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Significance of pollination services in crop and plant diversity in tropical Africa

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Abstract

There exist diverse communities of plants in the tropics. These plants offer habitat to a number of insect pollinators that directly or indirectly play a significant role in sustaining tropical biodiversity through pollination process. The insect pollinators are capable of transferring pollen grains from anther of one flower to the stigma of another or the same flower enabling wild plants and cultivated crops to reproduce. Among others, pollinator-dependent crops contribute to about 35% of the world crop production. About 94% of flowering plants in the tropical region estimated to receive animal pollination benefits. However, climate change, agricultural intensification, land use change, intensive monoculture and use of industrial pesticides and fertilizers are major threats to pollinators' exists. Although tropical Africa is blessed with diverse pollinators, its people are still lacking basic knowledge on pollination but also its implication as ecosystem service in maintaining tropical biodiversity. The intention of this review therefore is to bridge the knowledge gap among African communities by highlighting the significance of pollination services, threats facing pollinators and appropriate conservation strategies that could help to enhance pollinators for better ecosystem services in this region. Involvement of policy makers, farmers, land managers and private institutions to discuss issues related to ecosystem services will likely help to increase the level of awareness. Formulation of appropriate pollinators' conservation policies, conservation agriculture practicing, restoration of degraded habitats, habitat management and monitoring of pollinators' populations may be a good foundation towards protection of pollinators necessary for crop and plant diversity in tropical Africa.

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Introduction

Pollinators are animals or agents capable of transferring pollen grains from the anther of one flower to the stigma of another or the same flower within the ecosystem setting thus enabling wild plants and cultivated crops to reproduce (FAO, 1995; Kevan, 1999; Dar *et al.*, 2017). Pollination may be biotic or abiotic depending on pollen-transporting agent (Bolmgren *et al.*, 2003; Dar *et al.*, 2017). Biotic pollination occurs when the agent involved is a living organism (biological) unlike abiotic pollination whereby a physical agent such as wind and water facilitate the process (Ackerman, 2000). In the living world of flora and fauna, pollinators play an important role in crop production without which life on planet would be very challenging (Klein *et al.*, 2007; Power, 2010; Briggs *et al.*, 2013; Gill and Garg, 2014). There are numerous groups of biotic pollinators ranging from insects, birds to mammals (Waser *et al.*, 1996). Of these, bees are the most known and important insect pollinators of many crops and plant species in the world (Freitas and Paxton, 1996; Waser *et al.*, 1996; Larson *et al.*, 2001; Hegland *et al.*, 2009).

Pollination services and pollinators are of the world concern as far as crop production and biodiversity conservation is involved (Allen-Wardell *et al.*, 1998; Biesmeijer *et al.*, 2006; Zhang *et al.*, 2007; Ashworth *et al.*, 2009; Gallai *et al.*, 2009; Bommarco *et al.*, 2012; Toivonen *et al.*, 2016). In Africa, some studies on pollination have been carried out (Kasina *et al.*, 2009a; Munyuli, 2011b, Otieno *et al.*, 2011, Bartomeus *et al.*, 2014; Kiatoko *et al.*, 2014; Melin *et al.*, 2014; Samnegård *et al.*, 2016). Though these studies may have good information on pollination, majority of communities in this region have not benefited yet as they are still lacking basic knowledge on pollination service and its implication in maintaining tropical plants and crop production (Munyuli, 2011a). Apart from limited information that exists, appropriate methods to conserve pollinators in this region are also lacking. This is because of low level of understanding due to inadequate information regarding pollination systems and pollinators, which facilitate this natural process (Mayer *et al.*, 2011; Archer *et al.*, 2014).

The intention of this review therefore is to bridge the knowledge gap among African communities by highlighting the significance of pollination services, threats facing pollinators and appropriate conservation strategies that could help to enhance pollinators for better ecosystem services in this region. The review also highlights factors affecting pollinators' abundance and diversity and discusses appropriate strategies for their conservation and underlines areas for further studies within the region.

Pollinators and factors determining floral visitation

Biotic pollinators (Table 1) are either generalists or specialists based on the number of interactions they establish during flower visitation (Blüthgen *et al.*, 2006). Generalist pollinators can visit quiet large number of plant species depending on their preferences (Motten *et al.*, 1981; Memmott *et al.*, 2004). In contrast, specialist pollinators confine their foraging to only one or subset of species (Bawa, 1990; Michaloud *et al.*, 1996; Weiblen, 2002; Harrison and Rasplus, 2006; Cook and Segar, 2010). In so doing, specialist pollinators are more vulnerable to change when the ecosystem is degraded compared with the generalists (Dixon, 2009). There are various factors which affects pollinators-flower interaction and they are either biological; quantity and quality of pollen and nectar, size, scent, colour and shape of a flower or non-biological such as temperature, wind, light and distance between food source and nesting site. Extreme weather affects normal flight and foraging performance of many pollinators. For example, both social and solitary bees can freely visit and forage on flowers of various plants species but temperatures, strong winds, heavy rainfall, light intensity and relative humidity may affect their effectiveness (Szabo, 1980; Corbet *et al.*, 1993; Vicens and Bosch, 2000; Munyuli, 2011b; Classen, *et al.*, 2015). Species such as bumblebees are capable of sustained flight even at relative low temperature of less than 11°C unlike the honeybees (Corbet *et al.*, 1993). The distance between the nesting site and food source is another factor which can affect the movement of pollinators when foraging (Greenleaf *et al.*, 2007; Munyuli, 2011b).

As pollinators require energy for flying from nest to host plants, fliers with large body size have reported to have larger foraging range due to increased flight efficiency compared to small body size pollinators such as stingless bees (Harrison and Roberts, 2000; Zurbuchen *et al*, 2010). Although some large bees have foraging range of more than 5000m, most bees have a maximum foraging range of 3000m and others even less than 2000m (Beekman and Ratnieks, 2000). For example, solitary bees have been reported to forage between 100 and 1400m compared to larger fliers such as Bumble and Carpenter bees which have relative wide foraging range (Gathmann and Tscharntke, 2002; Zurbuchen *et al*, 2010). Biological factors such as shape and colour of flowers can also limit type of visiting pollinators for pollen and/or nectar. For example, bees normally visit yellow and pink-red flowers with open and wide petals for easy landing when collecting pollens and nectar (McCall and Primack, 1992). Their efficiency in visiting plants has been influenced by various colours disclosed by particular flowers (Reinhard *et al*, 2004). Species such as long-tongued butterflies are foraging mostly on tubular than open flowers as it also help to reduce competition among pollinators which are short-tongued (McCall and Primack, 1992). Apart from colour, pollinators also use unique scent signals produced by flowers to locate their preferred food instead of relying only on visual signals, which can also be produced by non-rewarding flowers i.e. deceit pollination (Cook *et al*., 2002; Reinhard *et al*, 2004; Terry *et al*., 2007; Wright and Schiestl, 2009; Castillo *et al*., 2012).

Moreover, the amount and nutritional quality of the nectar produced by host plants can also influence pollinators' visitation (Gumbert, 2000; Herrera *et al*, 2006). However, to keep the pollinator-plant interaction persisting, there is a need to balance the system by enhancing diverse plants composition and thus ensuring limitless forages for pollinators (Rands and Whitney, 2011). In agricultural landscapes where vegetation density and pollination services have been lowered due to human activities (Kovács-Hostyánszki *et al*., 2017), planting of native plants along the farm edges would help to recover the ecosystem and its ability to supply basic requirements for pollinators (Denisow and Wrzesień, 2015). Increased diversity of such plants around agricultural lands will possibly boost pollinators' abundance due to additional pollen and nectar even when field crops are off blooming (Hannon and Sisk, 2009; Sidhu and Joshi, 2016).

Studies focusing on finding out the effects of both biological and climatic factors on pollinators would be important to determine the quality of pollination system in the changing environmental condition in this region. Furthermore, understanding the current situation of climate change in tropical Africa would also help to better understanding the changing pollinators' population and how to go about regarding their conservation.

Table 1. Common pollinators essential for pollination systems in the tropics

Pollinator	Order (Family)	Plant/crop preference	Reference
Stingless bees (e.g. *Meliponini* sp, *Trigona* sp)	Hymenoptera (Apidae)	Various flowering plants of family *Fabaceae, Acanthaceae, Asteraceae, Cucurbitaceae, Commelinaceae, Lamiaceae,etc.*	Heard, 1999, Ricketts, 2004, Raina *et al*., 2011; Mwangi *et al*., 2012.
Fig wasps (e.g. *Ceratosolen capensis, Ceratosolen grandii, Dolichori* sp),	Hymenoptera (Agaonidae)	One or few closely related Ficus species. eg. *Ficus microcarpa, Ficus sur, Ficus maxima, Ficus salicifolia, Ficus sycomorus, etc.*	Wiebes, 1989; Michaloud *et al*., 1996, Ollerton *et al*., 2003; Harrison and Rasplus, 2006.
Other wasps e.g. *Tiphia* sp, *Hemipepsis* sp.	(Tiphiidae, Pompilidae)	Various flowering plants of family *Asteraceae, Lamiaceae, Fabaceae, etc.*	
Honey bees (*Apis mellifera* L.)	Hymenoptera (Apidae)	Various crops and flowering plants of family *Fabaceae, Asteraceae, Acanthaceae, Cucurbitaceae, Lamiaceae, etc.*	Freitas and Paxton, 1996; Ollerton *et al*., 2003; Munyuli, 2011b; Mwangi *et al*., 2012.
Flies (e.g. Syrphids and bee flies)	Diptera (eg. Syrphidae and	Various crops and flowering plants of family *Fabaceae, Asteraceae,*	Bhattacharya, 2004, Renner and Feil, 1993.

Pollinator	Order (Family)	Plant/crop preference	Reference
	Bombyliidae)	*Lamiaceae, etc.*	
Butterfly (eg. Common eyed pansy)	Lepidoptera (eg. Nymphalidae)	Various flowering plants of family *Rubiaceae, Asteraceae, etc,*	Bhattacharya, 2004; Asiko *et al.*, 2017
Beetles	Coleoptera (Curculionidae)	Various flowering plants of family *Asteraceae, Rubiaceae, etc.*	Renner and Feil, 1993.

Economic value of pollinators in crop production in the tropical Africa

Through pollination process, pollinators contribute to about 35% of the world crop production (Kevan *et al.*, 1990; Klein *et al.*, 2007; Otieno *et al.*, 2011; Chautá-Mellizo *et al*, 2012; Garibaldi *et al.*, 2013). In 2005, Gallai *et al.* (2009) reported an estimated economic value of insect pollination to be €153 billion for the world agriculture, of which fruits, vegetables and stimulant crops have revealed high economic value compared with other world crops. It has been reported that following exposure to pollinators, market value of world crops such as oilseed rape was found to increase due to improved seed weight and quality (Bommarco *et al.*, 2012). In the tropical Africa however, the value of pollination service for many tropical crops that heavily depends on unmanaged-wild pollinators are poorly understood. In a wide perspective, people are lacking basic knowledge both on market and non-market values of pollinators. For instance, about 90% of farmers who were interviewed in Uganda didn't know the importance of bees in their fields (Munyuli, 2011a). It is already established that crop yields will drop by 8% by 2050 in tropical Africa (FAO, 2014). This paves the way for efforts to address this food shortage by using environmental friendly approaches that will maximize crop yields, one of which is utilization of pollination service through enhanced farmland biodiversity (Klein *et al.*, 2007; Klein, 2009; Carvalheiro *et al.*, 2010; Carvalheiro *et al.*, 2012). Insect pollination has been reported to improve yield and markets by increasing both fruits and seeds set in many crops (Freitas and Paxton, 1996; Bhattacharya, 2004; Kiatoko *et al.*, 2014; Samnegård *et al.*, 2016). For instance, in western Kenya, Kasina *et al.* (2009a) found the increase in market value for common food crops grown there after they received pollination service by bees.

However, such services may be disturbed because most ecosystems which were intact some decades ago particularly in developing countries, are now threatened due to increasing demand for agricultural land (Aizen *et al.*, 2009). Thus, there is a greater need to take appropriate actions to minimize environmental pressures that would cause pollinator's decline. Conserving pollinators can increase chances of getting more crops yields that can lead into high-income generation and improved living standards of people (FAO, 1995; Allsopp, 2004).

Role of pollination services in the tropical African biodiversity

Natural pollination in the wild is essential requirement for reproduction and dispersal of tropical biodiversity (Midgley *et al.*, 1991; Harrison and Rasplus, 2006). Unlike in cropping systems where in some point there are human interventions such as breeding and artificial pollination to improve crop production, presence of pollinators has been very important to wild plant species where the system operates naturally (Fischer and Edmeades, 2010; Tester and Langridge, 2010). This is based on the principle that pollination is one of the obligatory services for flowering plants particularly pollinator-dependent species to reproduce (Briggs *et al.*, 2013). In the tropical African region where there is high diversity of flora and fauna associated with well-represented natural and semi-natural habitats such as rainforests, abiotic pollination seems to be passive process and the majority of plant species in this region are pollinated by animals (Renner and Feil, 1993; Culley *et al*, 2002; Sodhi *et al.*, 2004; Carvalheiro *et al.*, 2010). Although Ackerman (2000) criticized this argument, it has been postulated that ecosystems with closed canopies such as tropical rainforests tend to affect horizontal movement of pollen grains between the correlated plant species (Regal, 1982; Midgley *et al.*, 1991).

In addition, dominance of biotic pollination in this region may also be described by principles of evolutionary biology whereby floral structure of plants have believed to evolve in order to accommodate their coevolved pollinating partners (Bawa, 1990; Bolmgren *et al.*, 2003; Parachnowitsch and Kessler, 2010). On the other side, tropical rainforests can act as a reservoir of diverse pollen vectors (Blanche *et al.*, 2006) that are important for crop production considering that agriculture has become more pollinator-dependent over time particularly in developing countries (Aizen *et al.*, 2009). Availability of such habitats creates suitable environment for pollinators that can deliver services to the nearby crops or orchards and finally improve yields (Klein, 2009). It has been reported that about 94% of flowering plants in the tropical region are estimated to benefit from animal pollination (Ollerton *et al.*, 2011). Plant species including fruits and vegetables are highly depending on animal pollination and they are incapable of setting fruits and make their reproduction successful in absence of pollinators (Kevan *et al.*, 1990; Larson *et al.*, 2001; Pandit and Choudhury, 2001; Boulter *et al*, 2006; Klein *et al*, 2007). Although many flowering plants do offer nectar to pollinators afterward as attraction strategy, non-rewarding plants use different tactics to attract their pollinators (Gumbert, 2000; Castillo *et al.*, 2012). In the tropics, most insect pollinators ranging from large to small-sized visits flowers mainly for nectar and pollens as source of food. Stingless bees, which form a large group of tropical bees comprising the tribe Meliponini (Raina *et al.*, 2011) and Trigona (Bhattacharya, 2004), are among small insect pollinators attracted by nectar produced by many tropical flowering plants (Heard, 1999). Ecological assessment between tropical pollinators and wild plants is necessary to identify various chains of interactions and group them in their correct conservation status based on their population.

There is a need to investigate and closely monitor their population trend, addressing environmental and anthropogenic factors for better understanding and conservation measures.

Effects of environmental pressures on pollinator populations

Global decline of both managed and wild pollinators in recent years has raised concern to both conservationists and ecologists (Potts *et al.*, 2010; Dicks *et al.*, 2013). The decline has been contributed by a range of environmental pressures; agricultural intensification (Klein *et al.*, 2007; González-Varo *et al.*, 2013), climate and severe land use changes (Sala *et al.,* 2000; Weiner *et al.*, 2014; De Palma *et al.*, 2016), unsustainable farming approaches such as intensive monoculture (Wilcove and Koh, 2010; Norfolk *et al.*, 2012,) and use of industrial pesticides (Henry *et al.*, 2012; Whitehorn *et al.*, 2012). Understanding these factors is necessary for planning appropriate conservation programs as well as setting priorities both in national and global scale (Archer *et al.*, 2014).

Climate Change

There is evidence from other regions of the world like North America showing that climate change has impact on pollinator populations (Sala *et al.,* 2000; FAO, 2016). Extreme weather may affect the overall ecosystem performance and every component within it by causing stress to the system. Changing the ecosystem functioning not only disrupt the distribution and abundance of pollinators but also their effectiveness (Millennium Ecosystem Assessment, 2005). Climate changes may affect pollination service provisioning in agro-ecosystems by changing pollinators' community composition (Harrison *et al.*, 2015). In many African countries, information on pollination ecology and especially at country level is very scarce. The extent to which climate change has impacted the availability of food and other essential requirements for wild pollinators in tropical Africa has not been clearly discussed. Information on the magnitude in which the pollination networks have been affected by change in climate for tropical crops and plants is still unclear (FAO, 2016).

Because we need to understand the correlation between change in climatic factors and resources availability within the ecosystems, there is a need to clearly explore the mechanism behind this relationship.

For instance, it has been reported that temperature controls the access of pollinators to food resources (Classen, *et al.*, 2015) and may also affect visitation rate of both Lepidopterans and Hymenopterans when it increases (Pandit and Choudhury, 2001). However, to what degree of temperature change will continue to favour pollinators' activities need a detailed investigation. Continual rise of global warming is expected to be more detrimental in the tropics, where biological diversity is also higher (Deutsch *et al.*, 2008). Populations of insects confined in tropical lowland areas that experience low temperature variability, are projected to vast decline due to their low ability to tolerate changes in temperature (Bonebrake and Deutsch, 2012). Nevertheless, basic information on the ecological consequences of increasing temperature on pollination ecology is still limited (Hegland *et al.*, 2009). Does the temperature affect only foraging behaviour of pollinators or even the quality and quantity of the pollen produced by flowering plants when subjected to extreme temperature? All these issues need to be addresses for better understanding of possible detrimental factors related to climatic perturbations.

Parasites and diseases

Activities of pollinators are lowered by presence of diseases and/or pests as they affect metabolic activities that determine their performance (González-Varo *et al.*, 2013). Parasites such as varroa mites (Allsopp, 2004) have been reported to affect bee colonies in South Africa. A threat is even high when a disease happens to affect multiple host species from managed to wild pollinators. A study conducted by Graystock *et al.* (2013) has found the ability of disease infection, *Nosema ceranae* between different pollinator species of bumble bees and honey bees. Anderson and Giacon (1992) also highlighted the effect of diseases on pollinators' population. However, sufficient information on this area is still lacking particularly in tropical region (FAO, 1995).

Future research should focus on identifying common diseases and pests threatening pollinators' community particularly in understudied region of tropical Africa and suggest appropriate solution to reduce infections and spread.

Use of synthetic pesticides

Synthetic pesticides have strong chemicals that affect pollinators' activities. They can kill insect pollinators directly or can affect foraging efficiency, reproduction and behaviour of pollinators (Henry *et al.*, 2012; Gill and Garg, 2014; Kovács-Hostyánszki *et al.*, 2017), which in turn affect visitation rate. For instance, extensive use of synthetic pesticides such as neonicotinoids in commercially cultivated land has contributed much to the loss of pollinators worldwide (Whitehorn *et al.*, 2012). It is highly neurotoxic and has reported to affect foraging activities of both honeybees and wild pollinators (Van der Sluijs *et al.*, 2013). It has also found to repel insect pollinators such as Diptera and Coleoptera from visiting the contaminated part of the plant (Easton and Goulson, 2013). However, different agricultural management systems as well as level of production have influenced application of these pesticides. For example, in North America and European countries; high level of pesticide application has been due to high crop production through extensive monoculture (Horrigan *et al.*, 2002). In recent years, such agricultural methods are taking over even in developing countries replacing the traditional and sustainable ways farmers used to practice in previous decades. Although the main reason is to increase yields while minimizing production costs, it does not support agricultural biodiversity and it may cause agro-ecosystem damage in a long run (Richards, 2001). The adverse impact of agrochemicals is not observed only on pollinators' community (Brittain *et al.*, 2010; Otieno *et al.*, 2011) but also the flora component of the ecosystem. Decreased plants visitation by pollinators has found to affect plants reproduction especially pollinator dependent plants (Lundgren *et al.*, 2013). However, there are various ways to minimize or remove the effects of pesticides to agro-ecosystems.

One way is to opt organic farming practice, which has capacity to eliminate synthetic pesticides and encourage abundance and richness of pollinators in agro-landscapes (Kennedy *et al.*, 2013). Likewise, all activities causing negative effects to the ecosystem reduce its capacity to provide natural services including pollination, erosion control, water purification, disease and pest control and storm protection (Millennium Ecosystem Assessment, 2005). Therefore, all farming practices that increase crop yield while minimizing synthetic pesticides uses are rather desired to maintain natural ecosystems' services. Use of botanical pesticides, planting of wild plants that support natural enemies of pests in agricultural landscapes is highly recommended as alternative for pest control rather than synthetic pesticides, which impoverish agro-biodiversity.

Conservation policies and management actions on pollinators in tropical Africa

Anthropogenic pressures on land are always related with negative effects on the pollinators (Fig 1). Increased non-environmental friendly practices in tropical Africa have raised pressure on the available natural resources and thus reducing the ability of the agro-ecosystems to offer expected services (Van Hamburg and Guest, 1997). This may have been contributed by lack of appropriate regulating guidelines and directive policies with emphasis on protecting farmland and natural ecosystems and the associated creatures. However, lack of information on geographical distribution of various groups of pollinators has also been mentioned as common conservation challenge facing many developing countries including tropical Africa (Freitas *et al.*, 2009; IPBES, 2016). In tropical Africa where most of the countries have general policies on conservation of wildlife, measures to conserve pollinators have not been clearly prioritized (Eardley *et al.*, 2009). Although African Pollinator Initiative was established to protect and promote African pollination systems (FAO, 2007), more studies have concentrated in few countries including South Africa and Kenya (Ollerton *et al.*, 2003; Ollerton *et al.*, 2011; Otieno *et al.*, 2011; Mwangi *et al.*, 2012; Kiatoko *et al.*, 2014; Melin *et al.*, 2014).

However, many studies have focused mainly on bees (Eardley *et al.*, 2009; Kasina *et al.*, 2009b; Asiko *et al.*, 2017) with little attention on other wild pollinators, which also have significant impact on crop production. In other regions like North America, Europe and Latin America, various efforts and strategies to conserve pollinators have been widely practiced and supported by the government (Freitas *et al.*, 2009; Heath *et al.*, 2017). Due to increased decline in pollinators, there is a need to enhance society's knowledge on pollination systems by making the information easily available to farmers and other practitioners. The knowledge should broadly be extended and even include information on wild pollinators instead of focusing only on most managed pollinators such as honeybees (Goulson, 2003).

Increased awareness particularly on the economic importance of pollination service on crop production may encourage farmers to conserve pollinators to maximize such profit. There is a need to formulate appropriate trans-boundary conservation policies necessary to meet conservation goals between the countries and in a large scale (López-Hoffman *et al.*, 2010). However, implementation of already established pollinators' initiatives and pollinators' conservation programs would help to restore the decline populations.

Generally, management of existing pollinators' habitats such as hedgerow margins, sowing of flower strips, establishment of forest corridors shall be among the topmost pollinators' conservation strategies (Briggs *et al.*, 2013; Kennedy *et al.*, 2013; Feltham *et al.*, 2015; Westphal *et al.*, 2015; Heath *et al.*, 2017) in agro-landscapes of tropical Africa. In process of restoring the habitats, plant species that blooms throughout the year in farmlands and provide sufficient life requirements to large pollinator communities ranging from highly specialized to generalized and underground to tree nesting pollinators should be selected (Dixon, 2009; Peters *et al.*, 2013). In areas with severe habitat destruction due to agricultural intensification, farming systems that accommodate the agro ecological principles could help to restore damaged pollinators' habitats (Peters *et al.*, 2013; Scheper *et al.*, 2013; Nicholls *et al.*, 2016).

This is important because presence of suitable habitats will definitely favours many pollinator communities due to insurance for food, mating and nesting sites (Brosi *et al.*, 2008; Ashworth *et al.*, 2009; Kasina *et al.*, 2009b; Raina *et al.*, 2011).

It should be remembered that availability of specific life requirements for specific group of pollinators could largely limit the richness and distribution of each specific group. For example, population of hoverflies can highly be determined by availability of floral resources for both adult and larval food rather than nesting sites (Holzschuh *et al.*, 2016) but solitary bees distribution and abundance can greatly be limited to availability of nesting sites (Steffan-Dewenter and Schiele, 2008). In general, when conserving pollinators' habitats, you are protecting both rare and endangered pollinator species from extinction as well as increasing agricultural production because high-quality crops production normally depends on quality of natural services such as pollination provided by healthier ecosystem in proximity (FAO, 2014).

Immediate conservation actions will enhance population of pollinators and increase ability of the environment to provide natural ecosystem services required to support life of biodiversity on earth (Fig. 1).

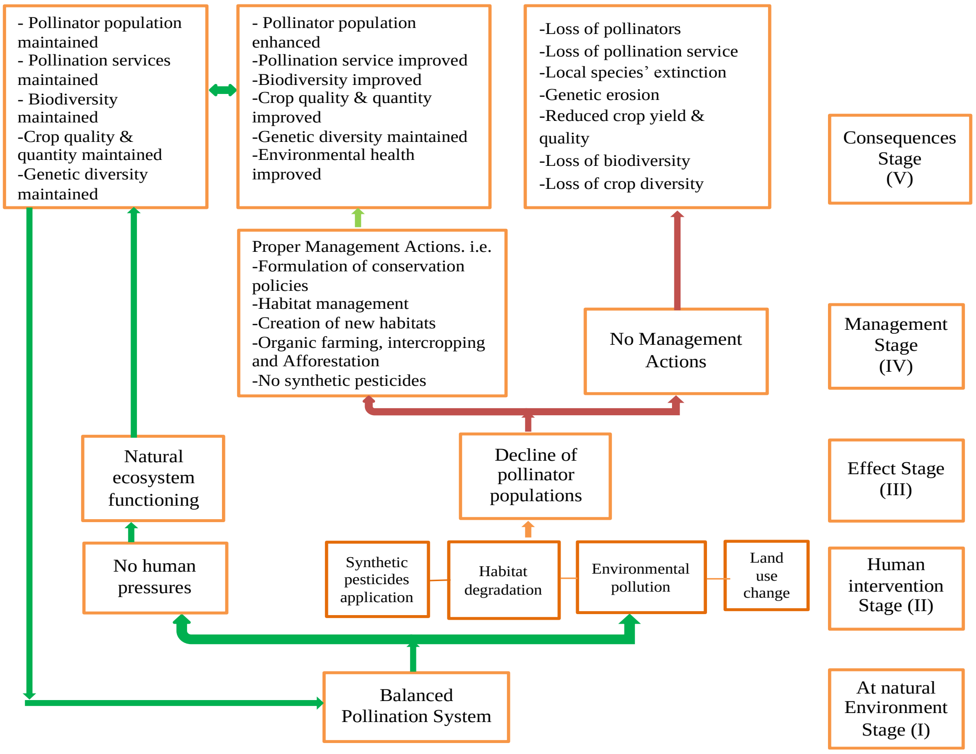

Fig. 1. Conceptual framework that demonstrates the strength and limitations of pollination system in the tropics due to anthropogenic pressures. Five stages are described here; stage 1 indicates a balanced pollination provisioning in the ecosystem when the environment remains intact or with very minimum disturbance. Stage 2 portrays how various human activities can affect the ecosystem, which in turn affects abundance and diversity of pollinators. On the other hand if the system remains unharmed without such pressures; the system would continue to provide optimum pollination service, as there is suitable environment for the pollinators to thrive. The decline in pollinators' population or leaving the natural ecosystem to maintain its functions is determined by presence or absence of human disturbances to the environment and this is described by effect stage 3. In the management stage 4, appropriate management actions could help to maintain, restore and conserve pollinators in the system otherwise; the environment will continue to degrade loosing pollinators and other essential ecosystem services. In stage 5, the system describes the consequences of management actions. If immediate conservation actions are taken, pollination and other natural ecosystem services and resources will be enhanced and maintained. However, if there is no management actions, the system will further be damaged and finally lead to loss of pollination services, resources and other associated ecosystem benefits.

Conclusion and future research needs

As land has many users, this work calls for realistic and permanent plans to minimize the risk of pollinators' loss and for this case there is need of involving multi- stakeholders such as policy makers, policy implementers, farmers, land managers and private institutions to discuss issues related to conservation and protection of pollinators. Initiating of conservation programs in tropical Africa to regularly monitor pollinators' population both in protected and agricultural landscapes would perhaps favour pollinators' assemblage. However, formulation of appropriate conservation policies would help to support implementation of such conservation programs and schemes. More studies are still needed across the region in order to understand the complexity of pollination systems and factors affecting them of which most of them are human driven.

Future studies in tropical Africa should focus on missing information on both rare and endangered pollinator species and the findings should be incorporated in the conservation policies and programs. However, understanding their distribution may also be of important, as it will help conservationists and stakeholders to identify areas that need immediate conservation intervention. Although afforestation and reforestation has been given attention mainly to combat climate change, it could also be practiced purposely to restore highly degraded areas and rejuvenate pollinators' habitats. There is also limited information to what extent the increasing distance between semi-natural habitats and crop fields has affected pollination system and crop yield of many tropical crops. Pollinator network is another component of pollination ecology that needs to be explored because it is the core factor determining strength of pollination system. Understanding the interaction between pollinators and their host plants is necessary for planning protection strategies. Factors influencing strength and weakness of the networks particularly those associated with human activities need to be highlighted and become well known to the public.

Studies aiming at obtaining baseline information on beneficial field margin plants that are native to tropical Africa including their identification and importance to pollinators should be conducted and the information shared to farmers and agricultural practitioners so that they understand the essence of maintaining these plants for improved pollination services. Moreover, elevating people's knowledge on pollination ecology and ecosystem services may be a good foundation towards enhancing of crop and plant diversity in the tropical Africa.

References

Ackerman JD. 2000. Abiotic pollen and pollination: ecological, functional and evolutionary perspectives. Plant Systematics and Evolution **222,** 167-185.
https://doi.org/10.1007/BF00984101

Aizen MA, Garibaldi LA, Cunningham SA, Klein AM. 2009. How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. Annals of Botany **103,** 1579-1588.
DOI: 10.1093/aob/mcp076

Allen-Wardell G, Bernhardt P, Bitner R, Burquez A, Buchmann S, Cane J, Cox PA, Dalton V, Feinsinger P, Ingram M, Inouye D, Jones CE, Kennedy K, Kevan P, Koopowitz H, Medellin R, Medellin-Morales S, Nabhan GP. 1998. The Potential Consequences of Pollinator Declines on the Conservation of Biodiversity and Stability of Food Crop Yields. Conservation Biology **12,** 8-7.

Allsopp M. 2004. Cape honeybee (*Apis mellifera capensis* Eshscholtz) and varroa mite (*Varroa destructor* Anderson and Trueman) threats to honeybees and beekeeping in Africa. International Journal of Tropical Insect Science **24,** 87-94.
DOI: 10.1079/IJT20041

Anderson DL, Giacon H. 1992. Reduced Pollen Collection by Honey Bee (Hymenoptera: Apidae) Colonies Infected with *Nosema apis* and Sacbrood Virus. Journal of Economic Entomology **85,** 47-51.
http://dx.doi.org/10.1093/jee/85.1.47

Archer CR, Pirk CWW, Carvalheiro LG, Nicolson SW. 2014. Economic and ecological implications of geographic bias in pollinator ecology in the light of pollinator declines. Oikos **123,** 401-407. DOI: 10.1111/j.1600-0706.2013.00949.x

Ashworth L, Quesada M, Casas A, Aguilar R, Oyama K. 2009. Pollinator-dependent food production in Mexico. Biological Conservation **142,** 1050-1057.

Asiko G, Julius K, Jared M, Christine K. 2017. Increasing Bee Forage for a Sustainable Bee Industry in Kenya. Journal of Food Science and Engineering **7,** 262-266. DOI: 10.17265/2159-5828/2017.05.004

Bartomeus I, Potts SG, Steffan-Dewenter I, Vaissière BE, Woyciechowski M, Krewenka KM, Tscheulin T, Roberts SPM, Szentgyörgyi H, Westphal C, Bommarco R. 2014. Contribution of insect pollinators to crop yield and quality varies with agricultural intensification. Peer J **2,** e328. DOI 10.7717/peerj.328

Bawa KS. 1990. Plant-Pollinator Interactions in Tropical Rain Forests. Annual Review of Ecology and Systematics **21,** 399-422.

Beekman M, Ratnieks FLW. 2000. Long-range foraging by the honey-bee, *Apis mellifera* L. Functional Ecology **14,** 490-496. DOI: 10.1046/j.1365-2435.2000.00443.x

Bhattacharya A. 2004. Flower visitors and fruitset of *Anacardium occidentale*. Annales Botanici Fennici **41,** 385-392.

Biesmeijer JC, Roberts SPM, Reemer M, Ohlemüller R, Edwards M, Peeters T, Schaffers AP, Potts SG, Kleukers R, Thomas CD, Settele J, Kunin WE. 2006. Parallel Declines in Pollinators and Insect-Pollinated Plants in Britain and the Netherlands. Science **313,** 351-354. DOI: 10.1126/science.1127863

Blanche KR, Ludwig JA, Cunningham SA. 2006. Proximity to rainforest enhances pollination and fruit set in orchards. Journal of Applied Ecology **43,** 1182-1187. DOI: 10.1111/j.1365-2664.2006.01230.x

Blüthgen N, Menzel F, Blüthgen N. 2006. Measuring specialization in species interaction networks. BMC Ecology **6,** 9. https://doi.org/10. 1186/1472-6785-6-9

Bolmgren K, Eriksson O, Linder, HP. 2003. Contrasting Flowering Phenology and Species Richness in Abiotically and Biotically Pollinated Angiosperms. Evolution **57,** 2001-2011. DOI: http://dx.doi.org/10.1554/02-444

Bommarco R, Marini L, Vaissière BE. 2012. Insect pollination enhances seed yield, quality, and market value in oilseed rape. Oecologia **169,** 1025-1032. DOI: 10.1007/s00442-012-2271-6

Bonebrake TC, Deutsch CA. 2012. Climate heterogeneity modulates impact of warming on tropical insects. Ecology **93,** 449-455. DOI: 10.1890/11-1187.1

Boulter SL, Kitching RL, Zalucki JM, and Goodall KL. 2006. Reproductive Biology and Pollination in Rainforest Trees: Techniques for a Community-level Approach. Cooperative Research Centre for Tropical Rainforest Ecology and Management, Rainforest CRC, Cairns, Australia, pp. 78.

Briggs HM, Perfecto I, Brosi BJ. 2013. The Role of the Agricultural Matrix: Coffee Management and Euglossine Bee (Hymenoptera: Apidae: Euglossini) Communities in southern Mexico. Environmental Entomology **42,** 1210-1217. DOI: http://dx.doi.org/ 10.1603/EN13087.

Brittain CA, Vighi M, Bommarco R, Settele J, Potts SG. 2010. Impacts of a pesticide on pollinator species richness at different spatial scales. Basic and Applied Ecology **11,** 106-115. DOI:10.1016/j.baae. 2009.11.007

Brosi BJ, Daily GC, Shih TM, Oviedo F, Duran G. 2008. The effects of forest fragmentation on bee communities in tropical countryside. Journal of Applied Ecology **45,** 773-783.
DOI: 10.1111/j. 1365-2664.2007.01412.X

Carvalheiro LG, Seymour CL, Nicolson SW, Veldtman R. 2012. Creating patches of native flowers facilitates crop pollination in large agricultural fields: mango as a case study. Journal of Applied Ecology **49,** 1373-1383.
DOI: 10.1111/j.1365-2664.2012.02217.x

Carvalheiro LG, Seymour CL, Veldtman R, Nicolson SW. 2010. Pollination services decline with distance from natural habitat even in biodiversity-rich areas. Journal of Applied Ecology **47,** 810-820.
DOI: 10.1111/j.1365-2664.2010.01829.x

Castillo RA, Caballero H, Boege K, Fornoni J, Domínguez CA. 2012. How to cheat when you cannot lie? Deceit pollination in *Begonia gracilis*. Oecologia **169,** 773-782.
DOI: 10.1007/s00442-012-2250-y.

Chautá-Mellizo A, Campbell SA, Bonilla MA, Thaler JS, Poveda K. 2012. Basic and Applied Ecology **13,** 524-532.
http://dx.doi.org/10.1016/j. baae.2012.08.013

Classen A, Peters MK, Kindeketa WJ, Appelhans T, Eardley CD, Gikungu MW, Hemp A, Nauss T, Steffan-Dewenter I. 2015. Temperature versus resource constraints: which factors determine bee diversity on Mount Kilimanjaro, Tanzania? Global Ecology and Biogeography **24,** 642-652.

Cook JM, Segar ST. 2010. Speciation in fig wasps. Ecological Entomology **35,** 54-66.
DOI: 10.1111/j.1365-2311.2009.01148.x

Cook SM, Bartlet E, Murray DA, Williams IH. 2002. The role of pollen odour in the attraction of pollen beetles to oilseed rape flowers. Entomologia Experimentalis et Applicata **104,** 43-50.
DOI: 10.1046/j.1570-7458.2002.00989.x

Corbet SA, Fussell M, Ake R, Fraser A, Gunson C, Savage A, Smith K. 1993. Temperature and the pollinating activity of social bees. Ecological Entomology **18,** 17-30.
DOI: 10.1111/j.1365-2311.1993. tb01075.x

Culley TM, Weller SG, Sakai AK. 2002. The evolution of wind pollination in Angiosperms. TRENDS in Ecology & Evolution **17,** 361-369. http://dx.doi.org/10.1016/S0169-5347(02)02540-5

Dar SA, Hassan GI, Padder BA, Wani AR, Parey SH. 2017. Pollination and evolution of plant and insect interaction. Journal of Pharmacognosy and Phytochemistry **6,** 304-311.

De Palma A, Abrahamczyk S, Aizen MA, Albrecht M, Basset Y, Bates A, Blake RJ, Boutin C, Bugter R, Connop S, Cruz-López L, Cunningham SA, Darvill B, Diekötter T, Dorn S, Downing N, Entling MH, Farwig N, Felicioli A, Fonte SJ, Fowler R, Franzén M, Goulson D, Grass I, Hanley ME, Hendrix SD, Herrmann F, Herzog F, Holzschuh A, Jauker B, Kessler M, Knight ME, Kruess A, Lavelle P, Le Féon V, Lentini P, Malone LA, Marshall J, Pachón EM, McFrederick QS, Morales CL, Mudri-Stojnic S, Nates-Parra G, Nilsson SG, Öckinger E, Osgathorpe L, Parra-H A, Peres CA, Persson AS, Petanidou T, Poveda K, Power EF, Quaranta M, Quintero C, Rader R, Richards MH, Roulston T, Rousseau L, Sadler JP, Samnegård U, Schellhorn NA, Schüepp C, Schweiger O, Smith-Pardo AH, Steffan-Dewenter I, Stout JC, Tonietto RK, Tscharntke T, Tylianakis JM, Verboven HAF, Vergara CH, Verhulst J, Westphal C, Yoon HJ, Purvis A. 2016. Predicting bee community responses to land-use changes: Effects of geographic and taxonomic biases. Scientific Reports **6,** 31153.
DOI: 10.1038/srep31153.

Denisow B, Wrzesień M. 2015. The Importance of Field-Margin Location for Maintenance of Food Niches for Pollinators. Journal of Apicultural Science 59, 27-37.
DOI: 10.1515/jas -2015-0002 2015

Deutsch CA, Tewksbury JJ, Huey RB, Sheldon KS, Ghalambor CK, Haak DC, Martin PR. 2008. Impacts of climate warming on terrestrial ectotherms across latitude. Proceedings of the National Academy of Sciences **105,** 6668-6672.
DOI: 10.1073/pnas.0709472105.

Dicks LV, Abrahams A, Atkinson J, Biesmeijer J, Bourn N, Brown C, Brown MJF, Carvell C, Connolly C, Cresswell JC, Croft P, Darvill B, De Zylva P, Effingham P, Fountain M, Goggin A, Harding D, Harding T, Hartfield C, Heard MS, Heathcote R, Heaver D, Holland J, Howe M, Hughes B, Huxley T, Kunin WE, Little J, Mason C, Memmott J, Osborne J, Pankhurst T, Paxton RJ, Pocock MJO, Potts SG, Power EF, Raine NE, Ranelagh E, Roberts S, Saunders R, Smith K, Smith RM, Sutton P, Tilley LAN, Tinsley A, Tonhasca A, Vanbergen AJ, Webster S, Wilson A, Sutherland WL. 2013. Identifying key knowledge needs for evidence-based conservation of wild insect pollinators: a collaborative cross-sectoral exercise. Insect Conservation and Diversity **6,** 435-446.
DOI: 10.1111/j.1752-4598.2012.00221.x

Dixon KW. 2009. Pollination and restoration. Science **325,** 571-573.
DOI: 10.1126/science.1176295

Eardley CD, Gikungu M, Schwarz MP. 2009. Bee conservation in Sub-Saharan Africa and Madagascar: diversity, status and threats. Apidologie **40,** 355-366.
DOI: 10.1051/apido/2009016

Easton AH, Goulson D. 2013. The Neonicotinoid Insecticide Imidacloprid Repels Pollinating Flies and Beetles at Field-Realistic Concentrations. PLoS ONE **81,** e54819.
DOI: 10.1371/journal.pone.0054819

FAO. 1995. Pollination of cultivated plants in the tropics. ISBN 92-5-103659-4, ISSN 1010-1365.

FAO. 2007. The Plan of Action of the African Pollinator Initiative, Food and Agriculture Organization of the United Nations Rome Italy.

FAO. 2014. Building a common vision for sustainable food and agriculture. Principles and approaches Rome.

FAO. 2016. Climate change and food security: risks and responses, Rome.
www.fao. org/3/a-i5188e.pdf).

Feltham H, Park K, Minderman J, Goulson D. 2015. Experimental evidence that wildflower strips increase pollinator visits to crops. Ecology and Evolution **5,** 3523- 3530.
DOI: 10.1002/ece3.1444.

Fischer RA, Edmeades GO. 2010. Breeding and Cereal Yield Progress. Crop Science **50,** 85- 98.
DOI: 10.2135/cropsci2009.10.0564

Freitas BM, Imperatriz-Fonseca VL, Medina LM, Kleinert AP, Galetto L, Nates-Parra G, Quezada-Eúan JJG. 2009. Diversity, threats and conservation of native bees in the Neotropics. Apidologie **40,** 332-346.
DOI: 10.1051/apido/2009012

Freitas BM, Paxton RJ. 1996. The role of wind and insects in cashew (*Anacardium occidentale*) pollination in NE Brazil. Journal of Agricultural Science **126,** 319-326.

Gallai N, Salles J, Settele J, Vaissière BE. 2009. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. Ecological Economics **68,** 810-821.

Garibaldi LA, Steffan-Dewenter I, Winfree R, Aizen MA, Bommarco R, Cunningham SA, Kremen C, Carvalheiro LG, Harder LD, Afik O, Bartomeus I, Benjamin F, Boreux V, Cariveau D, Chacoff NP, Dudenhöffer JH, Freitas BM, Ghazoul J, Greenleaf S, Hipólito J, Holzschuh A, Howlett B, Isaacs R, Javorek SK, Kennedy CM, Krewenka KM, Krishnan S, Mandelik Y, Mayfield MM, Motzke I, Munyuli T, Nault BA, Otieno M, Petersen J, Pisanty G, Potts SG, Rader R, Ricketts TH, Rundlöf M, Seymour CL, Schüepp C, Szentgyörgyi H, Taki H, Tscharntke T, Vergara CH, Viana BF, Wanger TC, Westphal C, Williams N, Klein AM. 2013. Wild pollinators enhance fruits set of crops regardless of honey bee abundance. Science **339,** 1608-1611. http:// dx.doi.org/10.1126/science.1230200.

Gathmann A, Tscharntke T. 2002. Foraging ranges of solitary bees. Journal of Animal Ecology **71,** 757-764.
DOI: 10.1046/j.1365-2656.2002.00641.x

Gill HK, Garg H. 2014. Pesticides: Environmental Impacts and Management Strategies; Chapter 8. http://dx.doi.org/10.5772/57399.

González-Varo JP, Biesmeijer JC, Bommarco R, Potts SG, Schweiger O, Smith HG, Steffan-Dewenter I, Szentgyörgyi H, Woyciechowski M, Vilà M. 2013. Combined effects of global change pressures on animal mediated pollination. Trends in Ecology & Evolution **28,** 524-530.
http://dx.doi.org/ 10.1016/j.tree.2013.05.008

Goulson D. 2003. Conserving wild bees for crop pollination. Food, Agriculture and Environment **1**, 142-144.

Graystock P, Yates K, Darvill B, Goulson D, Hughes WOH. 2013. Emerging dangers: Deadly effects of an emergent parasite in a new pollinator host. Journal of Invertebrate Pathology **114,** 114-119. http://dx.doi.org/10.1016/j.jip.2013.06.005

Greenleaf SS, Williams NM, Winfree R, Kremen C. 2007. Bee foraging ranges and their relationship to body size. Oecologia **153,** 589-596. DOI: 10.1007/s00442-007-0752-9.

Gumbert A. 2000. Color choices by bumble bees (*Bombus terrestris*): innate preferences and generalization after learning. Behavioral Ecology and Sociobiology **48,** 36-43.
DOI: 10.1007/s002650000213

Hannon LE, Sisk TD. 2009. Hedgerows in an agri-natural landscape: Potential habitat value for native bees. Biological Conservation **142,** 2140-2154.
DOI: 10.1016/j.biocon.2009.04.014

Harrison JF, Roberts SP. 2000. Flight respiration and energetics. Annul Review of Physiology **62,** 179-205.
https://doi.org/10.1146/annurev.physiol.62.1.179

Harrison RD, Rasplus J. 2006. Dispersal of fig pollinators in Asian tropical rain forests. Journal of Tropical Ecology **22,** 631-639.
DOI: 10.1017/S0266467 406003488

Harrison T, Winfree R. 2015. Urban drivers of plant-pollinator interactions. Functional Ecology **29,** 879-888.
DOI: 10.1111/1365-2435.12486

Heard TA. 1999. The role of stingless bees in crop pollination. Annual Review of Entomology **44,** 183-206.

Heath SK, Soykan CU, Velas KL, Kelsey R, Kross SM. 2017. A bustle in the hedgerow: Woody field margins boost on farm avian diversity and abundance in an intensive agricultural landscape. Biological Conservation **212,** 153-161.
http://dx.doi .org/10.1016/j.biocon.2017.05.031

Hegland SJ, Nielsen A, Lázaro A, Bjerknes A, Totland Ø. 2009. How does climate warming affect plant-pollinator interactions? Ecology Letters **12,** 184-195.
DOI: 10.1111/j.1461-0248.2008.01269.x

Henry M, Béguin M, Requier F, Rollin O, Odoux JF, Aupinel P, Aptel J, Tchamitchian S, Decourtye A. 2012. A Common Pesticide Decreases Foraging Success and Survival in Honey Bees. Science **336,** 348-350.

Herrera CM, Perez R, Alonso C. 2006. Extreme intraplant variation in nectar sugar composition in an insect-pollinated perennial herb. American Journal of Botany **93,** 575-581.
DOI: 10.3732/ajb.93.4.575

Holzschuh A, Dainese M, González-Varo JP, Mudri-Stojnić S, Riedinger V, Rundlöf M, Scheper J, Wickens JB, Wickens VJ, Bommarco R, Kleijn D, Potts SG, Roberts SPM, Smith HG, Vilà M, Vujić A, Steffan-Dewenter I. 2016. Mass-flowering crops dilute pollinator abundance in agricultural landscapes across Europe. Ecology Letters **19,** 1228-1236.
DOI: 10.1111/ele.12657

Horrigan L, Lawrence RS, Walker P. 2002. How Sustainable Agriculture Can Address the Environmental and Human Health Harms of Industrial Agriculture. Environmental Health Perspectives **110,** 445- 456.

IPBES. 2016. The assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production. S.G. Potts, V. L. Imperatriz-Fonseca, and H. T. Ngo, (Eds). Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany pp 552.

Kasina JM, Mburu J, Kraemer M, Holm-mueller K. 2009a. Economic Benefit of Crop Pollination by Bees: A Case of Kakamega Small-Holder Farming in Western Kenya. Journal of Economic Entomology **102,** 467-473. DOI: http://dx.doi.org/10.1603/029.102.0201

Kasina M, Kraemer M, Martius C, Wittmann D. 2009b. Farmers' knowledge of bees and their natural history in Kakamega district, Kenya. Journal of Apicultural Research and Bee World **48,** 126-133. DOI: 10.3896/IBRA.1.48.2.07

Kennedy CM, Lonsdorf E, Neel MC, Williams NM, Ricketts TH, Winfree R, Bommarco R, Brittain C, Burley AL, Cariveau D, Carvalheiro LG, Chacoff NP, Cunningham SA, Danforth BN, Dudenhöffer J, Elle E, Gaines HR, Garibaldi LA, Gratton C, Holzschuh A, Isaacs R, Javorek SK, Jha S, Klein AM, Krewenka K, Mandelik Y, Mayfield MM, Morandin L, Neame LA, Otieno M, Park M, Potts SG, Rundlöf M, Saez A, Steffan-Dewenter I, Taki H, Viana BF, Westphal C, Wilson JK, Greenleaf SS, Kremen C. 2013. A global quantitative synthesis of local and landscape effects on wild bee pollinators in agro ecosystems. Ecology Letters **16,** 584-599.
DOI: 10.1111/ele.12082.

Kevan GP. 1999. Pollinators as bioindicators of the state of the environment: species, activity and diversity. Agriculture, Ecosystems and Environment **74,** 373-393.

Kevan PG, Clark EA, Thomas VG. 1990. Insect pollinators and sustainable agriculture. American Journal of Alternative Agriculture **5,** 13-22.
DOI: 10.1017/S0889189300003179

Kiatoko N, Raina SK, Muli E, Mueke J. 2014. Enhancement of fruit quality in *Capsicum annum* through pollination by *Hypotrigona gribodoi* in Kakamega, Western Kenya. Entomological Science **17,** 106-110.
DOI:10.1111/ens.12030

Klein AM, Vaissière BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C, Tscharntke T. 2007. Importance of pollinators in changing landscapes for world crops. The Proceedings of the Royal Society of London Series B **274,** 303-313.

Klein AM. 2009. Nearby rainforest promotes coffee pollination by increasing spatio-temporal stability in bee species richness. Forest Ecology and Management **258,** 1838-1845.
DOI:10.1016/j.foreco.2009.05.005

Kovács-Hostyánszki A, Espíndola A, Vanbergen AJ, Settele J, Kremen C, Dicks LV. 2017. Ecological intensification to mitigate impacts of conventional intensive land use on pollinators and pollination. Ecology Letters **20,** 673-689.
DOI: 10.1111/ele.12762

Larson BMH, Kevan PG, Inouye DW. 2001. Flies and flowers: taxonomic diversity of anthophiles and pollinators. The Canadian Entomologist **133,** 439-465.

López-Hoffman L, Varady RG, Flessa KW, Balvanera P. 2010. Ecosystem services across borders: a framework for transboundary conservation policy. Frontiers in Ecology and the Environment **8,** 84-91.
DOI: 10.1890/070216

Lundgren R, Lázaro A, Totland O. 2013. Experimental pollinator decline affects plant reproduction and is mediated by plant mating system. Journal of Pollination Ecology **11,** 46-56.

Mayer C, Adler L, Armbruster WS, Dafni A, Eardley C, Huang S, Kevan PG, Ollerton J, Packer L, Ssymank A, Stout JC, Potts SG. 2011. Pollination Ecology in the 21st century: Key questions for future research. Journal of Pollination Ecology **3,** 8-23.

McCall C, Primack RB. 1992. Influence of Flower Characteristics, Weather, Time of Day, and Season on Insect Visitation Rates in Three Plant Communities. Journal of Botany **79,** 434-442.

Melin A, Rouget M, Midgley J, Donaldson JS. 2014. Pollination ecosystem services in South African agricultural systems. South African Journal of Science **110,** 1-9.
http://dx.doi.org/10.1590/ sajs.2014/20140078

Memmott J, Waser NM, Price MV. 2004. Tolerance of pollination networks to species extinctions. Proceedings of the Royal Society of London B **271,** 2605-2611
DOI:10.1098/rspb. 2004.2909

Midgley JJ, Bond WJ, Jarzembowski EA, Grubb PJ. 1991. How Important is Biotic Pollination and Dispersal to the Success of the Angiosperms? Philosophical Transactions of the Royal Society of London B **333,** 209-215.

Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-being: Synthesis, Island Press, Washington DC.

Motten AF, Campbell DR, Alexander DE, Miller HL. 1981. Pollination Effectiveness of Specialist and Generalist Visitors to a North Carolina Population of *Claytonia virginica*. Ecology **62,** 1278-1287.
DOI: 10.2307/1937292

Munyuli T. 2011a. Farmers' perceptions of pollinators' importance in coffee production in Uganda. Agricultural Sciences **2,** 318-333.
DOI:10.4236/as.2011.23043

Munyuli T. 2011b. Factors governing flower visitation patterns and quality of pollination services delivered by social and solitary bee species to coffee in central Uganda. African Journal of Ecology **49,** 501-509.
DOI: 10.1111/j.1365-2028.2011.01284.x

Mwangi D, Kasina M, Nderitu J, Hagen M, Gikungu M, Kraemer M. 2012. Diversity and abundance of native bees foraging on hedgerow plants in the Kakamega farmlands, western Kenya. Journal of Apicultural Research **51,** 298-305.
DOI 10.3896/IBRA.1.51.4.02

Nicholls CI, Altieri MA, Vazquez L. 2016. Agroecology: Principles for the Conversion and Redesign of Farming Systems. Journal of Ecosystem and Ecography **5,** 010.
DOI: 10.4172/2157-7625.S5-010

Norfolk O, Sadiki LL, Broughton B, Otieno M, Nuttman C. 2012. Tea breaks: how flower visitors can benefit from unplanned floral buffer strips in a Tanzanian tea plantation. African Journal of Ecology **51,** 380-384.

Ollerton J, Johnson SD, Cranmer L, Kellie S. 2003. The Pollination Ecology of an Assemblage of Grassland Asclepiads in South Africa. Annals of Botany **92,** 807-834.
DOI:10.1093/aob/mcg206.

Ollerton J, Winfree R, Tarrant S. 2011. How many flowering plants are pollinated by animals? Oikos **120,** 321-326.
DOI: 10.1111/j.1600-0706.2010.18644.x

Otieno M, Woodcock BA, Wilby A, Vogiatzakis IN, Mauchline AL, Gikungu MW, Potts SG. 2011. Local management and landscape drivers of pollination and biological control services in a Kenyan agro-ecosystem. Biological Conservation **144,** 2424-2431.
DOI: 10.1016/j.biocon.2011.06.013

Pandit S, Choudhury BC. 2001. Factors affecting pollinator visitation and reproductive success in *Sonneratia caseolaris* and *Aegiceras corniculatum* in a mangrove forest in India. Journal of Tropical Ecology **17,** 431-447.
DOI:10.1017/S02664 67401001298

Parachnowitsch AL, Kessler A. 2010. Pollinators exert natural selection on flower size and floral display in Penstemon digitalis. New Phytologist **188,** 393-402.
DOI: 10.1111/j.1469-8137.2010.03410.x

Peters VE, Carroll CR, Cooper RJ, Greenberg R, Solis M. 2013. The contribution of plant species with a steady-state flowering phenology to native bee conservation and bee pollination services. Insect Conservation and Diversity **6,** 45-56.
DOI: 10.1111/j.1752-4598.2012.00189.x

Potts SG, Biesmeijer JC, Kremen C, Neumann P, Schweiger O, Kunin WE. 2010. Global pollinator declines: trends, impacts and drivers. Trends in Ecology and Evolution **25,** 345-353.
DOI: 10.1016/j.tree.2010.01.007

Power AG. 2010. Ecosystem services and agriculture: tradeoffs and synergies. Philosophical Transactions of the Royal Society B **365,** 2959-2971.
DOI:10.1098/rstb.2010.0143.

Raina SK, Kioko E, Zethner O, Wren S. 2011. Forest Habitat Conservation in Africa Using Commercially Important Insects. Annual Review of Entomology **56,** 465-485.
DOI: 10.1146/annurev-ento-120709-144805.

Rands SA, Whitney HM. 2011. Field Margins, Foraging Distances and Their Impacts on Nesting Pollinator Success. PLoS ONE **10,** e25971.
DOI: 10.1371/ journal.pone.0025971

Regal PJ. 1982. Pollination by Wind and Animals: Ecology of Geographic Patterns. Annual Review of Ecology and Systematics **13,** 497-524.
https://doi.org/10.1146/annurev.es.13.110182.002433

Reinhard J, Srinivasan MV, Zhang S. 2004. Scent-triggered navigation in honeybees. Nature **427,** 411.
DOI:10.1038/427411a

Renner SS, Feil JP. 1993. Pollinators of Tropical Dioecious Angiosperms. American Journal of Botany **80,** 1100-1107.

Richards AJ. 2001. Does Low Biodiversity Resulting from Modern Agricultural Practice Affect Crop Pollination and Yield? Annals of Botany **88,** 165172.
DOI:10.1006/anbo.2001.1463.

Ricketts TH. 2004. Tropical Forest Fragments Enhance Pollinator Activity in Nearby Coffee Crops. Conservation Biology **18,** 1262- 1271.
DOI: 10.1111/j.1523-1739.2004.00227.x

Sala OE, Chapin III FS, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke LF, Jackson RB, Kinzig A, Leemans R, Lodge DM, Mooney HA, Oesterheld M, Poff NL, Sykes MT, Walker BH, Walker M, Wall DH. 2000. Global biodiversity scenarios for the year 2100. Science **287,** 1770- 1774.
DOI: 10.1126/science. 287.5459.1770

Samnegård U, Hambäck PA, Lemessa D, Nemomissa S, Hylander K. 2016. A heterogeneous landscape does not guarantee high crop pollination. Proceedings of the Royal Society B **283,** 1-9.
http://dx.doi.org/10.1098/rspb.2016.1472

Scheper J, Holzschuh A, Kuussaari M, Potts SG, Rundlöf M, Smith HG, Kleijn D. 2013. Environmental factors driving the effectiveness of European agri-environmental measures in mitigating pollinator loss – a meta-analysis. Ecology Letters **16,** 912-920.
DOI: 10.1111/ele.12128.

Sidhu CS, Joshi NK. 2016. Establishing Wildflower Pollinator Habitats in Agricultural Farmland to Provide Multiple Ecosystem Services. Frontiers in Plant Science **7,** 363.
DOI: 10.3389/fpls.2016.00363

Sodhi NS, Koh LP, Brook BW, Ng PKL. 2004. Southeast Asian biodiversity: an impending disaster. Trends in Ecology and Evolution **19,** 654-660.
DOI: 10.1016/j.tree.2004.09.006

Steffan-Dewenter I, Schiele S. 2008. Do resources or natural enemies drive bee population dynamics in fragmented habitats? Ecology **89,** 1375-1387.
DOI: 10.1890/06-1323.1

Szabo TI. 1980. Effect of Weather Factors on Honeybee Flight Activity and Colony Weight Gain. Journal of Apicultural Research **19,** 164-171.
DOI: 10.1080/00218839.1980.11100017

Terry I, Walter GH, Moore C, Roemer R, Hull C. 2007. Odor-Mediated Push-Pull Pollination in Cycads. Science **318,** 70.
DOI: 10.1126/science.1145147

Tester M, Langridge P. 2010. Breeding Technologies to Increase Crop Production in a Changing World. Science **327,** 818-821.
DOI: 10.1126/science.1183700

Toivonen M, Herzon I, Kuussaari M. 2016. Community composition of butterflies and bumblebees in fallows: niche breadth and dispersal capacity modify responses to fallow type and landscape. Journal of Insect Conservation **20,** 23-34.
DOI: 10.1007/s10841-015-9836-8.

Van der Sluijs JP, Simon-Delso N, Goulson D, Maxim L, Bonmatin J, Belzunces LP. 2013. Neonicotinoids, bee disorders and the sustainability of pollinator services. Current Opinion in Environmental Sustainability **5,** 293-305.
http://dx. doi. org/ 10.1016/j.cosust.2013.05.007

Van Hamburg H, Guest PJ. 1997. The Impact of Insecticides on Beneficial Arthropods in Cotton Agro-Ecosystems in South Africa. Archives of Environmental Contamination and Toxicology **32,** 63-68.
https://doi.org/10.1007/s002449900156

Vicens N, Bosch J. 2000. Weather-Dependent Pollinator Activity in an Apple Orchard, with Special Reference to *Osmia cornuta* and *Apis mellifera* (Hymenoptera: Megachilidae and Apidae). Environmental Entomology **29,** 413-420.
DOI: www.dx.doi.org/10.1603/0046-225X-29.3.413

Waser NM, Chittka L, Price MV, Williams NM, Ollerton J. 1996. Generalization in pollination systems, and why it matters. Ecology **77,** 1043-1060.
DOI: 10.2307/2265575.

Weiblen GD. 2002. How to be a fig wasp. Annual Review of Entomology **47,** 299-330.
https://dx.doi.org/10.1146/annurev.ento.47.091201.145213

Weiner CN, Werner M, Linsenmair KE, Blüthgen N. 2014. Land-use impacts on plant–pollinator networks: interaction strength and specialization predict pollinator declines. Ecology **95,** 466-474.

Westphal C, Vidal S, Horgan FG, Gurr GM, Escalada M, Chien HV, Tscharntke T, Heongh KL, Settele J. 2015. Promoting multiple ecosystem services with flower strips and participatory approaches in rice production landscapes. Basic and Applied Ecology **16,** 681-689.

Whitehorn PR, O'Connor S, Wackers FL. 2012. Neonicotinoid Pesticide Reduces Bumble Bee Colony Growth and Queen Production. Science **336,** 351-352.
DOI: 10.1126/science.1215025.

Wiebes JT. 1989. Agaonidae (Hymenoptera Chalcidoidea) and *Ficus* (Moraceae): fig wasps and their figs, IV (African *Ceratosolen*). Proceedings C **92,** 251-266.

Wilcove DS, Koh LP. 2010. Addressing threats to biodiversity from oil-palm agriculture. Biodiversity Conservation **19,** 999-1007.
DOI: 10.1007/s10531-009-9760-x

Wright GA, Schiestl FP. 2009. The evolution of floral scent: the influence of olfactory learning by insect pollinators on the honest signaling of floral rewards. Functional Ecology **23,** 841-851.
DOI: 10.1111/j.1365-2435.2009.01627.x

Zhang W, Ricketts TH, Kremen C, Carney K, Swinton SM. 2007. Ecosystem services and dis-services to agriculture. Ecological Economics **64,** 253-260.
https://doi.org/10.1016/j.ecolecon. 2007.02.024

Zurbuchen A, Landert L, Klaiber J, Műller A, Hein S, Dorn S. 2010. Maximum foraging ranges in solitary bees: only few individuals have the capability to cover long foraging distances. Biological Conservation **143,** 669-676.
DOI: 10.1016/j.biocon. 2009.12.003