INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 11, No. 4, p. 229-239, 2017
http://www.innspub.net

RESEARCH PAPER OPEN ACCESS

Roles of insect pollinators, natural enemies and farmers' knowledge on improving bean production in tropical Africa

Martin G. Mkindi[*1,2], **Patrick A. Ndakidemi**[1,2], **Ernest R Mbega**[1,2]

[1]*School of Life Sciences and Bio-Engineering, Nelson Mandela African Institution of Science and Technology, Old Arusha-Moshi Road, Tengeru, Arusha, Tanzania*

[2]*Centre for Research, Agricultural Advancement, Teaching Excellence and Sustainability (CREATES) in Food and Nutrition Security, The Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania*

Article published on October 30, 2017

Key words: Parasitoids, Ecosystem services, *Phaseolus vulgaris,* Providers of ecosystem services

Abstract

Ecosystem services play a significant role in sustainable agricultural development worldwide. Commonly examples of well-known groups of providers of ecosystem services are insect pollinators and natural enemies of bean pests. These providers of ecosystem services and other natural services are crucial for ecosystems' proper functioning and thereby sustaining plant growth, crop production and protection against crop pests. Literature provides evidence for a great role that the ecosystem services play in sustainable crop production. However, limited information is available on significance, farmer's knowledge and their functions in bean pest management in tropical Africa. Lack of understanding on the ecosystem services and the providers of ecosystem services can lead to improper providers of ecosystem services conservation as a consequence, increase pest pressure which can result in poor crop yields. Therefore, this review discusses the level of understanding of small scale farmers, significance and potential use of the ecosystem services (pollinators and natural enemies of bean pests) for sustainable bean production and further, outlines potential research gaps for management and optimization of the ecosystem services in the tropical Africa.

***Corresponding Author:** Martin G. Mkindi ✉ mkindim@nm-aist.ac.tz

Introduction

Ecosystem services in agriculture refers to any nature-based activity that is offered by providers of ecosystem services such as pollinators and natural enemies in different processes such as biological control of pests, soil formation, nutrient cycling and or other related processes (Power, 2010; Messelink *et al.,* 2014; Lacey *et al.,* 2015; Ndakidemi *et al.,* 2016). These providers of ecosystem services are very important in Agriculture. For instance, a report by Hoehn & Tscharntke, (2008); Bartomeus *et al.* (2014), and Melin *et al.* (2014) indicated that more than 75% of the world crops benefit from pollinators leading to improved crop yields ranging from 25% to 99%. In a study by Ollerton *et al.* (2011) and Rader *et al.* (2015), wild and managed bees have been estimated to be effective in pollinating more than 87% of flowering plants in the tropic and temperate zones worldwide. Although some reports on ecosystem services are available for many locations, the literature shows fewer studies and hence less data on pollinators, natural enemies and their roles in agriculture in the tropical Africa. Shackelford *et al.* (2013) identified only one study in Africa on pollinators and natural enemies as compared with many studies in North America and Europe. Within this limited line of studies, it has been apparently described that Africa is endowed with massive species of flowering plants whose presence can enhance the presence of the provider of ecosystem services (Blaauw *et al.*, 2015; Gaigher *et al.,* 2015).

Based on this phenomenon, authors hereby provide this review article to discuss the significance, farmer's knowledge and potential of the ecosystem services for improved bean production in the tropical Africa. Even though no studies on ecosystem services that were solemnly conducted in Africa, we already know well that common bean is a self-pollinating crop (Andersson *et al.*, 2014) and that some studies have shown that pollinators can improve pollination in beans leading to increased yields (Kelly, 2010; Woodcock, 2012). The rate of out crossing in beans ranges from 4-89% depending on the genotype used, environmental factors, geographical area, row space and the number of pollinating insects (Musallam *et al.,* 2004). This entails likely roles of pollination to facilitate the out crossing process. Studies conducted in the United Kingdom (UK) and Rwanda show an increased yield of about 60% to 69% due to pollinator's involvement in bean (Garratt *et al.,* 2014). Besides pollination services, the provider of ecosystem services particularly the natural enemies play a significant role in pest management worldwide (Gaigher *et al.,* 2015). The level of understanding and application of natural enemies in pest management particularly in beans is still under studied in Africa. Therefore, it is worth exploring the significance, level of understanding of small-scale farmers and potential use of the ecosystem services for sustainable providers of ecosystem services conservation and bean production in the tropical Africa.

Status and significance of Ecosystem services

Small-scale farming ecosystems are believed to provide conditions for the presence and functioning of ecosystem services if undisturbed (Garbach *et al.,* 2014). However, pollinators, natural enemies and their modes of functioning in these farming ecosystems are not well known especially in the developing countries including the tropical Africa. In other parts of the world such as the United States of America, some insects have been commercialized for different purposes including biological control of some agricultural pests (Bale *et al.,* 2008; Cranshaw, 2014) and pollination services (Garratt *et al.,* 2014; Flint & Dreistadt, 2005). For instance, the USA exports parasite free colonies of bumblebees (*Bombus sp.*) globally especially to temperate countries such as those in Europe, North America, South America and Asia for pollination purposes in greenhouse crops (Woodcock 2012; Graystock *et al.* 2013). In the tropical Africa, literature is limited on the status of use and significance of ecosystem services especially on understanding the providers of ecosystem services and their possible contribution to agriculture (Kovács-Hostyánszki *et al.,* 2017). In addition, the providers of ecosystem services are in the danger of decreasing due to climate change, habitat loss and fragmentation, agrochemicals, spread of alien species and diseases (Colley & Luna 2000; Jones & Gillett

2005; Patterns *et al.,* 2010; Potts *et al.,* 2010; Vanbergen & Initiative 2013; Goulson *et al.*, 2015; Tiedeken *et al.,* 2016). Therefore, there is a need for collective choices and studies on understanding phenomenon behind providers of ecosystem services habitat, ethno-ecological and social perspectives to fully preserve and utilize benefits offered by the ecosystem for sustainable crops including beans production in the tropical Africa.

Key Providers of Ecosystem Services

Key providers of ecosystem services are summarized in Table 1, showing interestingly that some of the player such as insects depending on growth stages can perform more than one role in the ecosystem settings.

For instance, Hoverflies (*Diptera: Syrphidae*) is both a pollinator (in adult stage) and predator of pests such as aphids, thrips, mites, and other small insects in the larval stage (Moquet, *et al.,* 2017). In performing their role, the provider of ecosystem services can be very effective. For example, the Ladybird beetle have been reported by Gurney& Hussey (1970) and Eric (2017) to reduce their pray particularly aphids by 99% in a seven days' time. Other provider of ecosystem services such as Trichogramma wasps (*Trichogramma pretiosum*) appear to be the smallest of all insects but very important in biological pest control for their ability to parasitize eggs of many different orders of insects (Sarwar & Salman, 2015).

Table 1. Key insect provider of ecosystem services, role in crops and their predilection sites.

Name of ecosystem providers (Order : Family)	Role in crops	Predilection site	Reference
Honey Bees (Hymenoptera: Apidae)	Pollinator	Red flowers with short tubes, Nectar source plant, river bank and forest area	(Fothergill, 2009; Padhye, *et al.,* 2012; Parandhaman, *et al.,* 2012; Prabakaran, *et al.,* 2014)
Butterflies (Lepidoptera: Rhopalocerae)	Pollinator (adult)	Red flowers with short tubes, Nectar source plant, river bank and forest area	(Fothergill, 2009; Padhye, *et al.,* 2012; Parandhaman, *et al.,* 2012; Prabakaran, *et al.,* 2014)
Moth (Lepidoptera: Psychidae)	Pollinator (Adult)	White or pale flowers with strong fragrance producing plants	Hopwood, (2010); (Moore & Hanks, 2004; Villanueva & Rodrigues, 2005)
Stingless bee (Hymenoptera: Apidae)	Pollinator	Wild plants & crops	(Anguilet, *et al.,* 2015; Ramalho *et al.,* 1990; Slaa *et al.,* 2006; Villanueva-g, *et al.,* 2005)
Hoverflies (Diptera: Syrphidae)	Both predator of aphids, thrips, mites, and other small insects and pollinator	Queen Anne's lace, dill, fennel, tansy, coriander, bishop's weed, coreopsis, gloriosa daisy, yarrow, the cosmos, sunflower, marigolds, candytuft, sweet *alyssum*,	Cooperative Extension Service (CES) (2010); Stewart *et al..,* (2007)
Green Lacewing (Neuroptera: Chrysopidae)	Predator of aphids, mites, whiteflies, caterpillars, small soft-bodied prey & adult are pollinators	Melon crop	(Aldrich, *et al..,* 2016; Keulder & Van den Berg, 2013; Rana, *et al.,* 2017)
Assassin Bug (Hemiptera: Reduviidae)	Predator of most insects	Legumes	(Stewart, *et al.,* 2007; Virla, *et al.,* 2015)

Name of ecosystem providers (Order : Family)	Role in crops	Predilection site	Reference
Hoverflies (Diptera: Syrphidae)	Pollinator (adult) & larvae are predator of aphids, thrips, and mite	Bishop's weed, coreopsis, gloriosa daisy, yarrow, cosmos, sunflower, marigolds, candytuft, sweet alyssum, decaying vegetation	(Cooperative Extension Service (CES) 2010; Stewart, *et al.* (2007); (Lee, *et al.,* 2001)
Ground Beetle (Coleoptera: Carabidae)	Both adults and larvae are the predator of aterpillars, cutworms, ants, maggots, earthworms, slugs, and other beetles	Arable crops, heavier soils, trees and shrubs	(Chin, and Brown 2010); (Ghahari *et al.,* 2009; Lövei & Sunderland, 1996; Woodcock *et al.,* 2014)
Lady Beetle (Coleoptera: Coccinellidae)	Predator	Polen and nectar producing plants	(Getanjaly, *et al.,* 2015; Almeida, *et al.,* 2011; Frank & Mizell, 2009; Sarwar, 2016; Sloggett, 2012; Snyder *et al.,* 2004)
Brown Lacewing (Neuroptera: Hemerobiidae)	Larvae are predator of insect eggs, leafhoppers, mites, red-banded thrips, mites, immature mealy bugs, moth eggs and small caterpillars.	Tree/shrub crops, flowering crops, vegetation, orchards, carrot family and sunflower family	(Lee, *et al..,* 2001; Kovanci & Kovanci, 2007; Rocca & Messelink, 2016; Stange, 1997)
Green Lacewing (Neuroptera: Chrysopidae)	Larvae are predator of aphids, mites, whiteflies, caterpillars, and other small, soft-bodied prey	Melon crop	(Bezerra *et al..,* 2010; Stange, 1997; Rana *et al..,* 2017)
Long legged (Diptera: Dolichopodidae	Predators of aphids, thrips, young caterpillars, and mites predators or scavengers in detritus in soil.	Tree crevices, field margins, and crops	(Mahr, *et al.,* 2008; James, *et al,* 2016; Kautz, *et al..,* 2014; Kazerani, *et al.,* 2015)
Robber Flies (Diptera: Asilidae)	Predator of Flies, wasps, Grasshoppers, leafhoppers, beetles, and butterflies. Larvae feed on small insects	Rotting wood, foliage, bark and seed heads of grasses (eggs)	(Cannings, 2014; Samin, *et al.,* 2011; Samin *et al.,* 2011)
Tachinid Flies (Diptera: Tachinidae)	Parasitoids of Green clover worm, bean leaf beetle, beetle larvae, grasshoppers and caterpillars	Crops pollen	Pesticide Action Network (PAN), 2014; (Bhoje, 2015; De Farias, *et al.,* 2012; Gammelmo & Sagvolden, 2007; Samin*et al.,* 2011)
Spiders (Araneae: Sparassidae)	Predators of red-banded thrips, plant hoppers, caterpillars and moths	Soil, low vegetation/woody plants (perennial crops)	Cooperative Extension Service (CES) (2010; Ndakidemi *et al.,* 2016)
Trichogramma Wasps (Hymenoptera: Trichogrammatidae	Parasitoids of army worm eggs, corn earworms, cutworms, European corn borer and bean pods borer (*Marucavitrata*)	Closely spaced plants	(Fernandes, *et al.,* 2010; Belmain, *et al.,* 2013; Olson & Andow, 2006; Romeis, Babendreier, Wäckers, & Shanower, 2005)

Role of provider of ecosystem services in crop pollination

Some providers of ecosystem services particularly insect pollinators have been reported to be capable of moving pollen from one flower part to the other in so providing grounds for fertilization, seed and fruit set (Cruz *et al.,* 2005; dos Santos *et al.,* 2009; Heard, 1999; Munyuli, 2011; Slaa *et al.,* 2006). Insect pollinators including bee species such as honey bees, stingless bees, carpenter bees have been considered to play a primary role in crop pollination than as for non-animal agents such as wind pollination (Kremen *et al.,* 2007; Garibaldi *et al.,* 2013; Nunes-Silva *et al.,* 2013). For instance, Ollerton *et al.* (2011) reported that about approximately 308,000 species i.e. 87.5% of crops are pollinated by insects and other animals while the remaining percent is done by abiotic pollen carriers such as the wind worldwide. Pollination by insects has been reported to contribute to the yield of beans and other crops (Musallam *et al.,* 2004; Aouar-sadli *et al.,* 2008; Mireille *et al.,* 2012). For instance, Nayak *et al.* (2015) reported an increase by 18.5% of yield compared with that in self-pollinating beans.

Other providers of ecosystem services such as natural enemies including predators, pathogens, nematodes and microorganisms are as well important in crop-pest interactions (Lee *et al.,* 2001; Flint & Dreistadt, 2005; Vinyard & Hoelmer, 2016). These natural enemies vary in size and mechanism in pest control. For instance, some natural enemies such as Ladybugs (*Hippodamia convergens*) are large enough to chew their prey (Soares, *et al.,* 2003), lay eggs e.g. parasitoid wasp on the host tissue (van Nouhuys & Kaartinen, 2008) while others such as bacteria, fungi and virus cause diseases in the host pests (Riddick, *et al.,* 2009; Singh, 2014). In most cases, natural enemies particularly insects are most active at the larval stage (Ndakidemi *et al.,* 2016) while adults may or may not have similar food needs (Stewart, *et al,* 2007).They are considered as a promising control technique due to their safety, species specific and long-term action on the target pests (Sanda & Sunusi, 2014). Natural enemies may occupy non-cultivated farm areas (non-crop habitats) especially with herbaceous plants as their habitat (Grzywacz & Stevenson, 2014; Bianchi *et al.,* 2006).

The predilection principles behind natural enemies on prey and or habitats are basically not well-known. However, some information is available for example flower nectars and terpenoids produced by plants following damage from herbivorous species (Wei *et al.,* 2007). In pest control, natural enemies are potentially viable options to reduce numbers of insect pests to an acceptable damaging level.

Use of natural enemies as control options have been tested in open and greenhouse condition and have shown to be cheap, having a low side effect to human, animal and are environmentally friendly (Bale *et al.* 2008; van Lenteren, 2012; Wyckhuys *et al.,* 2013; Gurr & You, 2015). However, in tropical Africa, limited or full application of natural enemies despite the role they play has not been vividly reported and/ or quantified. As a general opinion, conservation of natural enemies such as lady bird beetles (*Coleoptera: Coccinellidae*), lacewings (*Neuroptera Chrysopidae*) syrphid flies, Chalcidae, Bracoidae, and Ichneumonidae is essential in crop including common bean to small scale farmers as this can regulate over-dependence and counteract the increased cost of synthetic inputs (Messelink *et al.,* 2014). These insects are effective as they can pray and parasitize other insects such as aphids, scales, mealy bugs, leaf hoppers, and various types of soft-bodied insects while completing their life cycles (Evans, 2009). Some of them can feed on thousands of known insect pests. For example, Lady bird beetles can eat 5000 aphids or similar prey during its lifetime (Flint & Dreistadt, 2005; Cranshaw, 2014; Green *et al.,* 2015; Fasulo & Halbert, 2015; Ndakidemi *et al.,* 2016). Such action can make significant contribution in controlling aphids in bean fields.

Other providers of ecosystem services such as parasitoids whether through super parasitism, multi parasitism or hyper parasitism also play unique roles in agricultural crop protection (Lewis *et al.,* 1998). They are usually smaller than their hosts (Cohen *et al.,* 2016). Parasitoids have the characteristics of both predators and parasites (Extension, 2014; Zheng *et al.,* 2015). They can target hosts that are already infected and are among a well-known biological insect pest control strategy in the fields (Schmidt *et al.,* 2003; Mwanauta *et al.,* 2015). Their presence and effectiveness are favored by the presence of nectar which provides them with energy as they go around to search for the host (Lewis *et al.,* 1998). Parasitoids have ability to confiscate, change hormone and behaviour of the host pest to make a conducive environment for their development (Beckage, *et al.*, 2003; Libersat *et al.,* 2009). Most common parasitoids are those from families, Diptera (two-winged flies) and Hymenoptera (Saw flies, wasps and ants) (Hassell, 2000). They spend a significant portion of their life attached to or within a single host ultimately killing it (Libersat *et al.,* 2009). For example, to kill an aphid, larvae and pupa parasitoid pupates and grows within the aphids cuticle forming mummies (Chapman *et al.,* 1981). Parasitoids often complete their life cycle more quickly and increase their numbers faster than many predators (Messelink *et al.,* 2014; Grzywacz *et al.,* 2014). Parasitoids have been reported to contribute to about 33% of natural pest control (Getanjaly, *et al.*, 2015). The most known parasitoids are wasps and flies and their activity have been reported to show better results in insect control in the area where no insecticides are applied (Ampofo, 1996; Rehman & Powell, 2010). Pest management with parasitoids are cost-effective when pest densities are low (Wang & Keller, 2002). They are generally more delicate than predators and hence more vulnerable to pesticides (Gill & Garg, 2014). The role of different pollinators and natural enemies in providing ecosystem services is not well documented in the subsistence farming systems found in Africa. Understanding their roles will lead into yield increment with less agricultural inputs.

Role of farmers' knowledge on enhancement of ecosystem services in tropical Africa

Farmers possess knowledge and practices acquired through series of observation, beliefs, rules, and experiences and that are communicated from elders to younger ones and from one generation to another (Gadgil *et al.*, 1993; Boafo *et al.,* 2016; Parrotta *et al.,* 2016). Farming practices involving indigenous knowledge can enhance ecosystem preservation through multiple crop species management, landscape patchiness management, and other ways of responding to and managing beans and ecosystem surprises (Berkes *et al.,* 2000). Local knowledge can contribute to a good understanding of historical perspectives that can provide information to science (Chalmers & Fabricius, 2007; Sileshi *et al.,* 2009). Farmer's knowledge is very important in harnessing the ecosystem services because of its site specificity and practicability (Munyuli, 2011). African indigenous communities possess knowledge and perceptions on an ecosystem and their managements in relation to farming activities that are local to their areas of origin (Berkes *et al.,* 2000). This knowledge has been changing according to changes in environments, introduction of new technologies and social conditions (Parrotta *et al.,* 2016). Indigenous knowledge on types of crops, the timing of cropping, and ways of prevention the crops from pests and diseases and types of agents used for such prevention are important and traditionally practiced worldwide (Ardakani & Emadi, 2008). Statistics show that 2.1 -2.5 million people that are directly involved in small hold farming are in the tropics and 500 million are from developing country (IFAD 2013; Steward *et al.,* 2014). However, growing population and increased demand for food have changed the cropping system to expanded land and specific cropping (monocropping) in many locations worldwide and lesser in the developing countries including tropical Africa (Abate *et al.,* 2000). Tropical Africa possesses an enormous diversity of plants species which contribute to the presence of the providers of ecosystem services (Brondizio *et al.,* 2014). However, the decision on how to manage land for obtaining services from those providers of ecosystem services are currently affected by lack of understanding of the role of providers of ecosystem services by farmers including those growing bean on one hand and different dynamics like climatic changes topographical constraint, social values, increased farming and household characteristic on the other (Lamarque *et al.,* 2014). It seems also that, there is little research attention, poor regional research collaboration and lack of clear policy support framework for the ecosystem services and providers of ecosystem services in tropical Africa (Machekano *et al.,* 2017). It is apparent that some small scale farming communities still practice intercropping, conservation farming, mixed cropping and non-tillage cropping all of which ensure the presence of a great diversity of species that enhance natural ecosystem services (Munyuli, 2013; Dicks *et al.,* 2016; Puech *et al.,* 2015). There is information that use of pesticidal plants is positively practiced either as extract or intercropped with crops for insect pest control (Singh *et al.,* 2017). However, farmers' indigenous knowledge on botanical pesticides need to be improved (Mkindi *et al.,* 2015). Integrating processes such as botanical pesticides and providers of ecosystem services management is not demarcated or characterized in the tropical Africa. For any successful invention, bottom up approaches have shown a great success across the world in a number of technologies. Use of indigenous knowledge and experience therefore provides for baseline information and a way to improve agricultural sustainability through the ecosystem services management.

Potential of ecosystem services in pest management and bean production in tropical Africa

Common beans production is currently constrained by high pests pressure and poor seed set mainly due to pollen deficit (Mwanauta, *et al.,* 2014). With the increasing awareness on beneficial attributes associated with ecosystem services, there is no doubt that the communities will realize their benefits and practice ways to harness full potential of the providers of ecosystem services for improved bean production. It is already reported that the providers of ecosystem services have proved to be effective in bean pest management and pollination in other locations outside the tropical Africa (Bale *et al.,* 2008; Slaa *et al.,* 2006). Though threatened, effort of encouraging conservation of the providers of ecosystem services is being promoted at global, regional and national scales worldwide (Gill, *et al.,* 2016; Tscharntke *et al*., 2012). More research on the utilization and conservation of the providers of ecosystem services for their effect on yield increment through pest reduction and pollination are constantly considered the most critical agenda in sustainable crops production worldwide (Cane *et al.,* 2007; Garibaldi *et al.,* 2013; Nunes-Silva, *et al.,* 2013; Getanjaly, *et al.,* 2015). As far as the tropical Africa is concerned, it is obvious that farmers can increase beans production through the management of landscape and agricultural ecosystems which will automatically conserve the providers of ecosystem services (Munyuli, 2013). This should go hand in hand with discouraging excessive use of synthetic pesticides which not only pose side effects on human health and are of higher costs, but also negatively affect beneficial insects including the providers of ecosystem services (Grzywacz, *et al.,* 2014; Kedia, *et al.,* 2015; Mkindi *et al.,* 2015; Mwanauta *et al.,* 2015; Parker, *et al.,* 2013; Mkindi *et al.,* 2017). Moreover, there is need to create awareness among bean farmers and encourage collective choices for managing and harnessing the full potentiality of the providers of ecosystem services to realize what the ecosystem services is currently and will be doing in beans production in the tropical Africa.

Conclusion and research needs

In conclusion, ecosystem services and providers of ecosystem services and other natural services are crucial for ecosystems' proper functioning and thereby sustaining plant growth, crop production and protection against pests. Use of existing natural resources particularly those obtained through ecosystem services as stipulated in this review are worth of identifying, testing and utilizing in the tropical Africa. This can easily be achieved because of the diverse nature of crops, altitudes, climates and habits for the providers of ecosystem services in the region. Research however is needed on rigorous understanding of ecosystem services and providers of ecosystem services and other natural services, possible dynamics and factors affecting their survival and functions and how to better harness them for improved bean and other crops production in the tropical Africa.

Reference

Abate T, Van Huis A, Ampofo JKO. 2000. Pest management strategies in traditional agriculture: an African perspective. Annual review of entomology **45(1),** 631-659.

Abate T, Ampofo JKO. 1996. Insect pests of beans in Africa: their ecology and management. Annual review of entomology **41(1),** 45-73.

Abrol DP. 2012. Value of Bee Pollination. In Pollination Biology Springer Netherlands pp. 185-222.

Bale JS, Van Lenteren JC, Bigler F. 2008. Biological control and sustainable food production. Philosophical Transactions of the Royal Society of London B: Biological Sciences **363 (1492),** 761-776.

Bartomeus I, Potts SG, Steffan-Dewenter I, Vaissiere BE, Woyciechowski M, Krewenka KM, Bommarco R. 2014. Contribution of insect pollinators to crop yield and quality varies with agricultural intensification, Peer J2, e328.

Beckage NE, Gelman DB. 2004. Wasp parasitoid disruption of host development: implications for new biologically based strategies for insect control. Annual Reviews in Entomology **49(1),** 299-330.

Berkes F, Colding J, Folke C. 2000. Rediscovery of traditional ecological knowledge as adaptive management. Ecological Applications **10(5),** 1251-1262.

Boafo YA, Saito O, Kato S, Kamiyama C, Takeuchi K, Nakahara M. 2016. The role of traditional ecological knowledge in ecosystem services management: the case of four rural communities in Northern Ghana. International Journal of Biodiversity Science, Ecosystem Services & Management **12(1-2),** 24-38.

Cohen JE, Jonsson T, Müller CB, Godfray HCJ, Savage VM. 2005. Body sizes of hosts and parasitoids in individual feeding relationships. Proceedings of the National Academy of Sciences of the United States of America **102(3),** 684-689.

Cornelius ML, Dieckhoff C, Vinyard BT, Hoelmer KA. 2016. Parasitism and predation on sentinel egg masses of the brown marmorated stink bug (Hemiptera: Pentatomidae) in three vegetable crops: importance of dissections for evaluating the impact of native parasitoids on an exotic pest. Environmental Entomology, nvw134.

Chalmers N, Fabricius C. 2007. Expert and generalist local knowledge about land-cover change on South Africa's Wild Coast: can local ecological knowledge add value to science? Ecology and Society 12(1).

Chapman RF, Bernays EA, Simpson SJ. 1981. Attraction and repulsion of the aphid, *Cavariella aegopodii*, by plant odors. Journal of Chemical Ecology **7(5),** 881-888.

Cranshaw WS. 2014. Lady Beetles. Colorado State University **(311),** 1.

Cruz DDO, Freitas BM, Silva LAD, Silva EMSD, Bomfim IGA. 2005. Pollination efficiency of the stingless bee *Melipona subnitida* on greenhouse sweet pepper. Pesquisa agropecuária brasileira **40(12),** 1197-1201.

Dicks LV, Wright HL, Ashpole JE, Hutchison J, McCormack CG, Livoreil B, Sutherland WJ. 2016. What works in conservation? Using expert assessment of summarized evidence to identify practices that enhance natural pest control in agriculture. Biodiversity and Conservation **25(7),** 1383-1399.

Dos Santos SA, Roselino AC, Hrncir M, Bego LR. 2009. Pollination of tomatoes by the stingless bee *Melipona quadrifasciata* and the honey bee *Apismellifera (Hymenoptera, Apidae)*. Genetics and Molecular Research **8(2),** 751-757.

Evans EW. 2009. Lady beetles as predators of insects other than Hemiptera. Biological Control **51(2),** 255-267.

Flint ML, Dreistadt SH. 2005. Interactions among convergent lady beetle (*Hippodamia convergens*) releases aphid populations and rose cultivar. Biological Control **34(1),** 38-46.

Gadgil M, Berkes F, Folke C. 1993. Indigenous knowledge for biodiversity conservation. Ambio 151-156.

Garibaldi LA, Steffan-Dewenter I, Winfree R, Aizen MA, Bommarco R, Cunningham SA, Bartomeus I. 2013. Wild pollinators enhance fruit set of crops regardless of honey bee abundance. Science **339(6127),** 1608-1611.

Garbach K, Milder JC, Montenegro M, Karp DS, DeClerck FAJ. 2014. Biodiversity and ecosystem services in agro ecosystems. Encyclopedia of agriculture and food systems **2,** 21-40.

Garratt MP, Coston DJ, Truslove CL, Lappage MG, Polce C, Dean R, Potts SG. 2014. The identity of crop pollinators helps target conservation for improved ecosystem services. Biological Conservation **169,** 128-135.

Getanjaly RVL, Sharma P, Kushwaha R. 2015. Beneficial Insects and Their Value to Agriculture. Research Journal of Agriculture and Forestry Sciences **3,** 25-30.

Gil RJ, Baldock KC, Brown MJ, Cresswell JE, Dicks LV, Fountain MT, Ollerton J. 2016. Chapter four-protecting an ecosystem service: approaches to understanding and mitigating threats to wild insect pollinators. Advances in Ecological Research **54,** 135-206.

Gurney B, Hussey NW. 1970. Evaluation of some coccinellid species for the biological control of aphids in protected cropping. Annals of Applied Biology **65(3),** 451-458.

Green OO, Garmestani AS, Albro S, Ban NC, Berland A, Burkman CE, Shuster WD. 2016. Adaptive governance to promote ecosystem services in urban green spaces. Urban ecosystems **19(1),** 77-93.

Grzywacz D, Stevenson PC, Mushobozi WL, Belmain S, Wilson K. 2014. The use of indigenous ecological resources for pest control in Africa. Food Security **6(1),** 71-86.

Hassell MP. 2000. Host-parasitoid population dynamics. Journal of Animal Ecology **69(4),** 543–566 https://doi.org/10.1046/j.1365-2656.2000.00445.x

Heard TA. 1999. The role of stingless bees in crop pollination. Annual review of entomology **44(1),** 183-206.

Kedia A, Prakash B, Mishra PK, Singh P, Dubey NK. 2015. Botanicals as ecofriendly bio rational alternatives of synthetic pesticides against *Callosobruchus* spp. (Coleoptera: Bruchidae) a review. Journal of food science and technology **52(3),** 1239-1257.

Kelly JD. 2010. The story of bean breeding, white paper prepared for bean CAP & PBG works on the topic of dry bean production and breeding research in the USA. Michigan State University, 1-29.

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(5),** 673-689.

Klein AM, Vaissiere BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C, Tscharntke T. 2007. Importance of pollinators in changing landscapes for world crops. Proceedings of the Royal Society of London B: Biological Sciences **274(1608)**, 303-313.

Kremen C, Williams NM, Aizen MA, Gemmill-Herren B, LeBuhn G, Minckley R, Winfree R. 2007. Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change. Ecology letters **10(4),** 299-314.

Lamarque P, Meyfroidt P, Nettier B, Lavorel S. 2014. How ecosystem services knowledge and values influence farmers' decision-making. PloSone **9(9),** e107572.

Lewis WJ, Stapel JO, Cortesero AM, Takasu K. 1998. Understanding how parasitoids balance food and host needs: importance to biological control. Biological control **11(2),** 175-183.

Libersat F, Delago A, Gal R. 2009. Manipulation of host behavior by parasitic insects and insect parasites. Annual review of entomology **54,** 189-207.

Machekano H, Mvumi BM, Nyamukondiwa C. 2017. Diamondback Moth, *Plutella xylostella* (L.) in Southern Africa: Research Trends, Challenges and Insights on Sustainable Management Options. Sustainability **9(2),** 91.

Messelink GJ, Bennison J, Alomar O, Ingegno BL, Tavella L, Shipp L, Wäckers FL. 2014. Approaches to conserving natural enemy populations in greenhouse crops: current methods and future prospects. BioControl **59(4),** 377-393.

Moquet L, Laurent E, Bacchetta R, Jacquemart AL. 2017. Conservation of hoverflies (*Diptera, Syrphidae*) requires complementary resources at the landscape and local scales. Insect Conservation and Diversity.

Munyuli T. 2011. Farmers' perceptions of pollinators' importance in coffee production in Uganda. Agricultural Sciences **2(03),** 318.

Munyuli MT. 2013. Pollinator biodiversity in Uganda and in Sub-Sahara Africa: landscape and habitat management strategies for its conservation. International Journal of Biodiversity and Conservation **3(11),** 551-609.

Musallam IW, Haddad NJ, Tawaha ARM, Migdadi OS. 2004. The importance of bee-pollination in four genotypes of faba bean *(Vicia faba L.)*. International Journal of Agriculture and Biology **6(1),** 9-12.

Mkindi AG, Mtei KM, Njau KN, Ndakidemi PA. 2015. The Potential of Using Indigenous Pesticidal Plants for Insect Pest Control to Small Scale Farmers in Africa. American Journal of Plant Sciences **6(19),** 3164.

Mkindi A, Mpumi N, Tembo Y, Stevenson PC, Ndakidemi PA, Mtei K, Belmain SR. 2017. Invasive weeds with pesticidal properties as potential new crops. Industrial Crops and Products.

Mwanauta RW, Mtei KA, Ndakidemi PA. 2014. Prospective bioactive compounds from *Vernonia amygdalina, Lippia javanica, Dysphania ambrosioides* and *Tithonia diversifolia* in controlling legume insect pests. Agricultural Sciences **5(12),** 1129.

Mwanauta RW, Mtei KM, Ndakidemi PA. 2015. Potential of Controlling Common Bean Insect Pests (Bean Stem Maggot (*Ophiomyia phaseoli*), Ootheca (*Ootheca bennigseni*) and Aphids (*Aphis fabae*)) Using Agronomic, Biological and Botanical Practices in Field. Agricultural Sciences **6(05),** 489.

Nunes-Silva P, Hrncir M, da Silva CI, Roldão YS, Imperatriz-Fonseca VL. 2013. Stingless bees, *Melipona fasciculata*, as efficient pollinators of eggplant (*Solanum melongena*) in greenhouses. Apidologie **44(5),** 537-546.

Ndakidemi B, Mtei K, Ndakidemi PA. 2016. The Potential of Common Beneficial Insects and Strategies for Maintaining Them in Bean Fields of Sub Saharan Africa. American Journal of Plant Sciences **7(3).**

Olson DM, Andow DA. 2006. Walking pattern of Trichogram manubilale Ertle & Davis (*Hymen optera; Trichogram matidae*) on various surfaces. Biological Control **39(3),** 329-335.

Ollerton J, Winfree R, Tarrant S. 2011. How many flowering plants are pollinated by animals? Oikos **120(3),** 321-326.

Parker JE, Snyder WE, Hamilton GC, Rodriguez-Saona C. 2013. Companion planting and insect pest control. In Weed and Pest Control-Conventional and New Challenges. InTech.

Parrotta J, Yeo-Chang Y, Camacho LD. 2016. Traditional knowledge for sustainable forest management and provision of ecosystem services. International Journal of Biodiversity Science, Ecosystem Services & Management **12(1–2),** 1–4.

Puech C, Poggi S, Baudry J, Aviron S. 2015. Do farming practices affect natural enemies at the landscape scale? Landscape ecology **30(1),** 125-140.

Rader R, Bartomeus I, Garibaldi LA, Garratt MP, Howlett BG, Winfree R, Bommarco R. 2016. Non-bee insects are important contributors to global crop pollination. Proceedings of the National Academy of Sciences **113(1),** 146-151.

Rehman A, Powell W. 2010. Host selection behavior of aphid parasitoids (Aphidiidae: *Hymenoptera*). Journal of Plant Breeding and Crop Science **2(10),** 299-311.

Riddick EW, Cottrell TE, Kidd KA. 2009. Natural enemies of the Coccinellidae: parasites, pathogens, and parasitoids. Biological control **51(2),** 306-312.

Riddick EW. 2017. Identification of Conditions for Successful Aphid Control by Ladybirds in Greenhouses. Insects **8(2),** 38.

Romeis J, Babendreier D, Wäckers FL, Shanower TG. 2005. Habitat and plant specificity of *Trichogramma* egg parasitoids—underlying mechanisms and implications. Basic and Applied Ecology **6(3),** 215-236.

Sarwar M, Salman M. 2015. Biological Insecticide Trichogramma spp. (Hymenoptera : *Trichogram matidae*) Strikes for Caterpillar Control. International Journal of Entomology Research **1(1),** 31–36.

Sileshi G, Nyeko P, Nkunika P, Sekematte B, Akinnifesi F, Ajayi O. 2009. Integrating ethno-ecological and scientific knowledge of termites for sustainable termite management and human welfare in Africa. Ecology and Society **14(1).**

Singh A, Weisser WW, Hanna R, Houmgny R, Zytynska SE. 2017. Reduce pests, enhance production: Benefits of intercropping at high densities for okra farmers in Cameroon. Pest Management Science.

Singh HB. 2014. Management of plant pathogens with microorganisms. Proc Natl Acad Sci **80,** 443-454.

Soares AO, Coderre D, Schanderl H. 2003. Influence of prey quality on the reproductive capacity of two phenotypes of *Harmonia axyridis* PALLAS (Coleoptera: *Coccinelidae*).

Slaa EJ, Chaves LAS, Malagodi-Braga KS, Hofstede FE. 2006. Stingless bees in applied pollination: practice and perspectives. Apidologie **37(2),** 293-315.

Tscharntke T, Clough Y, Wanger TC, Jackson L, Motzke I, Perfecto I, Whitbread A. 2012. Global food security, biodiversity conservation and the future of agricultural intensification. *Biological conservation* **151(1),** 53-59.

Van Nouhuys S, Kaartinen R. 2008. A parasitoid wasp uses landmarks while monitoring potential resources. Proceedings of the Royal Society of London B: Biological Sciences **275(1633),** 377-385.

Wang XG, Keller MA. 2002. A comparison of the host-searching efficiency of two larval parasitoids of *Plutella xylostella*. Ecological Entomology **27(1),** 105-114.

Wei J, Wang L, Zhu J, Zhang S, Nandi OI, Kang L. 2007. Plants attract parasitic wasps to defend themselves against insect pests by releasing hexenol. *PLOS one* **2(9),** e852.

Wilby A, Thomas MB. 2002. Natural enemy diversity and pest control: patterns of pest emergence with agricultural intensification. Ecology Letters **5(3),** 353-360.

Woodcock TS, Initiative CP. 2012. Pollination in the agricultural landscape. Best Management Practices for Crop Pollination. Guelph, ON, Canada: Canadian Pollination Initiative, University of Guelph.

Zheng XL, Li J, Su L, Liu JY, Meng LY, Lin MY, Lu W. 2015. Ecological and morphological characteristics of parasitoids in Phauda flammans (*Lepidoptera, Zygaenidae*). Parasite *22*.