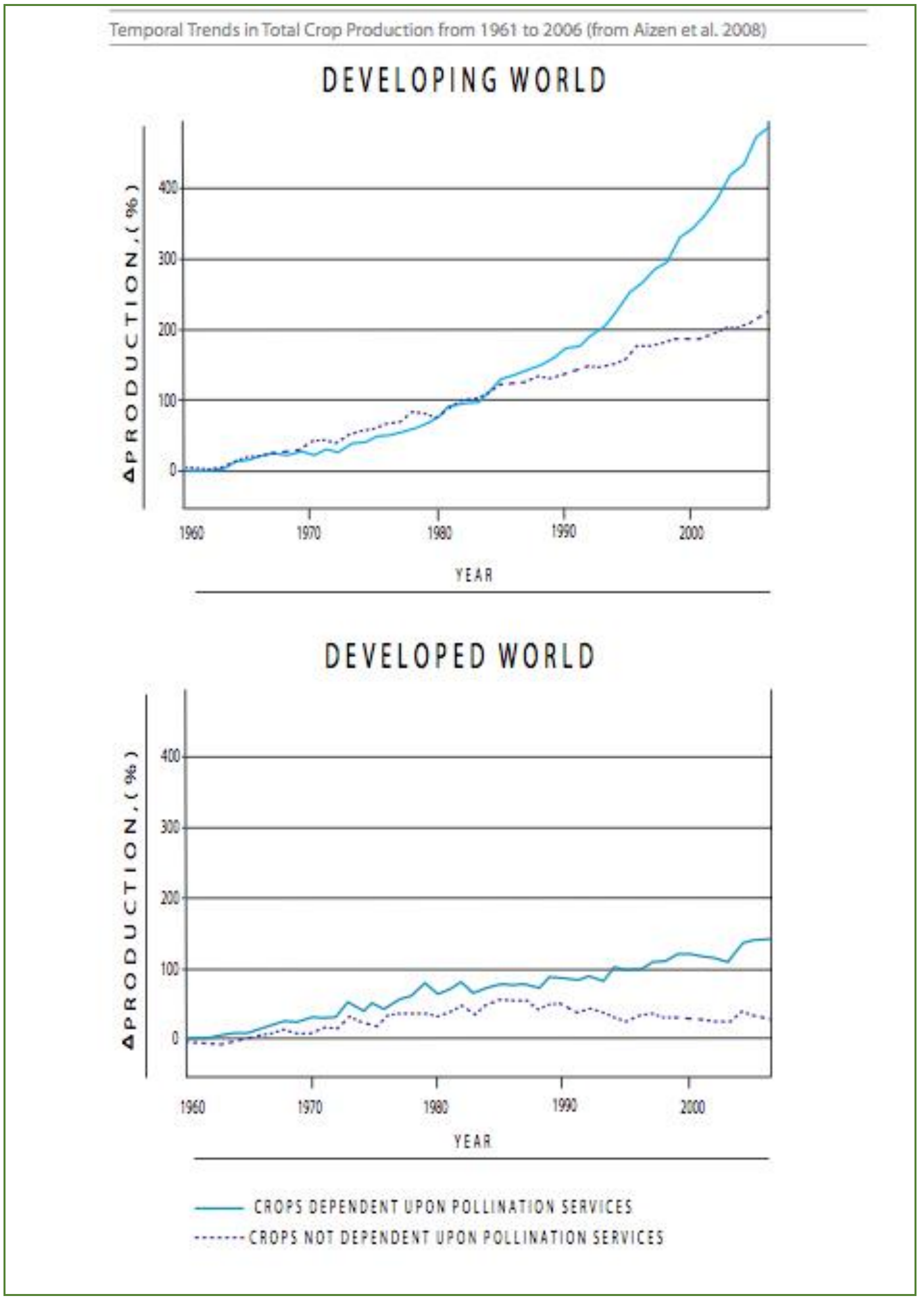


Fig. 15. Temporal trends in Total Crop Production from 1961 to 2006 (from Aizen 2009, page 2).

The small fraction of total agricultural production that depends directly on pollinators has increased four-fold during the last five decades, whereas the fraction of food production that does not depend on pollinators has only increased two-fold. Current trends, linked to the increase in the horticultural sector, show vastly greater increases in pollinator-dependent crops in developing regions of the world than in developed countries. Therefore, global agriculture is now twice as pollinator-dependent compared to five decades ago, a trend that has been accelerating since the early '90s. Yet, a rapidly increasing human population will reduce the amount of natural habitats through an increasing demand for food-producing areas, urbanization and other land-use practices, putting pressure on the ecosystem service delivered by wild pollinators. One way of understanding such trends is to consider what the losses in agricultural production would have been in the past and what they would be now, should animal pollinators disappear, as an indicator of overall vulnerability of different countries in Africa. (Figure 16 below).

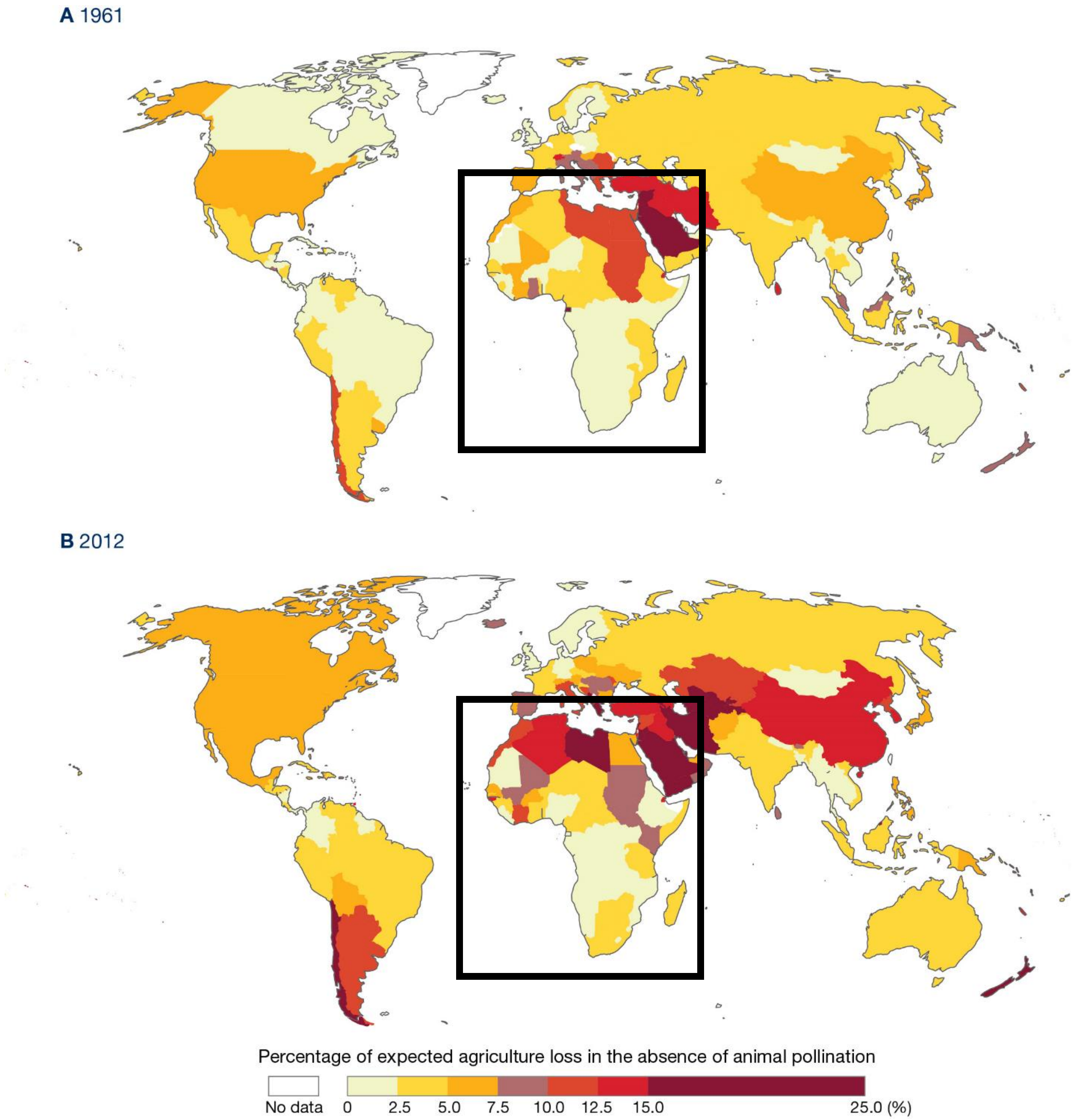


Figure 16. World map showing agriculture dependence on pollinators (i.e., the percentage of expected agriculture loss in the absence of animal pollination, categories depicted in the coloured bar) in 1961 and 2012 based on FAO dataset (FAOSTAT, 2013) and following the methodology of Aizen et al. (2009).

At the local scale, yields of many pollinator-dependent crop species have been shown to be positively related to wild pollinator diversity (Garibaldi et al., 2013). As a consequence, reductions in crop yield have been found in agricultural fields with impoverished bee faunas despite high honey bee abundance. While pollination efficiency varies considerably between species and crops, wild bees as a group have been found, on average, to increase crop yield twice as much as honey bees on a per-visit basis (Garibaldi et al., 2013).

Trends in supply of pollinators for agriculture- wild pollinators

A global analyses of FAO data did not show slowing in yield growth of pollinator-dependent crops relative to pollinator-independent crops over the last five decades (1961-2007), although the trend in declines of some native bees may change this situation (Garibaldi et al., 2011). Globally, yield growth and stability between 1961-2008 has been negatively associated with the increasing dependency of crops on biotic pollination. Thus, those crops with a stronger dependence on pollination show relatively less yield growth and stability than those with less or no dependence. Cultivation of pollinator-dependent crops largely accounts for the 30% expansion of the global cultivated area occurring during the last fifty years. FAO data revealed that crops that largely depend on pollinators have experienced the fastest global expansion in cultivated area. However, these crops exhibited the slowest average growth in yield and highest inter-annual yield variability. To express this in simple terms, the more a crop is dependent on pollination, the more likely it is to (a) be increasing in the land area over which it is produced; (b) to have slow yield growth; thus increases in production are largely due to increases in land area over which it is produced and (c) have less stable yields on average than non-pollinator dependent crops. While none of these facts prove causality, it has been hypothesized that a chain of events could be occurring in which the areas of wild or semi-wild habitat that often promote wild pollinator populations may be increasingly being cleared for cultivation, leading to slow yield growth and instability of yields in pollinator-dependent crops.

Trends in supply of pollinators for agriculture- managed pollinators

In many parts of Africa bees are still kept in simple boxes, straw skeps, hollow logs, walls of houses, bark tubes and clay pots, and entire honey combs are cut from these hives. However, there have now been many decades during which training in apiculture has been provided throughout the continent, using hive systems that allow for greater management of colonies. It has been documented that trends toward greater use of managed honeybee colonies for crop pollination (e.g. apples in South Africa, Johannsmeier 2001) has been a major practice in increasing levels of pollination service to agricultural production (Hauser and Mpuya, 3004; Melin et al., 2014).

Status and Trends in Crop pollination deficits (Global and within the African region)

A recent worldwide meta-analysis including data for 41 crops grown in 600 cultivated fields distributed across all continents, except Antarctica, reveals that diverse assemblages of wild bees seem to be important to reduce pollination deficits and sustain high yields of many pollinator-dependent crops (Garibaldi et al., 2013; Figure 17). Specifically, this study found that flower visitation by wild bees increases crop fruit and seed set, on average, twice as much as visitation by the domesticated honey bee, *Apis mellifera*, on a per-visit basis. Furthermore, declining pollination provided by wild bees might not be substituted by stocking fields with more honey bee hives, although honey bees can add to the pollination provided by wild bees (Garibaldi et al., 2013). Whereas complementary pollinating activity between wild bees and honey bees can explain this overall additive effect, diverse pollinator assemblages ensure the inclusion of one or more species of efficient pollinators. For instance, yield of marketable French bean production in the Mt. Kenya region was found to be positively correlated with the abundance of carpenter bees (*Xylocopa* spp.), despite high abundance of honey bees (Masiga et al., 2014).

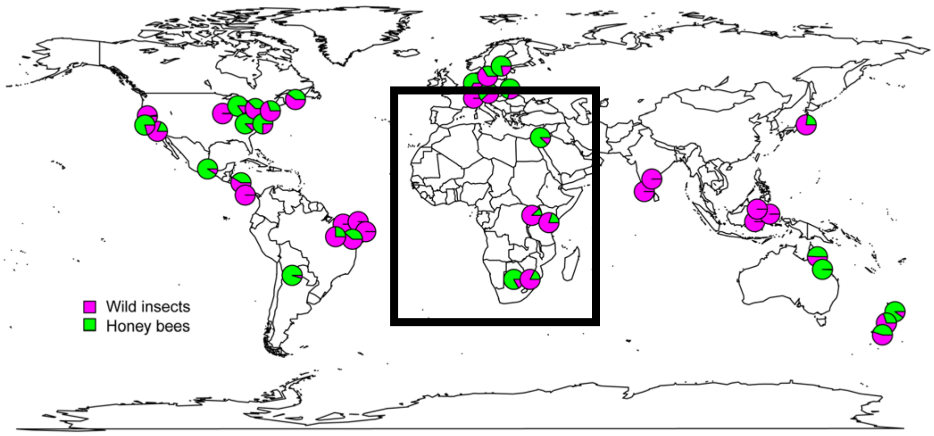


Fig. 17. Locations of the 41 crop systems studied. Symbols indicate the percentage of total visitation rate to crop flowers contributed by honey bees (*Apis mellifera* L.) and wild insects. Honey bees occur as domesticated colonies in transportable hives worldwide, as a native species in Europe (rarely) and Africa, or as feral populations in all other continents, except Antarctica. Three datasets from Africa include those from South Africa (2) and Kenya (1).

The impacts of agricultural intensification on pollinators has been the focus of many studies, however, most of these have been carried out in North America or Europe, under quite different farming systems from those found in Africa. One study carried out in Kenya focused on pigeon pea farming systems and examined how agricultural intensification affected pollinator guilds (Otieno et al. 2015). For this study, agricultural intensification included aspects of landscape complexity (i.e. resource diversity), distance of crop field to natural habitat (i.e. resource accessibility) and management practices (namely insecticide application). They found bee abundance to be correlated with fruit set; they also found a positive correlation of carpenter bee abundance and fruit set. As with the findings of the aforementioned meta-analysis to which this study contributed, visitation by wild bees increased crop fruit and seed set.

A recent global analysis (Kleijn et al. 2015), which includes data from 20 pollinator-dependent crops in about 1400 crop fields, proposes that the contribution of wild bees to crop production is limited to a subset of bee species that are common in agroecosystems. It seems likely that: 1) crop pollination deficits are common and 2) enhanced and sustained yields of many crops can be better ensured by both promoting specific pollinator species and the maintenance and restoration of diverse pollinator communities. While the analysis was global in scope, it could include only one relevant study from Africa (Carvalheiro 2012).

Drivers and Response

Direct Drivers

A wealth of observational, empirical and modelling studies worldwide point to a high likelihood that many drivers have affected, and are affecting, wild and managed pollinators negatively. However, a lack of data, particularly outside Western Europe and North America, and correlations between drivers make it very difficult to link long-term pollinator declines with specific direct drivers. Changes in pollinator health, diversity and abundance have generally led to locally reduced pollination of pollinator-dependent crops (lowering the quantity, quality or stability of yield) and have contributed to altered wild plant diversity at the local and regional scales, and resulted in the loss of distinctive ways of life, cultural practices and traditions as a result of pollinator loss. Other risks, including the loss of aesthetic value or wellbeing associated with pollinators and the loss of long-term resilience in food production systems, could develop in the longer term. The relative importance of each driver varies between pollinator species according to their biology and geographic location. It can be quite difficult to explicitly rank drivers according to their risk of causing harm, since drivers can combine or interact in their effects.

Land use change

Since 1961, croplands have been expanding at the global scale and on most continents including Africa, with concomitant global reductions in forest and grasslands (http://faostat.fao.org/; a global annual average of 0.2% increase of croplands, accompanied by a reduction of 0.16% of forest land per year). This pattern was also revealed in modelled reconstructions of land cover using historical land use data for the last 300 years (Hansen et al., 2013; Hooke and Martín-Duque, 2012; Klein Goldewijk and Ramankutty, 2004; Ramankutty and Foley, 1999). By 2030, most optimistic scenarios predict a net forest loss associated with a 10% increase in the area of agricultural land, mainly in the developing world (Haines-Young, 2009). Urban areas are also predicted to expand as a consequence of 66% (vs. 54% today) of the increasing global human population expected to be living in urban areas by 2050 (UN, 2014). Forecasts suggest global increases are expected to be larger in developing countries, mainly in Asia and Africa (UN, 2014). For example, in East Africa between 1960 and 2000, the population in urban areas of Kenya grew from 7 to 30% of the total population (Tiffen, 2003).

Outside of the African region (i.e. Europe and North America), research on the effect of habitat loss and degradation on pollinators and pollination is scant. Below we report on the few studies that have examined these aspects within the African region.

Habitat fragmentation

Habitat fragmentation can affect plant reproductive success negatively. In the renosterveld shrublands in South Africa, pollinator diversity and reproductive success (i.e. fruit and seed set) of perennial plant species were measured in three different habitat sizes: small, medium and large (Donaldson et al., 2002). Although they found that pollinator species (bees, flies and butterflies) were not affected by varying habitat fragment sizes, they did find habitat fragment size did affect the abundance of particular bee and monkey beetle species. A global review and meta-analysis of 53 studies and 89 wild plant species showed a large and negative effect of fragmentation on pollination and on plant sexual reproduction (Aguilar et al., 2006). This meta-analysis included wild plant species *Berkheya armata, Brunsvigia radulosa, Cyanella lutea, Gerbera aurantiaca, Gladiolus liliaceus, Ornithogalum thyrsoides, Oxyanthus pyriformis, Pterygodium catholicum, Trachyandra birsuta,* found in shrublands, temperate forests and grasslands of South Africa.

Habitat isolation and connectivity

Habitat isolation and connectivity can also affect the delivery of crop pollination, measured as the relationship between fruit set and/or crop visitation rates of different pollinators and distance to resource-rich habitats. Synthesis of data across several pollinator taxa, pollinated crops and wild plant species from different biomes showed that pollinator diversity and abundance, and flower visitation, decrease with increasing distance from resource-rich locations (Garibaldi et al., 2011; Klein et al., 2007; Ricketts et al., 2008). Ricketts et al. (2008) synthesized results from 23 studies representing 16 crops on five continents, including Africa, found exponential declines in pollinator richness and native visitation rate with increasing distance from resource-rich areas. This correlation was more negative for visitation rate than for pollination richness. Visitation rates dropped more steeply in tropical than in temperate regions, and were steeper but not significantly different for social compared to solitary bees (see also Klein et al., 2002).

Box B. Habitat matters: eggplants in southwestern Kenya and the role of the agricultural matrix in conserving pollination services (Gemmill-Herren and Ochieng, 2008)
The interspersion of wild habitats together with cultivated land increases landscape heterogeneity and may increase pollination services to target crops such as eggplants (*Solanum melongena*). Eggplant flowers are hermaphroditic and capable of some self-pollination (Free, 1993). The flowers have abundant pollen normally expelled on to the female flower parts by "buzz pollination" and while normally "buzz pollination" is achieved by larger bees such as those in the *Bombus* (bumble bee) or *Xylocopa* (carpenter bee) genera, honey bee (*A. mellifera)* visitation has been shown to significantly increase fruit weight in eggplant (Levin, 1989).

In the Nguruman farming area of southwestern Kenya, eggplant crops are being grown intensively on plots recently cleared from riverine umbrella Acacia (Acacia tortilis (Forsk.) Hayne) forests. In this area, two solitary bee species, *Xylocopa caffra* and *Macronomia rufipes* were identified as effective pollinators of the eggplant. The visitation rates of these pollinators to eggplant flowers declined significantly with distance from the wild habitat, which in turn significantly reduces the seed set of at least one variety of eggplant. The increase in pollen deposition by increased pollinator visits close to wild habitat showed a significant increase in seed numbers.

Increased landscape heterogeneity and "higher quality" habitats may provide more diversity and options for floral and nesting resources for wild (social and solitary) bee species, with consequent impacts on crop yields. In addition to the study featured in Box B, in South Africa it was shown that mango trees more than 500 m from natural habitat had mango production over 40% lower than those bordering natural habitat (Carvalheiro et al, 2010). More recently, this was supported by a recent meta-analysis of 39 studies (605 sites) evaluated the effects of farm and landscape management on wild bees for 23 crops (Kennedy et al. 2013)

Land Management Practices

Clearly specific land management practices will have impacts on pollinator populations. While there are not systematic studies of different African farming systems on pollination services, a focus in other regions has compared organic or diversified farming systems versus conventional monoculture management. It has been shown that the lower levels or lack of inorganic fertilisers, pesticides, increased number of cultivated crops, smaller field sizes, diverse edge vegetation and higher local complexity, which can be defined as within-field wild plants, crops or plant diversity in the crop margins, can have considerable positive effects on pollinators and pollination (Garibaldi et al., 2014; Kremen and Miles, 2012; Shackelford et al., 2013). For example, a large meta-analysis found that more than 70% higher total bee abundance and 50% higher total species richness of wild bees could result from diversified farming systems (Kennedy et al., 2013). In South Africa, within large mango, *Mangifera indica* L. (Anacardiaceae) plantations, flying visitors to mango flowers were reduced by pesticide use and isolation (or distance) from natural habitats which can affect final fruit production. However, the integration of small patches of native flowers within these large plantations can ameliorate the decline of flower visitors to mango, thereby improving final fruit production and sustaining pollinator diversity within agricultural landscapes (Carvalheiro et al., 2012).

There are some caveats in applying a simple comparison between "organic" and "conventional" farming systems. Not all studies found increased pollinator species richness/abundance or increased diversity of plants on organic farms. On 205 farms in Europe and Africa (i.e. Tunisia and Uganda), Schneider et al. (2014) found that at farm scale, the diversity of bees was affected by the presence of non-productive land cover types rather than by the farming system (organic or not). On a regional scale, organic farming was beneficial to both species richness of plants and bees, but differences were not significant if tested separately within each of the 12 regions; meaning organic farm benefits with respect to species richness seen at the field level decrease when observed or scaled up to greater spatial levels/scales. Moreover, management type (organic vs. conventional) does not always match with plant or crop diversity. Conventional farms can be as diverse as organic ones (e.g., in Sweden – Andersson et al., 2005), while there are very large organic monocultures too.

The comparisons merit greater examination within Africa. Some of the studies mentioned above compared high-input systems with traditional land-use systems, the latter including classically low-input low-output livestock systems, arable and permanent crop systems, and mixed systems, that persist mainly in upland and remote areas of Europe (Plieninger et al., 2006). Most of these traditionally managed landscapes have disappeared in Europe today due to intensification or land abandonment (Stoate et al., 2001); however, they remain common in Africa.

The creation or maintenance of more diverse agricultural landscapes may result in more diverse pollinator communities and enhanced crop and wild plant pollination. Local diversification and tempering the intensity of land management should support pollinators and pollination; "ecologically intensifying" some traditional farming systems in Africa may sustain current levels of diversification while increasing yields.

Agricultural Pesticides

Globally, pesticide use on agricultural land varies according to the regional or local pest and disease pressures (FAOSTAT 2014) as well as factors such as the purchasing capacity and cultural practices of the farmers (Schreinemachers and Tipraqsa 2012; Heong et al. 2013; Heong et al. 2014). In many countries for which data are available (e.g., in the USA, Brazil and Europe) the total tonnage of pesticides used in agriculture is stable or increasing over time since the 1990s (OECD 2013; FAOSTAT 2014). For many other countries (e.g., in Africa and Asia) data are incomplete or absent. Some variations in pesticide use are driven by changing agricultural practices, for example, herbicide application in the USA has increased and insecticide tonnage decreased, both associated with the increase in the cultivation of herbicide resistant crops and with changes in efficacy (USDA 2014). However, even as globally pesticide tonnage has decreased, the toxicity of pesticide molecules on the market have markedly increased (Fig 18). Relative to their potency, modern insecticides are applied at higher rates than DDT was applied, which properly should cause alarm and prompt careful management (Cresswell 2016).

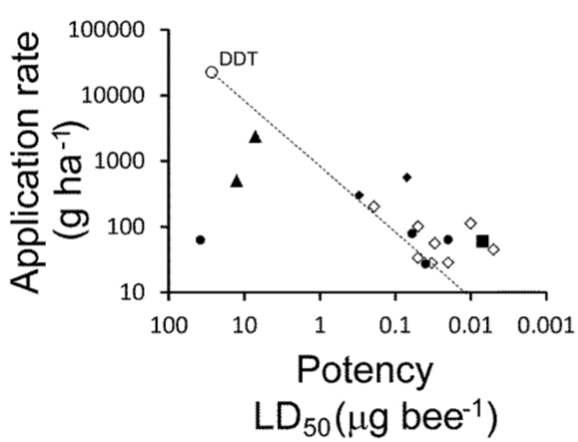


Fig. 18. Application rates of agricultural insecticides (also called 'plant protection products', or PPPs) relative to their potency. DDT is indicated by a labelled open circle and the dashed line indicates application rates if they decreased in proportion to increased potency relative to DDT. Chemical families of PPPs are indicated as follows: carbamates – closed triangles; neonicotinoids – closed circles; organophosphates – closed diamonds; phenylpyrazole (fipronil) – closed square; pyrethroids – open diamonds. Data are typical values obtained from a range of sources including the scientific literature, regulatory documents, agricultural extension departments and manufacturers' labels.
(from Cresswell 2016, p. 156)

Where data is available for developing countries, pesticide use has been seen to increase rapidly, sometimes against a low base level. However, international consensus over the level of risk posed by some of these pesticides has often not been reflected in reductions in the use of these chemicals in developing countries (Schreinemachers and Tipraqsa 2012).

In many high- and middle-income countries enforced restrictions on the use of organochlorine, organophosphate and carbamate insecticides that pose a high risk to human and environmental health have resulted in their replacement by neonicotinoids and pyrethroids (e.g., see Figure 19). For example, one of the significant changes in pesticide application methodology in the EU/US over the last 20 – 30 years has been the development of soil- or seed-applied systemic insecticides (e.g., the neonicotinoids) as an alternative to multiple foliar/spray applications (Foster and Dewar 2013). This class of systemic insecticides is now used on a wide range of different crops/application combinations in field and tree crops including foliar sprays, soil drenches and seed treatments in over 120 countries, including some in the African region, accounting for at least 30% of the world insecticide market (Nauen & Jeschke 2011; Simon-Delso et al. 2015). Their persistence in water and soil, uptake into crops and wild plants and subsequent transfer into pollen and nectar (Krupke et al. 2012, Johnson & Pettis 2014) potentially representing a significant source of exposure has led to concerns that they pose a unique, chronic sublethal risk to pollinator health (Van der Sluijs et al. 2013). In contrast, in low- and lower-middle income countries many of the older classes of insecticides are still widely used and excessive use due to lack of user training and stewardship is a significant concern (see Africa case study, Box C) (Tomlin 2009; Schreinemachers and Tipraqsa 2012; Heong et al. 2013).

Box C: Case Study: Pollinators and Pesticides in Africa

In Africa, there is a high demand for pollination for many crops (Gemmill-Herren et al. 2014). At the same time, pollinators are exposed to similar environmental pressures that have been associated with declines elsewhere in the world including inappropriate use of pesticides

Data on the pattern and amount of pesticide use in Africa are also very difficult to obtain and almost impossible to estimate for any single African country due to a lack of detailed lists of pesticide production and imports into these countries. The environmental impact of pesticides on pollinators has been reported by local farmers through the observation of the abundance of bees that populate their hives or through fluctuations in honey production. Efforts to evaluate pesticide impacts on pollinators are needed throughout the African continent, as existing studies are limited and geographically widely spread, and some of these raise great concerns.

For example, traditional beekeepers in Burkina Faso have noted that their hives situated near cotton fields treated with pesticides had lower numbers of adult bees and were less productive than those which were kept farther away (Gomgnimbou et al. 2010). In Kenya, bee abundance and seed set was observed to be higher in organically grown coffee in Kiambu County as compared to conventional farms with use of pesticides (Karanja et al., 2011). Similarly, Otieno et al. (2011) found pesticide use was negatively related to pollinator abundance in fields in Eastern Kenya. However, another study (Muli et al. 2014) suggested impacts may not be severe in all cases; relatively low levels of residues of up to four pesticides were detected in 14 out of 15 honey bee hives sampled across Kenya. In South Africa, pesticide use and isolation from natural habitat were associated with declines in flying pollinators and in mango production (Carvalheiro et al. 2012), although this effect was not consistent between years (Carvalheiro et al. 2010). There is a clear need for more studies of impacts of pesticides on pollinators and pollination given the economic importance of insect-pollinated crops throughout the African continent (Archer et al. 2014; Steward et al. 2014) and indeed across many developing countries.

Potential impacts of pesticides on pollinators

The use of insecticides is of particular concern due to their potential for effects on non-target insect pollinators due to their inherent toxicity (UNEP 2010; EASAC 2015). Although there is also evidence that some pesticide co-formulants such as adjuvants (used to enhance application and uptake of the pesticide) or synergists may also show toxicity at high doses (Donovan and Elliott 2001; Ciarlo et al. 2012; Zhu et al. 2014; Mullin et al. 2015). Insecticides vary widely in their mode of action from molecules interacting with nerve receptors to those affecting energy metabolism and development (e.g. insect growth regulators). Novel pesticides and modes of action are continually sought to address rapid development of resistance in target pests (Ohta and Ozoe 2014). There are very limited data available globally on actual usage of insecticides (as opposed to sales data) by farmers on crops attractive to pollinators from which to base a global assessment of potential risk. However, data from Kenya, Brazil and the Netherlands demonstrate the differences among countries in the availability of pesticides that are inherently toxic to bees (Figure 19; (van der Valk et al. 2013).

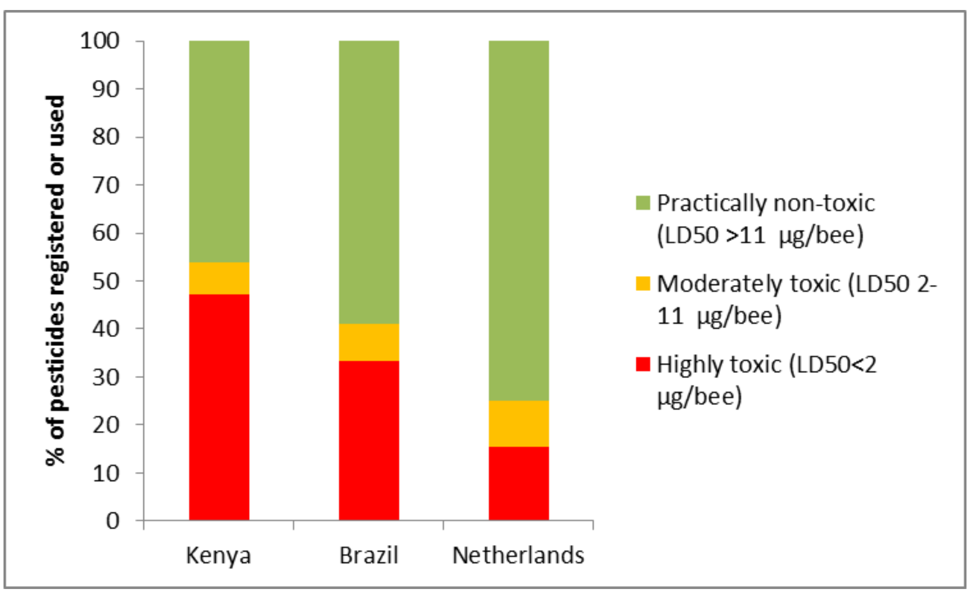


Figure 19: Hazard (LD_{50}) of pesticides used on bee-attractive focal crops in Brazil (melon and tomato), Kenya (coffee, cucurbits, French bean and tomato) and the Netherlands (apple and tomato) (% pesticides refers to number registered or used) (data from van der Valk et al. 2013).

There is evidence that the identity of pesticides present and scale of the exposure of honey bee colonies (levels in pollen, nectar/honey and wax) differ between crop type (Pettis et al. 2013) and regions reflecting differences in pesticide approval and use (Bogdanov 2006; Johnson et al. 2010; Mullin et al.

2010; Chauzat et al. 2011; Al-Waili et al. 2012). However, quantitative data on an individual pollinator's exposure to pesticides is limited, i.e. actual ingestion by a foraging bee, not measured residues. Almost all studies on pollen and nectar consumption have been on honey bees and often extrapolated from estimated nutritional requirements as a proxy for foraging rate (Thompson 2012) rather than measured directly. Exposure factors have been evaluated for wild bees on focal crops in Brazil, Kenya and the Netherlands (van der Valk et al. 2013).

Beyond honey bees, pesticides can lead to a decline in overall pollinator richness at a local scale. Again, using the example of mango plantations in South Africa, pesticides were found to be associated with a decline in the mango floral visitors (i.e. adversely affected pollinators) and was associated with declines in fruit production of two cultivars of mango (Carvalheiro et al 2010, 2012). The extent to which pesticides adversely affects pollinators most likely depends on frequency and magnitude of its use. In an earlier study in the same system pesticide application (organic farming practices vs. conventional farming practices) had no significant effect on any of the three groups of flower visitors (crawling insects, wild flying insects and managed honey bees) (Carvalheiro et al., 2010).

The use of pesticides and fertilizers on crops such as pigeon peas (*Cajanus cajan*) in Kenya can have an important negative effect on pollinator richness and abundance (Otieno et al., 2011), or on the reduction in floral diversity and floral resources over time. On a matter of scale, within fields, they found pesticide use to be a key negative predictor of pollinator, pest and predator abundance. In contrast, within fields, the use of fertilizers significantly increased both pollinator and chewing/sucking insect pest abundance (Otieno et al., 2011).

Other than a handful of studies on this topic, there has been very little focus or research conducted on the effect of insecticides or pesticides on pollinators in Africa (Rodger et al., 2004).

Chemical Use: Fertilisers

Globally, agricultural management is increasingly using high levels of inorganic fertiliser in place of organic manures (e.g. Richards, 2001; Figure 20). Global demand for fertilizer is expected to show a successive growth of 1.8 percent per year and to reach 200 million tonnes by the end of 2018 (FAO, 2014). Intensive fertiliser application per field can result in decreased diversity and cover of the less competitive wild plant species, and subsequent loss of forage for pollinators (Kleijn et al., 2009; Kovács-Hostyánszki et al., 2011).

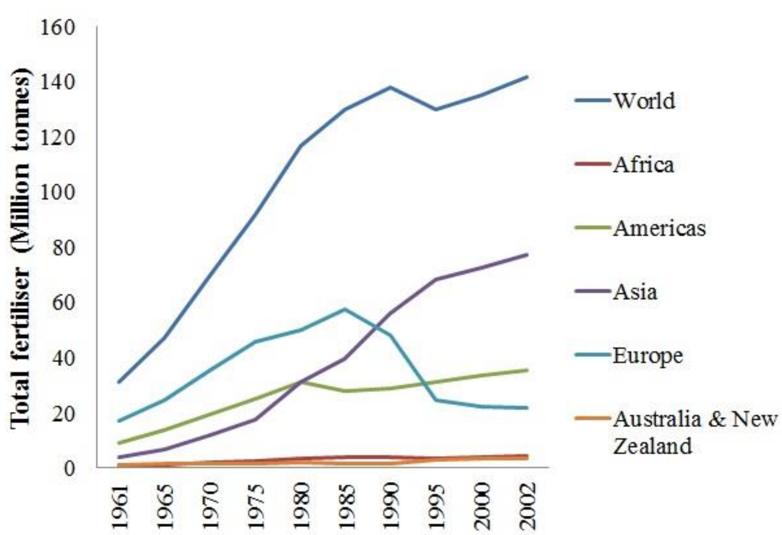


Figure 20. Total fertiliser consumption worldwide and separately at the different continents during the last half century. Data are shown in Million tonnes (FAO, 2014).

Tilling

Other management practices such as tilling can also influence pollinators and pollination services but have been studied to an even lesser extent in Africa. Tillage systems have a great influence on topsoil organic matter content, and other soil properties, which influence erosion and water quality. A global literature review found in many cases increased soil carbon sequestration with no-till compared to conventional tillage (Palm et al., 2014). Moreover, in a large assessment on no-till practices, a global meta-analysis across 48 crops and 63 countries examining 610 studies showed that overall no-till reduces yields, yet when no-till is combined with the other two conservation agriculture principles of residue retention and crop rotation, its negative impacts are minimized, and moreover it significantly increases rain-fed crop productivity in dry climates (Pittelkow et al., 2015). Meeting the future global food demand is a major challenge and the results of the meta-analysis suggest that no-tillage in addition to other management practices/conservation agriculture principles can result in agronomic benefits in water-limited and/or water-stressed regions and countries; this is especially important for sub-Saharan Africa as millions of hectares in its dry climates have been identified as “suitable for sustainable intensification efforts” (Pittelkow et al., 2015; ICARDA, 2014)[1].

The strong links between no-till and conventional tillage systems on pollinators and pollination services in Africa have not been documented. Tillage is sometimes harmful to ground-dwelling insects including pollinators (Julier and Roulston, 2009); some of these wild ground-dwelling pollinators (solitary bees), overwinter in the topsoil such as *Peponapis pruinosa* (Purvis and Fadl, 200;). Schuler et al. (2005) examined wild pollinator populations in squash and pumpkin sites and found that the density of squash bee density was related to tillage practices and on farms were they did not till (no-tillage) the density of squash bees were three times higher than those recorded on tilled farms. This study was conducted in the United States but the implications of tilling practices on ground-dwelling insects in the African region could be similar.

Other direct drivers

Fire can have significant, negative impact on plant reproductive success and is associated with statistically significant lower fruit set (McKechnie and Sargent, 2013). In the Cape Floristic Region of South Africa, nectar-feeding bird abundance and species richness was found to decrease in post-fire vegetation, and floral arrays within burnt vegetation received no visits by nectar-feeding birds (Geerts et al., 2012). Some studies, however, have shown that fire-dependent communities have indirectly and positively impacted pollinators by altering plant density and distribution (Van Nuland et al., 2013, Charnley and Hummel, 2011). Moreover, fires in Mediterranean climates are necessary for seed dispersal and germination (Pausas and Vallejo, 1999).

Pests of both managed and wild bees

Honey bee pests are numerous and include many invertebrates and some vertebrates (Morse et al., 1990). Birds can be problematic; "bee eaters" (*Merops* sp.) are pests in managed apiaries in the Old World (Fry, 2001; Kastberger and Sharma, 2000). Several hornets are major pests around the world

[1]International Center for Research in the Dry Areas (ICARDA) Geoinformatics Unit. http://gu.icarda.org/en/ (2014).

(Oldroyd and Wongsiri, 2009), and *Vespa velutina* has recently spread to Europe from Southeast Asia (Villemant et al., 2011). Invasive wasp species (*Vespula germanica* and *Polistes dominula* in South Africa have been found to prey on bees. Another pest that has recently expanded its host range is the small hive beetle, *Aethina tumida*, moving from Africa to the USA, Australia, Portugal and Italy in the past 20 years (Hood, 2004; Neumann and Elzen, 2004; Mutinelli, 2014). The small hive beetle has the potential to damage bees beyond the genus *Apis* and may threaten bumble bees (Hoffmann et al., 2008) as well as stingless bees (Greco et al., 2010). Of the known pest, the parasitic mites are most problematic, as they switch host and spread worldwide (Morse et al., 1990, Oldroyd and Wongsiri, 2009).

The checkered beetle (*Trichodes apiarius*) is commonly found in Europe and North Africa parasitizing both Megachile and Osmia bee species (Krunić et al., 2005), while *Trichodes ornatus* is common in North America (Fairey et al., 1984, Bosch and Kemp, 2001). According to Eves at al. (1980) this beetle can cause losses up to 89%, but on average around 30% in managed colonies. Methods of control are usually mechanical, like sorting the cocoons (Fairey et al., 1984) or eliminating the beetles using aromatic attractant bait traps (Wu and Smart, 2014).

Box D*. Varroa destructor* in South Africa: Lessons learned
Insect pollinators suffer from a broad range of parasites, with honey bee-specific ectoparasite *Varroa destructor* mites attacking and transmitting viruses among honey bees (*Apis mellifera*) being a notable example. Worldwide, most managed European honey bee colonies are infected by *Varroa destructor* – with a few exceptions: Australia, Fiji and Reunion island and possibly some central African countries such as the Democratic Republic of Congo) (Ellis and Munn, 2005; Potts et al., 2010).

Varroa destructor was first found on European honey bees in 1958 and since then the transport and uncontrolled movement of honey bees has led to its spread in Europe, North Africa, South America and to the USA (De Jong et al 1984; Needham 1988; Matheson 1995). *Varroa* were discovered in South Africa in October 1997 and has spread throughout South Africa since and is now found in almost all commercial and wild honey bee populations (Allsopp, 2006).

When the mite was detected/discovered in South Africa, the majority of beekeepers did not use chemical varroacides to combat *Varroa destructor*. Presently, long-term monitoring of both wild and commercial honey bee populations indicate a relative tolerance of African bees to the *Varroa* mite; making *Varroa* a mere incidental pest.

Varroa destructor is concluded not to be a serious threat to honey bees and beekeeping in Africa, and in part due to the management decisions regarding the use of chemical varroacides (pesticides) which could hinder the development of natural mite tolerance in Africa. Of the major regions in the world, only Australia and central Africa are at present free of the *Varroa* mite.

(Source: Allsopp, M. 2006. Analysis of Varroa destructor infestation of southern African honey bee populations. MSc thesis. University of Pretoria. Pp. 302)

Indirect Drivers

Indirect drivers (demographic, socio-economic, institutional, and technological) are producing environmental pressures (direct drivers) that alter pollinator biodiversity and pollination. The growth in the global human population, economic wealth, globalized trade and commerce and technological developments (e.g. increased transport efficacy), has transformed the climate, land cover and management intensity, ecosystem nutrient balance, and biogeographical distribution of species.

The African Agriculture Status Report (AGRA 2014) summarises evidence on increases in the frequency and severity of extreme events and climatic change within the continent. This can be expected to have consequences for pollinators and pollination in Africa. In a recent survey along elevational contrasts in Mount Kilimanjaro, Tanzania (Classen et al., 2015), temperature was shown to have strong positive effect on species richness, with higher levels of bee–flower interactions at higher temperatures. Pollinators can be expected to largely respond by contracting or expanding their ranges according to new climatic patterns (Kjøhl et al., 2011). Thus the possibility of crops losing key pollinating species, or mismatches in the ranges of crops and their pollinators, is a real threat. Resilience, however is built in agroecosystems through biodiversity. A diverse assemblage of pollinators, with different traits and responses to ambient conditions, is one of the best ways of minimizing risks due to climatic change. The "insurance" provided by a diversity of pollinators ensures that there are effective pollinators not just for current conditions, but for future conditions as well (Bartomeus et al. 2013).

International trade is an underlying driver of land-use change, species invasions and biodiversity loss. The global expansion of industrialised agriculture driven by increased or changing consumption in the developed and emerging economies will continue to drive ecosystem changes in the developing world that are expected to affect pollinators and pollination. The area of land devoted to growing pollinator-dependent crops has increased globally in response to market demands from a growing and increasingly wealthy population, albeit with regional variations. For example, all of the West African countries together produce approximately 56 per cent of world's stimulant crops (i.e. coffee, cocoa, tea etc.) and are vulnerable to pollinator loss; the economies of these countries and the livelihoods of the farmers and people connected to these commodities could be strongly affected by a loss in pollinator services (Gallai et al., 2009; Power 2010). Closely linked to globalization of agricultural production and trade is anticipated increases in agricultural inputs, which all potentially threaten pollinators and loom on the horizon (Brown et al. 2016).

Multiple pressures that individually impact the health, diversity and abundance of many pollinators across levels of biological organisation (from gene to biome scales), can combine in their effects and thereby increase the overall pressure on pollinators. This variety of threats (often anthropogenic) to pollinators and pollination poses a potential risk to food security, human health and ecosystem function. The actual magnitude of interactions between these different pressures varies with location and among pollinator species, according to their biological attributes. Nonetheless it is likely that changes in pollinator biodiversity and pollination are being exacerbated by both the individual and combined effects of multiple pressures.

Summary of Drivers

Land use is currently the main driver of land cover change, leading to changes in land cover composition and configuration. It is well established that habitat loss and degradation, as well as loss of connectivity, reduction in patch sizes, and fragmentation negatively affect pollinator diversity, abundance and richness. These changes can negatively affect community stability, pollination networks and the survival and evolutionary potential of pollinator and plant species. Finally, these changes also result in a reduction of plant fruit set, which is of critical importance for food security, ecosystem services and human welfare in wild and agricultural environments.

Land management alters most ecosystems, having considerable impact on pollinator communities, and crop and wild plant pollination. Large-scale, chemically-intensive agricultural systems that simplify the agroecosystem through specialization on one or several crops are among the most serious threats to natural and managed ecosystems. Agricultural management practices such as increased fertiliser use, intensive tillage systems, heavy use of pesticides and herbicides, high grazing/mowing intensity or badly-timed management actions decrease pollinator diversity dramatically, while influencing and reducing the effectiveness of ecological functions and services, like pollination.

Finally, large monoculture systems reduce both foraging and nesting resources for pollinators by removing flowering weeds and native plants and reducing crop diversity, and decreasing availability of undisturbed soil patches, hollow stems, shrubs, trees and dead wood that are needed for nesting sites. While certain mass-flowering crops provide large amounts of foraging resources (i.e. nectar and/or pollen) for some pollinators, these pulsed resources provide only temporary benefits that cannot sustain most pollinators throughout their life cycle.

Responses

Creating a more diversified agricultural landscape based on principles from sustainable agriculture, agroecology and organic farming management (i.e. intercropping, polyculture, crop rotations, cover-cropping, fallowing, agroforestry, insectary strips and hedgerows), has the potential to maintain rich pollinator communities, promote connectivity, and increase pollination of crops and wild plants, as well as improve livelihoods for smallholder farmers that make up the majority of the farming community and provide an estimated 50 – 70% of the world's food (Altieri et al., 2012; Herrero et al., 2010). However, concerns have been raised as to whether such techniques can be equally productive. Existing evidence suggests that organic farming methods are on average 10 – 25% less productive than conventional farming methods (Badgley et al., 2007; de Ponti et al., 2012; Seufert et al., 2012; Ponisio et al., 2015), although these yield gaps are reduced to 5 – 9% in organic farming that takes full advantage of diversification practices (intercropping and crop rotations) (Ponisio et al., 2015). Although organic farming suffers relatively small yield gaps, these yield gaps are balanced by enhancements that they provide to multiple aspects of sustainability (Kremen and Miles, 2012). A meta-analysis by Crowder and Reganold (2015) showed first, that organic systems with price premiums were significantly more profitable (22–35%) and had higher benefit/cost ratios (20–24%) than conventional agriculture, and second, that price premiums were far higher than necessary to establish equal profitability with conventional systems. Given their multiple sustainability benefits, these results suggest that organic farming systems could contribute a larger share in feeding the world at a lower price premium. A major gap in our understanding is how to reduce yield gaps in these more sustainable systems. Research, extension and infrastructure investment in sustainable agriculture, agroecology and organic farming management methods has been orders of magnitude less than in conventional scale agriculture (Ponisio et al., 2015; Carlisle and Miles, 2013), suggesting that increased investment in these techniques could lead to greater yields and profits, and to broader adoption (Parmentier, 2014). The lack of sustainability of monoculture systems that are highly dependent on chemical inputs, however, indicates the urgent priority for improving the productivity of more sustainable systems that will also promote pollinators.

Specifically, diversified farming systems are beneficial for biodiversity and ecosystem services, including pollinators and crop pollination. Provision of different crops and crop varieties not only benefits pollinators but also increases crop genetic diversity, potentially enhancing pollination. Maintenance of diverse wild plant communities within the crop fields and orchards provides a high variety of foraging resources before and after the crop flowering period that supports wild and managed bee health, and increases wild pollinator diversity and abundance on these fields with positive effects on crop pollination. Within-field diversification and application of less intensive management practices, will be more effective if wild flower patches and a diverse landscape structure is available nearby or around the managed sites. Furthermore, the conservation of pollinator habitat can enhance overall biodiversity and other ecosystem services such as biological pest control, soil and water quality protection (Kremen et al., 2012; Kremen and Miles 2012), and these secondary benefits should be incorporated into decision making (Wratten et al., 2012).

Knowledge systems

Diverse knowledge systems, including science and indigenous and local knowledge, contribute to understanding pollinators and pollination, their economic, environmental and socio-cultural values and their management globally. Scientific knowledge provides extensive and multidimensional understanding of pollinators and pollination, resulting in detailed information on their diversity, functions and steps needed to protect pollinators and the values they produce. In indigenous and local knowledge systems, pollination processes are often understood, celebrated and managed holistically in terms of maintaining values through fostering fertility, fecundity, spirituality and a diversity of farms, gardens and other habitats. The combined use of economic, socio-cultural and holistic valuation of pollinator gains and losses, using multiple knowledge systems, brings different perspectives from different stakeholder groups, providing more information for the management of and decision-making about pollinators and pollination.

The African Pollinator Initiative (2007) noted: **"**Traditional knowledge could offer guidance to the study, conservation and monitoring of pollinators. The local communities will also need to be involved in training and conservation. A farmer in Kitui District, a semi-arid part of Kenya, noticed flowers of pigeon peas dropping off without pod formation. The solution was to smear a few plants in the field with honey. This shows the perception of pollination and attracting pollinators in traditional knowledge. By their practices of favoring heterogeneity in land-use as well as in their gardens, by tending to the conservation of nesting trees and flowering resources, by distinguishing the presence of a great range of wild bees and observing their habitat and food preferences, many indigenous peoples and local communities are contributing to maintaining an abundance and, even more importantly, a wide diversity in insect, bird and bat pollinators."

Amongst important forms of traditional knowledge in Africa of importance to pollination management is the understanding of uncultivated plants. While agronomists may look at these plants as weeds, to many local communities the wild plants in farm landscapes may have particular meanings for men and women; for example, they may indicate soil fertility, or may have utility as botanical pesticides or medicinals. Many such plants provide alternative resources for crop pollinators. By being valued through traditional knowledge, their contribution to biological diversity can be sustained.

Traditional landscapes maintain wild flower patches that are often threatened by abandonment of these management practices, especially in remote sites. Cessation of management, such as grazing, mowing on grasslands, leads to vegetation succession that can have considerable negative consequences on the pollinator fauna. Therefore, maintenance of ecosystem healthy and optimal management at such valuable, traditionally managed systems is highly beneficial.

Capacity building in managing pollination services

Pollination ecosystem services can be supported by farming approaches such as providing suitable foraging and nesting habitat within bee flight ranges of crop fields. Tailoring pollinator-supportive measures to the wide range of potential crop situations that depend on bee-mediated pollination services is essential for gaining the greatest benefit in crop productivity. This will require improved understanding of crop- and region-specific approaches that can be implemented economically by farmers at the scale at which they have control over land management decisions. Recent research results from annual and perennial production systems indicate the returns that are possible from investment in local-scale practices to support wild bees (Isaacs et al. 2016). Appropriate measures may be quite different in Africa; see Box D.

Box E. Cassava in Ghanaian vegetable farms

It is a common practice in Ghana for some vegetable growers to line their field boundaries with one or two rows of cassava plants (Figure X). These plants are used to mark the field boundaries from their neighbor's farm. This is a practice which has socio-economic value as well as ecological value to their farms. Socio-economically, the farmers stand to gain not only from vegetables but they also could harvest some cassava from their farms. This means that he/she would not need to travel to a separate farm to get their carbohydrate needs. Also, this practice is a kind of mix or multiple cropping where the farmer has more than one crop type in the farm, providing food security by mitigating against crop failure. The other benefit of having a cassava border crop around a vegetable farm is typically unknown to the farmer. Most cassava will flower 3 months after planting, and this species produces profuse amounts of nectar that attract bees and other flower visitors. Hence the vegetable stands a good chance of receiving visitation by pollinators, which are attracted to the cassava flowers for resources. Even though this phenomenon is still under investigation, there is likelihood that vegetable crops such as eggplant, tomato and pepper benefit from pollinators which visit cassava flowers. (from Isaacs et al. 2016).

Managing for Pollinators and Natural Enemies Simultaneously

With respect to the interactions between pollination and pest-control services, a recent study (Shackleford et al 2013) carried out a meta-analysis on the distributions of pollinators and natural enemies in agroecosystems. They found that some pollinators and natural enemies seem to have compatible responses to landscape complexity, and it might be possible to manage agroecosystems for the benefit of both. However, too few studies have compared the two, - and very few of these studies have been carried out in Africa.

Pesticides

To effectively enhance crop production, local-scale management tactics that provide 'bottom-up' support of pollinators must also be coordinated with minimizing the 'top-down' restrictions on bee survival and reproduction that can be caused by pathogens, parasites, and pesticides (Isaacs et al. 2016). Two publications produced by FAO on assessing risk of pesticides to wild pollinators and a companion guide on "Pollinator safety in Agriculture" provide guidance on assessing risks to key bee groups and mitigating against harmful impacts.

Developing alternative pollinators: example of Meliponiculture

Stingless bees (Meliponini) are a traditional honey, propolis and wax source in South and Central America (Cortopassi-Laurino et al., 2006, Nates-Para, 2001; 2004), Australia (Heard and Dollin, 2000), Africa ((Kajobe, 2013, Eardley and Kwapong 2013, Kwapong et al., 2010) and Asia (Cortopassi-Laurino et al., 2006), with global reviews in Heard 1999 and Vit et al., 2013) Recently their role as possible managed pollinators of agricultural crops is also raising interest (Slaa et al., 2006; Giannini et al., 2014). Stingless bees are an important asset to fulfill the growing agricultural demand for pollination, because they could compensate for the local declines in honey bee populations (Brown and Paxton, 2009, Jaffé et al., 2010, van Engelsdorp and Meixner, 2010, Viana et a. 2014, Nunes-Silva et al. 2013) by assuring enough pollinators (Aizen and Harder, 2009) and by pollinating crops more effectively (Garibaldi et al., 2013). Across developing countries, stingless beekeeping (also known as meliponiculture), remains essentially informal, technical knowledge is scarce, and management practices lack standardization. Commercialized bee products, including honey, colonies, and in a few cases crop pollination, are generally unregulated, and demand often exceeds supply. Meliponiculture thus remains a largely under-exploited business (Jaffé et al., 2015).

In most African countries stingless bees are hunted for their honey instead of being managed, which can lead to the destruction of wild colonies however, meliponiculture does exist in Tanzania and Angola (Cortopassi-Laurino et al., 2006; Jaffé et al., 2015). While in e.g. Ghana (Kwapong et al., 2010) and Kenya (Macharia et al., 2007) an interest to develop stingless bee management has been identified. Stingless bees were found to be as often managed for pollination purposes as for honey production, already at the end of the last century according to the survey conducted by Heard and Dollin (2000).

Meliponiculture in these countries can take various forms and use different traditional and modern techniques or types of hives depending on the target bee species (Cortopassi-Laurino et al., 2006). In some countries, stingless bee honey producers often operate individually and informally. There is strong potential for such producers to be organized into producer societies to improve the marketability of their honey, and to be trained on stingless bee resources management as well as honey harvesting techniques. This is much needed because little is known about the floral and non-floral resources of stingless bees compared to honeybees. Furthermore, some of the stingless species have been lost through poor methods of honey harvesting and destruction of nesting habitats.

Capacity building through education

Efforts to increase capacity in understanding and managing pollinators can be seen at several levels within Africa. At the farm level, curricula on pollination, the farm ecosystem, and ecological interactions have been introduced in Kenya and Ghana through the Farmer Field Schools approach. Through Farmer Field Schools, trainers are trained on specific issues, and they in turn train farmer groups.

An impressive effort to increase the scientific knowledge base on pollination in Africa has been noted in a recent reanalysis of the literature on pollination in Africa (Gemmill-Herren et al. 2014). This reanalysis, based on the original analysis of Rodger et al. (2004), has shown that over the previous decade an additional 62 new studies have been carried out in the continent between 2004 and 2013 (Fig. 21) The studies making the largest contribution (n=34) had an applied subject, always with an agricultural focus. The geographic location making the largest contribution over this period was East Africa (n= 39) (Fig 2). Thus more attention needs to be given to pollination research in other areas of Africa.

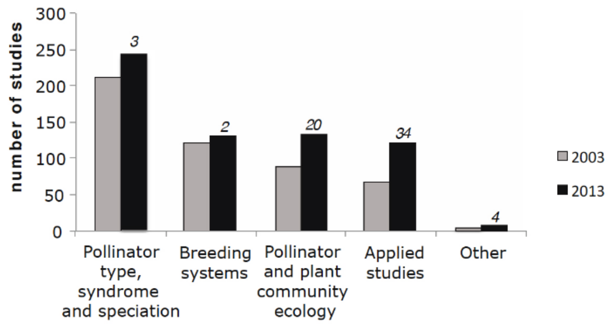


Figure 21. Classification of pollination studies carried out in Africa as identified in 2003, and in 2013, by subject matter. (from Gemmill-Herren et al 2015, p.46).

Capacity building through public awareness

Global public awareness and interest in pollinators and pollination has grown steadily over the last decade (Martins et al. 2016). Coverage of pollination issues in mainstream, regional and social media has steadily increased. Analysis of trends over the past decade using data from Google indicates recent peak interest and coverage of this issue between 2007 – 2009. This coincides with the general awareness of the public (particularly in the developed world) around the emergence, analysis and debate of colony-collapse disorder affecting honeybees. Subsequently pollinators, and in particular bees, have been the subject matter of cover/lead/feature media articles in a wide range of popular media formats exploring the links between honeybees and crop pollination. However, despite the increasing global awareness, it appears that public awareness about the breadth and diversity of pollinators, both in agricultural and natural habitats, remains biased towards honey bees. Increasing media coverage of the connections between agricultural productivity, food and nutritional security and the conservation of biodiversity remains an important area. In Africa, national symposia have been held in Ghana on the importance of pollinators, garnering national and international news attention. In Kenya, a colourful series of public awareness material has been generated, targeting farmers and the general public (Martins 2016 and Fig 22).

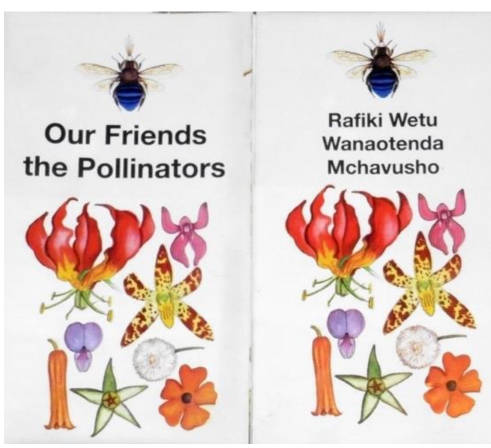


Figure 22. Cover of book recently developed and distributed digitally and through social media by Nature Kenya, with > 3000 downloads in the first few months of publication; content from the book has been accessed through mobile platforms by

150,000 farmers. Reprinted with permission of Nature Kenya and Dino Martins.

Policy measures to support pollinator-friendly farming
Environmentally friendly management methods, such as organic farming, diversified farming systems, polyculture farming, crop rotations, and conservation practices within agricultural management prescribed under policy instruments such as agri-environment schemes, are based on such practices. Also integrated pest management (IPM), which combines biological and cultural control with informed use of chemicals as part of a system approach to provide targeted and efficient pest management solutions, could have beneficial effects on pollinators by improving habitat and minimizing the use of insecticides applied (Gentz et al., 2010). Each of these farming systems needs to be supporting by enabling policy environments; for example, in some countries such as the Philippines, Farmer Field School training on IPM has become institutionalized and is a part of national and provincial budgets.

Knowledge gaps, priority capacity building and research areas for Africa

In this section, gaps in knowledge and critical areas for capacity building in pollination and pollinators are flagged, based on the summary of the information presented above.

Fundamental biology: In a continent often considered to be the cradle of evolution for many taxa, including humans and bees (Michener 1969), a greater understanding of the contribution of animal pollinators to the evolution of biological diversity in the continent would be a valuable contribution to fundamental biology. The high dependence, in the tropics, of plant communities on pollination has not been studied in the tropical forest zone of Africa. The patterns of high bee diversity in arid regions, found in many parts of the world, has not been documented in Africa. The vulnerability presented to sustaining biodiversity, by possible high pollination deficits in biodiversity hotspots, has only been documented in South Africa (Vamosi et al., 2006). The role of pollinators as ecosystem architects and "high-end recyclers" as critical to ecosystem health merits as much attention is given to the low-end recyclers, such as elephants.

Pollination dynamics in tropical forests of Africa: as noted above, there is a distinctive gap in ecological understanding of pollination dynamics in the tropical forests of Africa. Given the knowledge base derived from other tropical regions, where the dependence of natural ecosystems on pollination is extraordinarily high, this gap is one that should be urgently addressed to advance the understanding of the sustainability of tropical forest ecosystems in Africa.

Taxonomy of pollinators: A wealth of studies over the last decade, including cases from Africa, point to the critical importance of wild pollinators. Yet, Africa has a dearth of taxonomists trained to identify wild pollinator taxa, including bees, moths, wasps, flies and other insects. For this purpose, the taxonomic capacity to identify pollinators needs strengthening because pollinator may only visit certain crops types, and not all flower visitors are pollinators.

Assessment of pollinator declines: There is need to develop a systematic assessment of the occurrence and consequences of pollinator declines to agricultural production over a range of crops all over the world. A protocol to assess pollination deficits has been developed through collaboration between FAO and the Institut National de la Recherche Agronomique (INRA) in France, and applied to 44 cropping systems around the world (but only 3 within Africa). The protocol should be applied to a range of cropping systems, both extensive and intensive, to detect and assess the extent to which insufficient pollination limits crop productivity across crops and across regions.

Crop pollination critical to food security in Africa: Additional to the comprehensive lists of leading globally traded crops that have dependence on pollinators, in Africa, there are many indigenous and agroforestry crops that are both pollinator-dependent and essential for food security on local levels. Few have been the focus of pollination studies. Marula (*Sclerocarya birrea*), for example, is an important agroforestry crop; both fruit and moth caterpillars that feed on the Marula foliage are harvested from wild trees in southern Africa. However, not all communities understand that they must conserve male trees even though they do not bear fruit.

Pollination and food waste: As the world's attention turns increasingly to reducing food waste, understanding and addressing the role of insufficient pollination leading to sub-marketable fruits and vegetables provides a key area of intervention that merits more study and capacity building.

Identification of specific agricultural measures: While considerable work has been undertaken to document the importance of pollinators to sustainable agriculture in Africa, work is still required to identify agricultural management practices that can increase the amount of pollination and thus yield of pollinator dependent crops. The next step will be to translate the knowledge base on pollination and other ecosystem services into a set of practices using biological processes that can be implemented to sustainably increase agricultural production in Africa. There is a strong need to understand how such ecosystem services can be enhanced and sustained, such that they provide a sustainable underpinning for production and livelihoods. For example, Farmers can supply pollinator foraging resources by encouraging the establishment of attractive indigenous plant species that flower throughout the year, or increase nesting sites (e.g. by providing wooden bee nests or empty reeds for solitary bees), and applying conservation tillage to safeguard ground nesting bees. Documentation is needed on flowering plants species that can be used in hedgerows, fallows and natural habitats adjacent to the farms to provide a source of nectar, food, nesting opportunities and shelter for wild pollinators.

Unrealised potentials to increase crop productivity through pollination: As recently documented – and of great relevance to agriculture in Africa – smallholders (with holdings smaller than two hectares) can increase yields by a median value of 24%, through improved pollination management resulting in higher flower-visitor density. For larger holdings, such an increase could occur through enhancing pollinator diversity (Garibaldi et al., 2016). These results, repeated in detail here, are relevant as they may serve as a counterpoint to current trends, in which many pollinator-dependent crops, particularly in the developing world, are expanding in areal extent, but not in per-hectare productivity. Thus, a concerted effort through both research and extension, to realise the benefit of small-scale diverse crop cultivation, including set-aside of natural and semi-natural areas that may benefit communities of producers, would be a logical focus for future work. Along with other pioneering work in Africa on the impacts of agricultural intensification on pollination, management practices such as pesticide applications need to be considered. The support and contribution of smallholder farmers is key to fostering sustainability (Steward 2014).

Agricultural pesticides: There is little information available about the effects of pesticides on pollinators in Africa, although ample documentation of pesticide impacts on pollinators from studies in North America and Europe. Studies are needed to provide basic information on lethal and sub-lethal effects of how these pesticides are used by farmers in Africa, on both social and solitary bees.

Alternative pollinators: The model of managing stingless bees for pollination, as well elaborated in Latin America, has proved inspirational to a number of groups within Africa over the last decade. However, little in the way of scientific studies on ecology and management of alternative pollinators has as yet been carried out.

Crop pollination ecology: Although pollinator diversity has been flagged as a key input to crop productivity in other regions, there have been few comprehensive assessments of the impact of pollinator diversity and pollinator assemblages on crops in Africa, nor on how to manage and sustain such diversity. Determining the lifecycles of wild pollinators (generation time, number of generations in a year, timing of reproduction) and assessing how they interact with crops during growing seasons, e.g., pollinator availability during off-season cultivation through irrigation and alternative food plants for pollinators when crops are not in flower. Development of pollinator management strategies including inventories of wild pollinators requires detailed understanding of their phenology, life history and distribution in relation to crop growing patterns.

Economic valuation of crop pollination: As noted above, the accuracy of the economic methods used to estimate economic values of pollination is limited by numerous data gaps, and most studies focus on developed nations. Explicit estimation and consideration of economic benefits through tools such as cost-benefit analyses and multi-criteria analyses provide information to stakeholders and can help inform land-use choices with greater recognition of pollinator biodiversity and sustainability.

Tools to assess costs and benefits on a farm level: It is recognized that for farmers to implement pollinator friendly practices, the benefits accrued from improved pollination service they receive must outweigh the costs of such practices. Participatory methods could assist farmers in recording costs and benefits of their practices. Many pollinator-friendly practices may involve minimal costs, such as to encourage (or not weed) selected wild flowering plants, that are not pernicious weeds, near crops. Other measures, such as the disuse of certain crop land to allow for native plant restoration and reducing the application of pesticides, involve a more complex understanding of the costs and benefits. Research on the barriers and incentives for the uptake of ecological intensification practices, including pollinator-friendly measures, is also needed to support a transition to a more sustainable form of agriculture built on the enhancement of ecosystem services.

Honey and beeswax production within Africa: There have been high expectations for "rivers of honey" that should flow from the Acacia-studded landscapes of Africa, yet levels of production have been relatively low. Large quantities of honey and beeswax production tends to come from only a very few countries, suggesting that there is considerable scope for increasing the production of these high-value products in similar ecologies. An enhanced understanding of honey flows across African landscapes could benefit from a better understanding of traditional knowledge amongst communities such as Ogiek in Kenya, who followed bee migrations across time and space.

Threats to honey bee hive health in Africa: Different assessments of honey bee hive health from South Africa as opposed to Kenya highlight how patchy the understanding of this is in Africa. The fact that many colonies in Africa originate from swarm trapping provides some compelling differences from other regions, with implications for higher genetic diversity, meriting greater study. Areas of high incidence of migratory bee keeping versus regions where this is not practiced, also merit greater investigation to understand impacts on bee health.

Pollinators and climate change: Climate change is expected to lead to fluctuating and frequently reduced crop yields in Africa, as El-Niño-like events increase as is predicted in most climate models. Diversification and cultivating drought tolerant annual fruits and vegetables is one of the options that have been proposed for farmers adapting to climate change. But little is known about how pollinators may adapt their life history strategies when growing seasons are either shorter, or lengthened with irrigation, and research addressing this is needed. In wild ecosystems, groups such as fig wasps which are a highly critical resource for wide variety of animals throughout the continent have been shown in other regions of the world to be vulnerable to local extinctions due to climate change events. Yet almost nothing is known about the size and variability of pollinating wasp populations in Africa, or other taxa which may be susceptible to climate change impacts. Thus the importance of regional bee collections in Africa must be stressed, along with the possibility of repatriation of information from European Museums where such many collections of regional importance are housed

Recognition and appreciation of local and traditional knowledge: An important basis for such research on pollination in Africa is the recognition that considerable local knowledge already exists. Interventions to sustain ecosystem services are likely to be highly site-specific and will need to be developed through a synthesis of existing, traditional knowledge and innovations by agricultural researchers.

Capacity building needs: Formal education. While an impressive amount of new research on pollinators and pollination has been carried out in Africa over the last decade, many of the researchers trained have come from the biology or conservation disciplines. Throughout formal education in Africa, and particularly at University level, the understandings of pollination need to be mainstreamed in the discipline of Agriculture, Entomology and Agronomy.

Capacity building needs: Farmer education. While initial efforts to bring pollination understanding into Farmer Field School training, much more is needed along these lines, to build the capacity in managing pollination services. It is most logical that farmers will be interested not in managing pollination alone, but in the whole suite of ecosystem services that can be enhanced through ecological approaches. Yet very little training material, or training courses, have been availed in Africa on these subjects.

Increasing public awareness: Pollination as a factor in food production and security has been little understood and appreciated, in part because it has been provided by nature at no explicit cost to human communities. Now that stock is being taken of the impacts from losses of pollinators, the public needs a good understanding of what specifically they can do to protect pollinators. In Kenya, local communities have been surprised to learn that large carpenter bees are not actually pests, and contribute to the yields of their crops, thus changing their use of pesticides on these bees. Methodologies for collection of information by “citizen scientists” may be a key way of engaging the public and deepening the understanding of conserving pollinators.

Markets for pollinator-dependent crops

Diversification into horticultural crops is becoming an avenue to poverty alleviation amongst many farmers around the world. For farmers to benefit from expansion into horticultural production, market access is critical. Fruits and vegetables are traditionally sold in regularly convened markets in centers of population. Although the presence of supermarkets in developing countries is a rapidly increasing phenomenon, horticultural produce tends to be largely locally sourced. Supermarkets can still offer favourable access for farmers growing horticultural produce. In addition, urban consumers tend to be more concerned and conscious of how their fruits and vegetables have been grown (for example whether there may be pesticide residues in their food), thus there may be a potential for capturing price premiums for crops grown under sustainable practices. An important aspect of market access for producers of pollinator-dependent crops, however, is that many of these crops (fruits in particular, but also vegetables) are highly susceptible to spoilage. It is increasingly recognized that food waste has tremendous impacts on both food security, farmer livelihoods, and natural resource use thus more investment in efficient supply chains has multiple benefits. More research on the role of pollination in reducing food waste, as has been shown in strawberries and runner beans, would be of great value.

Policy analysis: Pollination rarely receives much attention in the policy arena, but the farming category to which it substantially contributes, horticultural production, is growing in importance in Africa. African governments recognize the need to increase food production to provide food security for growing populations, yet the supply of fruits and vegetables remains little addressed component in fighting hunger and malnutrition. Multiple drivers affect, and will increasingly impact the future of horticultural production in Africa, and the contribution of pollination services to production. Where there are markets with value chains that dictate standards, such standards can shape agricultural practices. For example, in some markets, fruit is only marketable if it is blemish-free, leading to increased use of pesticides for cosmetic purposes. In other instances, produce must not exceed limits of pesticide residues, leading to decreased use of pesticides. Pollinators cannot be protected in nature reserves alone, and so there is need to establish policies that guide pollinator protection in all terrestrial ecosystems including urban areas due to the prevailing threats such habitat modification, pollution and use of chemicals pose.

Summary

In view of growing demands for food and agricultural land, it is imperative in Africa to recognize the interdependence between human needs and biodiversity conservation. Identification of the many knowledge gaps as outlined above merit the immediate attention of decision makers, researchers and farmers, for targeted capacity building and management actions. A major challenge in this region to safeguarding pollinators and pollination services is identifying management practices that are considered “ecologically-intensive” and able to meet parallel demands for food production, and subsequently both poverty alleviation and environmental sustainability.

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