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Full Length Research Paper

Pollinator biodiversity in Uganda and in Sub-Sahara Africa: Landscape and habitat management strategies for its conservation

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Previous pollinator faunistic surveys conducted in 26 different sites indicated that farmlands of central Uganda supported more than 650 bee species, 330 butterfly species and 57 fly species. Most crop species grown in Uganda are pollinator-dependents. There is also a high dependency of rural communities on pollination services for their livelihoods and incomes. The annual economic value attributable to pollinating services delivered to crop production sector was estimated to be worth of US$0.49 billion for a total economic value of crop production of US$1.16 billion in Uganda. Despite the great contribution of pollinators to crop yields, there is still lack of knowledge of their conservation strategies in Uganda. Policies, actions, farming practices, critical landscape management techniques and conservation measures for spatio-temporal stability and maintenance of pollinator communities in farmlands of Uganda include (i) the protection and maintenance of high cover (>20%) of natural and semi-natural habitats, (ii) forming mosaic farm-landscapes mimicking natural systems to enhance mediated ecosystem services delivery and agroecosystems resilience to climate change, (iii) field plants and habitat manipulation for spatio-temporal provision of floral resources, (iv) promoting awareness campaigns and sensitization policy makers about the importance of conserving pollinators and (v) encouraging farmers to adopt pollinator-friendly farming practices.

Key words: Conservation strategies, policy changes, awareness and sensitization campaigns, pollination services marketing, farmlands, Uganda.

INTRODUCTION

Importance of pollination services for biodiversity and food security

Pollination is key ecosystem function that is insect-critically derived. It is a basis for the maintenance of biodiversity in agricultural and natural landscapes. An estimated 60 to 80% of wild plants and 35% of global crop production depends on animal pollination (Gallai et al., 2008). At least 450 crop species globally depend on pollination by bees. Crop species that depend on the ministrations of bees for their existence also provide 35% of the calories consumed by humans each year, and most of the vitamins, minerals and antioxidants (Klein et al., 2007). The ecological, agricultural and economic importance of pollinators is immense and yet inestimable. The value of pollination to agricultural production worldwide is currently estimated to be worth US$226 billion (€153 billion) per year or approximately 39% of the world crop production value (€625 billion) from the total value of 46 insect pollinated direct crop species (Gallai et al., 2009). Although one-third of the world's food production relies on animals for pollination and that the estimated annual value of this service is worth US$226 billion, it is however projected that insect pollinators may be account (responsible) for more than one-third US$1 trillion in annual sales of agricultural products worldwide (Munyuli, 2010). Majority of African countries depend mainly on subsistence agriculture as their main occupation. Many cash crops, vegetables and non timber forest products including medicinal plants and nuts that support African economies depend mainly on pollination services delivered by different types of pollinators (Munyuli, 2010; Munyuli, 2011b). This places high risk on African economies that over rely on pollinator-dependent agricultural crops in case of pollinator decline. Pollinators provide extremely valuable services and benefits to society. By increasing food security, pollinators contribute to the improvement of livelihoods and to the significant increase of income of some of the world's poorest people found in Sub-Sahara Africa including Uganda.

Pollinator faunistic surveys (bees, butterflies) were conducted in 26 different study sites in farmlands of central Uganda during from January 2006 to February 2008. More than 650 bee species and 331 butterfly species (Appendix 4) belonging to different functional groups (life history and ecological traits) were recorded (Munyuli, 2010) for the checklist of pollinator species recorded). In addition, crop pollination studies in central Uganda (Munyuli, 2010) (Appendix 1) show that biotic pollinators are vital inputs of the crop production sector. The majority of grown crops that provide energy, vitamins, and proteins to human being in Uganda are pollinator- dependents. Reduced crop yields and deformed fruit often are likely to result from insufficient pollination rather than from a deficiency of other agricultural inputs, such as agrochemicals in Uganda. Economic assessment carried out in central Uganda show that farmers fetch more than 50% net gain from services provided by bees to specific traditional crops (Munyuli, 2010). The economic value attributable to pollinating services delivered to crop production sector was estimated to be worth of US$0.49 billion for a total economic value of crop production of US$1.16 billion per annum (Munyuli, 2011). This showed that agriculture in Uganda owes much of its production to animal pollination. There was an annual growth of 5.78% of land allocated for the cultivation of pollinator-dependent crops compared to 1.12% for the land area dedicated for the production on non-pollinator-dependent crops. There is a growing dependency in cultivation of pollinator-dependent crops in Uganda (Munyuli, 2011). Agriculture contributes significantly to the GDP (gross domestic product) in Uganda. Pollination service account for a high value in the GDP as compared to other ecosystems services such as forest ecosystem services that account for about 3% of the national GDP. Give the importance of pollinators for farmers and for the national economy, there is a need to develop strategies to conserve pollinators and services for biodiversity conservation and food security in rural landscapes of Uganda and Sub-Sahara Africa.

Much as pollinators (bees) are known to pollinate most of the world's wild plant species and provide economically valuable pollination services to crops (Winfree, 2010), their knowledge of strategies for conservation biology lags far behind other beneficial taxa such as parasitoids and predators (Winfree, 2010). However, pollinators are among biotas that are very sensitive to disturbance; particularly to anthropogenic activities (that is pesticides use, habitat destruction and loss, grazing intensity, etc) and to intensification in land-use systems and to change in farming practices (Kremen and Ricketts, 2000; Sjödin et al., 2008; Potts et al., 2010). Bees are important plant pollinators and any decline in numbers or species due to anthropogenic disturbances constitutes a significant threat both to biological diversity and their ecosystem services and to whole agricultural economics (Kosior et al., 2007). To halt population declines and species extinctions of bees, it may be necessary to preserve aspects of traditional farming practices and develop policies and affordable legal protection frameworks for pollinators (Kosior et al., 2007) in all countries of the world. Drivers of pollinator loss include habitat loss and fragmentation, agrochemicals, pathogens, alien species, climate change and the interactions between them. Drivers of global environmental change such as habitat fragmentation, overexploitation, species invasions, climate change and pollution have the potential to modify plant-animal interactions (Aguirre et al., 2011; Potts et al., 2010). Anthropogenic, environmental and climate changes and the introduction of alien species have been predicted to affect plant–pollinator interactions (Schweiger et al., 2010) and the delivery of pollination services to crops at the global level. In addition parallel declines in bee species richness and insect-pollinated plants indicate a potential reduction in pollination services and/or in available flower resources for flower-visiting insects (Schweiger et al., 2010). The impacts of climate change on pollination services delivery may be more destructive in sub-Sahara Africa and in Uganda where there is a high livelihood dependency of human being to pollination services (Munyuli, 2010). Thus the need to set conservation strategies before pollinators can decline.

Similarly, habitat fragmentation affects negatively assemblage of floral visitors and pollinators of many flowering plant species (Aguirre et al., 2011). Habitat fragmentation can affect pollination processes because pollinator mobility may be restricted across fragments embedded in the matrix of heavily transformed landscape. Habitat loss poses a major threat to pollinator biodiversity, although species-specific extinction risks are inextricably linked to life-history characteristics (Bommarco et al., 2010) of pollinators. Habitat loss can lead to clear shifts in the species composition of wild bee communities (Bommarco et al., 2010); and shifts in species composition can have potential implications for conservation of biodiversity, ecosystem functions and provisioning of services. For example, social bees are negatively affected by habitat loss more than solitary bees irrespective of body size (Bommarco et al., 2010). Pollinator declines can result in loss of pollination services which have important negative ecological and economic impacts that can significantly affect the maintenance of wild plant diversity, wider ecosystem stability, crop production, food security and human welfare (Holzschuh et al., 2009). Maintaining diverse, healthy and abundant communities of wild pollinators within farmland presents a challenge to both farmers and conservationists/policy-makers. However, conserving pollinator-supporting habitats within farmlands can clearly bring benefits to both agriculture and conservation (Carvalheiro et al., 2010). Most pollinators can be enhanced by high proportion of non-crop habitats (semi-natural and natural habitats) and by connecting linear and non linear features of the landscape with biological corridor (hedgerows, etc). Stopping habitat loss can ensure adequate pollination of wild plants and crops and make crop production a more profitable business for small-scale farmers in rural landscapes of Uganda.

The protection of pollination services is multi-dimensional and requires the involvement of all stakeholders (farmers, policy-makers, land-use planers, researchers, extension services agents, development agents, educators, etc) and the development of well coordinated mechanism and strategies that link well local landscape drivers to regional and global factors. Bees require multiple resources to complete their life cycle, including pollen, nectar, and nest substrates and nest-building materials. These resources are often gathered from different locations, making bees reliant on multiple, “partial habitats”. Practically, bees require three main basic types of resources to persist in a landscape: (i) floral resources (both pollen and nectar) for provisioning nest cells and for sustenance, (ii) appropriate nesting substrate or other nest-building materials and, (iii) the provision of suitable abiotic conditions (microclimate and local topography). Similarly, butterfly communities are tied to the spatio-temporal availability of larval host plants, refugia and nectaring resources in the landscape. These resources are often gathered from different locations, making bees reliant on multiple “partial habitats”. Therefore, survival of pollinators (bees, butterflies, hoverflies, etc) in the farmland depends on how much foraging habitat (area and quality) and breeding/nesting habitat (area and quality) are conserved and maintained healthy in the agricultural matrices. The need to design strategies for conserving pollinators in farmlands is driven by their ecological and economic importance (Freitas et al., 2009; Brown and Paxton, 2009; Donaldson, 2002) to society. Hence, guaranteeing spatio-temporal crop production stability and food security in face of future climate is the chief reason for developing strategies for the conservation of pollinators in agricultural landscapes (Eardley et al., 2009). Designed and proposed strategies will also contribute to on-farm biodiversity conservation in Uganda. These strategies are applicable in other countries in Sub-Sahara Africa, particular countries located around the Equator with similar land-use and habitats characteristics.

METHODOLOGICAL APPROACHES

The idea of proposing conservations strategies for pollinators in Uganda came with field observations. In fact, a study was conducted between 2006 and 2008 to collect information on patterns of pollinator biodiversity and economic value of pollination services in Uganda. Pollinators were found to be playing a critical role in livelihoods and were at risk for declining in face of current land-use practices and global environmental change. In addition to the results of the study, search for literature describing conservation strategies for pollinators was conducted and filtered for application in sub-Sahara Africa region. The analysis of the different findings from the literature (publications) combined to author personal field observations led to the drafting of this paper presented as a synthesis of information. It was observed that although research was still required in many areas of pollination (Mayet et al., 2011) and conservation measures, there was a need to put in place as a precaution measure in the intervening time to avoid further decline or erosion in pollinator diversity services, since such situation can lead to food insecurity of future generations. From field observations, the majority of farmland bees recorded were wood/ground-nesters, solitary, polylectic, long-tongued and generalist foraging habitat users (Munyuli, 2010). Similarly, the majority of butterfly species recorded in farmlands of central Uganda were “forest-dependent species” and or “widespread species” (Munyuli, 2010) and potential effective pollinator species. Thus conservation of pollination services delivered by Apoidea and Lepidoptera in central Uganda has to meet requirements of these different dominant pollinator guilds through development of appropriate management of local and landscape habitat factors.

Generally, conservation of pollination services require a landscape scale approach that incorporates patches of native vegetation throughout agricultural patches (Winfree et al., 2009). The landscape management for conservation of pollinators involves understanding basic aspects of pollinator biology and ecology in agricultural landscapes (Goulson, 2003b; Potts et al., 2001; Franzén and Nilsson, 2010). Therefore, agricultural lands that best promote pollinator services are a mosaic of agro-ecosystems and non agro-ecosystems especially where the non agro-ecosystems include forest cover, may be the best. From field observations and based on this back ground (earlier described), it was therefore believed that developing pollinator conservation strategies may critical to the enhancement of pollination services and a great opportunity to increase crop production profitability in Uganda and in other parts of sub-Sahara Africa. During field observations, natural and semi-natural habitats were recorded in different part of Uganda. Their potential roles as providers of habitats for pollinators are hereby reviewed as well as strategies for their protection in agricultural landscapes of central Uganda proposed. In this mini-review, strategies and practices to conserve natural and semi-natural habitats to prevent predicted further decline in pollinators and services are presented first. Then, policy measures to implement the proposed strategies are provided by reviewing the literature and summarizing main recommendations from various publications. Later, knowledge about pollinator-friendly and pollinator-friendly practices is condensed. Finally, policy measures as well as further research needed to strengthen the strategies are highlighted in this mini-review.

The results of the review of literature supporting field observations are presented in this biodiversity conservation report in respective order of their importance. The proposed conservation strategies will be analyzed in different study including: (i) pollinator-friendly semi-natural habitat management strategies; (ii) pollinator-friendly natural habitat management practices; (iii) pollinator-friendly field management and farming practices, (iv) pollinator-friendly landscape management practices and strategies,(v) compensation of farmers for sustainable conservation of pollinators in agricultural landscapes, (vi) policies for conservation of pollinators in agricultural landscapes (vii) dissemination strategies of information on pollinators, (viii) monitoring pollinator communities in rural landscapes and (ix) pollinator-unfriendly farming practices.

POLLINATOR-FRIENDLY SEMI-NATURAL HABITAT MANAGEMENT STRATEGIES

Management of linear features of “uncropped areas” in farmlands

“Un-cropped areas” are defined as all areas and features on a farm that are not subject to the agricultural practices (Marshall et al., 2003). Such areas include field margins, conservation headlands, hedges, woodland, ditches, unimproved pasture and semi-natural rough grazing (Marshall et al., 2003). The management of linear features of semi-natural habitats can provide essential foraging and nesting habitats to pollinating insects as well as: (i) enhancing overall biodiversity in farmlands, (ii) improving crop yields and quality and (iii) securing a sustainable farming and environmental balance. The following study are examining strategies for the management of “un-cropped areas” to provide both nesting and foraging sites to pollinators.

Management of hedgerows and live fences

Hedgerows represent approximately 15% of semi-natural features found in farmlands of central Uganda (Munyuli, 2010). They also serve as windbreaks and livestock fences, provide erosion control, and can stabilize dunes and water runoff, and produce firewood, fodder, fruits, and medicinal plants. Planting hedgerows (a good farm landscape management practice) is generally promoted for its positive environmental outcomes. Apart from possible aesthetic values, hedgerows are food and nesting resources for a large variety of animals, including pollinators such as birds, bats and insects (Marshall et al., 2003). Hence, hedgerows are of key importance for biodiversity and services conservation in agricultural landscapes. Hedgerows planting can enhance biodiversity and improve specific ecosystem services and functions such as climate regulation services. Single or multiple-species hedges are frequently used for erosion control where they directly contribute to increased agricultural production, not only through feeding and protecting beneficial insects, including pollinators, but also through maintaining or improving soil and providing additional crops or food. Hedgerows (with woody perennial plantings) and vegetated field margins can harbor insects that regulate pests or increase pollination through increased diversity of beneficial insects. In fact, hedgerows have been found to support higher bee species richness and population density than other agricultural or natural habitats (Hannon and Sisk, 2009) in USA. Therefore, it is recommended to famers to conserve and improve hedgerow to serve as corridors connecting various types of semi-natural and natural habitats and gardens in the farm landscape.

Well managed hedgerows as biological corridors can act as conduits for pollinators (butterflies, bees) involved in short-distance movements. Hence, hedgerow as biological corridors can enhance pollen dispersal and pollinator movements in the farm landscape. Connected corridors will favor dispersal of many wild bees as well as enhancing their ability to find abundant floral resources in nearby fields. It is therefore interesting to manage landscape such as non-fragmented habitats (forest reserves, wetlands, etc), forest remnant patches and isolated fragments (tree plantations, woodlots, woodlands, forest patches, forest fallows) found within the farm landscape are connected by corridors (hedgerows and related semi-natural habitats such as young fallows, etc) to small-scale monoculture/polyculture farms (fields) and agroforestry systems to provide sufficient refugia to pollinators and enable their free movements across different land-uses within the landscape. In forest-agriculture mosaic regions, habitats that are heterogeneous, structurally diverse are of great importance for the diversity, abundance and community structure of bees. Such habitats in the farmlands are reservoirs of pollinators and can act as ‘‘pollinator rescue” of the typical adjacent forest remnant bee communities. The maintenance of high-quality habitats within the farm landscape with well-connected semi-natural networks will enable pollinator species to move easily within different habitats and land-use of the farm-landscape as well as enabling pollinator species to build up strong populations to deliver pollination services of high quality and quantity to crops grown nearby. In fact, it as bee observed that, mobility is an important trait for butterfly population persistence in farmlands. Butterfly species richness do increasing with increased patch area and with decreasing isolation (Öckinger et al., 2009; Schmucki and de Blois, 2009). Hence, local habitat and landscape management that increase connectivity of different landscape elements with hedgerows as biological corridors can contribute to the persistence and enhance mobility of pollinators like butterflies within the entire farm landscape. Besides the preservation and ecological management of natural habitat remnants, which are essential for cultivated and wild plant species and pollinator community, the maintenance, improvement or restoration of a hedgerow network should be strongly encouraged in rural landscapes of Uganda.

Ensuring connectivity via functional biological corridors that enhance pollen dispersal between populations will help to conserve pollinators in farmlands of central Uganda and in other parts of sub-Sahara Africa. It is critical to prevent the further destruction of hedgerows and related semi-natural habitats in central Uganda. Given the ecological functions of these corridors, management and maintenance of hedgerows and the network of semi-natural habitats that hedgerows connect to fields should be considered and integrated (by policy-makers and land-use planners) in the design of agricultural areas to promote sustainable agriculture practices in Uganda. Farmers should be advised to manage their lands such as some kind of ‘‘ecological networks’’ of open lands (fields) interconnected to linear and non linear semi-natural habitats and natural habitats through hedges (biological corridors), enable easy movements of pollinators delivering pollination services to crops and wild plants. Majority of pollinators are not very sensitive to the size of the hedge. However, they are sensitive to the structure, vegetation complexity of the hedge. Therefore, since in central Uganda, most farmers hold small portion of the land, it can be recommended to set large hedges in the margins of the fields; but producers should make effort to set structurally complex hedges comprising several vegetation strata. Maintaining and making hedgerows for several years can offer greater opportunities for bees to survive in agricultural landscape since the habitat will be relatively stable. Some fast growing tree species can provide shade to other plant species whereas other plants in the hedge are providing refuge and forage for pollinators. The introduction in hedgerows of fast-growing multi-purposes native tree species that are nitrogen fixing legumes such as *Calliandra calothyrsus*, *Acacia* sp. *Moringa oleifera*, *Sesbanian sesban*, *Desmodium* sp., etc., can enhance the provision of floral resources.

In Uganda, several tree species were frequently observed being visited by a diversity of bees (*Xylocopa*, *Apis*, *Megachile*, *Tetralonia*, *Tetraloniella*, *Megachile*, etc) that are efficient pollinators of many fruits and vegetable crops. For example, in Masaka and Mukono districts, hedgerows were commonly found to be composed of *Tithonia diversifolia* mixed with *C. calotyrsus* and or *S. sesban,* and several grass and herb species (Munyuli, 2010). Some farmers even planted fruit species (*Persea america*: Avocado) in the hedgerows. This kind of hedgerow is important for pollinators. Contrastingly, roadside hedges were found to be planted with *Glyricidium* sp., *Ficus* sp*.*, *Vernonia* sp. and “elephant grass” (*Hypparrhenia* sp.) for fodder. This kind of hedgerows may not be suitable as foraging habitat for pollinators. Probably by improving through introducing seedling of more legumes among these grasses can improve the value of such hedgerows for pollinators.

Overall, the principle of improving semi-natural habitat for the benefit of pollinators involves creating some kind of equilibrium between Poaceae and Fabaceae plant species grown. Hedges can also be planted with nectariferous, soil-improving species, or receive minimum management like non-tillage, additional seeding, and periodic cuttings in order to maintain successional growth at a preferred stage for heading tree species planted at the center.

Live fences are conspicuous features of agricultural landscapes common across the tropics. They are features delineating crop fields, pastures, and farm boundaries and forming elaborate networks of tree cover across rural landscapes. Fences (non living and living posts) are very common in rural areas, and represent important landscape elements in Uganda. Living fences are particularly important for conservation, especially when agroforestry tree and fruit tree species are planted in the fence. Fences are very common structures in rural tropical landscapes due their widespread use in controlling domestic animal movements, protecting cultivated areas, and defining the borders of private properties. Live fences differ from hedges in that they are less dense, contain fewer plant species, usually support one or more strings of wire, and are entirely anthropogenic features, in contrast to hedges which may originate from natural regeneration, relict vegetation or from planting (Harvey et al., 2005). Overall, in central Uganda, many live fences are used by several wood-nester guild bees. Live fences house numerous bee species associated with grasslands and rangelands in Uganda (Munyuli, 2010). Several indigenous tree species (genera: *Erythrina, Gliricidia, Cordia, Vernonia, Euphorbia, Erythrina, Ficus, Maesopsis, Acaccia, Cassia*, etc) are used as live fences in Uganda (Munyuli, 2010). Farmers who raise cattle should be sensitized about the secondary role of live fences for the pollination of cultivated forages for their livestock. Bees inhabiting these habitats do pollinate forage species (*Trifolium* sp.) that are grown by cattle keepers to improve the nutrition of their animals (Munyuli, 2010). Butterflies also use several fence trees as shelter in Uganda (Munyuli, 2010).

The protections of hedgerows will benefits pollinators that use these habitats as preferred foraging/nesting habitats.

Management of field margins

In regions with intensively managed agricultural systems, vast uninterrupted monocultures of crop species dominate landscapes, and refuge for wild species is often relegated to small areas of untreated or specially set-aside land (field margins) within these monocultures. Field margins separate monoculture fields by providing a semi-managed area of uncultivated land around field edges, and may include hedgerows and other more permanent landscape features (Rands and Whitney, 2010). The margins act as miniature reserves within the mosaic of agricultural land, and can act as a valuable resource, offering both differing degrees of refuge for wild species and resources for them to use, as well as acting as a potential green corridor. Managed field margins offer a means of reducing the impact of agricultural monocultures within intensively managed environments. Field margins offer several ecological and agricultural benefits. Also, they can be managed to maximize multiple ecological services in farmlands. Field margins can prevent soil erosion and nutrient runoff, act as windbreaks and provide habitats for beneficial insect species for agriculture (Olson and Wäckers, 2007; Forister, 2009). Field margins are landscape features that effectively enhancing species immigration to and emigration from field habitats and may thus be considered as classical biological corridor at the same level with hedgerow. If field margins are well managed in conjunction with adjacent boundary features, especially hedgerows, to create complex vegetation structures, they can help in the protection and conservation of biodiversity in farmlands, through provision of food resources and through increasing refugia and nesting sites for a range of animals inhabiting arable lands (Vickery et al., 2009). Hence, proper field boundary management can lead to the attraction of beneficial insects (biocontrol agents, pollinators, etc) in fields.

Margins can contribute to increasing and maintenance of regional biodiversity, they can also act as a means of enhancing ecosystem services such as pollination within the agricultural landscape (Rands and Whitney, 2010). Field margins can provide benefits such as pesticide drift reduction, and enhance the abundance of both crop pollinators and natural enemies of crop pests. To increase the floral and faunal diversity of arable lands, improved field margins (field margins enhanced with floral resources and microhabitats) have been recently established as a new ecological compensation measure in several parts of the world, particularly in Europe (Junge et al., 2009). If properly managed, field margins can be important reservoirs of pollinators of crops established in the adjacent fields. They sometime support significant higher number of wild bee species as natural habitats compared to fields, depending on the quality of the surrounding landscape (Munyuli, 2010). Quiet often, field margins may harbor a high number of bee genera (genera composition) compared to natural habitats and crop field habitats although it is also common to record high abundance of bees in fields than in field margins/natural habitats (Munyuli, 2010). Worldwide, the cultivation of”pollinator-attraction crop species and varieties” is often done in the margins of fields (Olson and Wäckers, 2007). Field boundary pollinator-attraction crops cultivation is a pollinator management technique with potential of increasing pollinator diversity in farmlands (Potts et al., 2009; Carvell et al., 2007; Adler and Hazzard, 2009; Mandelika and Roll, 2009). For example, field margins and similar semi-natural habitats have been suggested as suitable habitats for butterfly conservation in rural landscapes (Boriani et al., 2005).

More recently, Potts et al. (2009) found that pollinator biodiversity (particularly bees and butterflies) could be restored in agricultural landscapes in UK by developing and implementing novel management strategies to improved grasslands and field margins. Crop fields that are established very far from field margin semi-natural habitats may not benefit from services of solitary bee species (Zurbuchen et al., 2010). Therefore, farmers should be advised to maintain connected field margin semi-natural habitats nearby their crop fields to benefit maximum services delivered by solitary bees that dominate the bee fauna found in central Uganda (Munyuli, 2010). The introduction of novel flower-rich habitats in field margins and grasslands can be very beneficial for pollinators using such habitats (Carvell et al., 2007; Olson and Wäckers, 2007; Heard et al., 2007). Sowing semi-natural habitat areas with melliferous and polleniferous species can be a good contribution to the promotion of beekeeping and to the protection of biodiversity in agricultural landscapes (Decourtye et al., 2007). Use of native perennial plants in conservation seed mixes in field margins and related semi-natural features, is also a strong tool that can help to ensure year-round provision of floral resources to support beneficial insects, including pollinators in the agricultural landscape (Carvell et al., 2006; Isaacs et al., 2009). Sown wildflower strips are increasingly being established in European countries within agri-environmental schemes to enhance biodiversity (Haaland et al., 2011). These sown wildflower strips are said to support higher insect abundances and diversity than cropped habitats.

Suggested suitable field conservation measures for bumblebees and other bees in UK include: (i) maintenance of flower-rich sites; (ii) restoration of species-rich grasslands; (iii) sowing pollen and nectar mixes; (iv) encouraging clover ley crops and a return to crop rotations as an alternative to the use of fertilizers and (v) promoting wildlife-friendly gardening (Goulson, 2011). Sowing grass–legume mixtures is said to be more beneficial for pollinators compared to grass monoculture that it is largely used by farmers. The numbers and diversity of pollinators does increasing in sown wild flower, especially if pollen- and nectar-rich flower plants were mixed to them (Haaland et al., 2011) in field margins. Field margins with Fabaceae-rich seed mixes sown synchronically to crops are essential in order to conserve wild bee populations within crop fields (Carvell et al., 2007). In the Netherlands it was also found that increasing plant species richness of the field margins could increase pollinator visitations (Musters et al., 2009). Also, sown flower strips (creation of flower resources) in the field margins were found to be effective at increasing syrphid pollinator species richness and abundance in adjacent wheat fields in arable landscapes in Germany (Haenke et al., 2009; Pywell et al., 2005). Therefore, to increase the effectiveness of pollinator biodiversity-orientated restoration measures and conservation strategies, the area covered by wild flower strips should be increased, particularly in hedgerows, field margins and related semi-natural habitats (Aviron et al., 2009a). Creating patches with high plant diversity within farmland is a measure that can benefit pollinators in rural landscapes of Uganda.

Farmers from Uganda and those from other parts of Sub-Sahara Africa should be encouraged to adopt such practice. Weed diversity increases flower visitor diversity, hence ameliorating the measured negative effects of isolation from natural habitats. The presence of weeds can allow pollinators to persist within fields, thereby maximizing benefits of the remaining patches of natural habitat in margins for crops productivity enhancement. Overall, conservation of semi-natural natural patches combined with promoting flowering plants within crops can maximize productivity and, therefore contributing towards sustainable agriculture in rural landscapes in sub-Sahara Africa. Field margins (Appendix 3c: Plate 11) represent approximately 45% of semi-natural features found in farmlands of central Uganda (Munyuli, 2010). In Uganda, field margins, in contrast to hedges, do not necessarily consist of perennial or woody species and they are not common semi-natural features. Herbaceous vegetation (more generally known as herbs; defined as non woody and sub-woody plants) found in field provide a number of floral resources to a diversity of pollinators. The improvement and proper management of such vegetation by farmers is critical for the survival of pollinators in rural landscapes of Uganda. The vegetation frequently found in field margins is composed of weed/herb/grass species in central Uganda. The majority of these plants found growing in field margins attracts diverse and abundant pollinators during blooming seasons. Such field margins are essentially important as foraging habitat for pollinators and not as nesting habitat for bees because these habitats are seasonal.

The majority of farmers maintain field margins for at most two cropping seasons per year. Farmers from central Uganda could also improve field margins by growing a mixture of several wild legume species within the field margins. The cultivation of attractive nectar-pollen plants with diverse flower colours and shapes can be a good strategy for “pulling pollinators into the fields”. Deliberate planting of a mixture of wild flowering herbs/weeds/grass/shrubs/trees within field margins is one of the good habitat management practices that should be adopted by farmers. Practically, improving field boarder habitats can increase the density and diversity of pollinator in crop fields. The principle consists of mixing several annual and bi-annual weeds/herbs for availability over time of floral resources since they will flower at different periods of the year. It is proposed and recommended that a mixture of flowering plant in margin semi-natural habitats is done respecting the following proportion: 20% Poaceae + 60% Fabaceae + 20% trees and shrubs. Appropriately sown, these agricultural surfaces can offer various sources of nectar and pollen and habitat for pollinators.

Plant species that are mass pollen- nectar producing and that are fast growing include several herbaceous and weed plant species that are common in farmland of central Uganda: *Acanthus pubescens*, *Asystasia gangetica*, *Justicia flava*, *Aspilia africana*, *Bidens pilosa*, *Crassocephalum vitellinum*, *Emilia javanica*, *Erlangea tomentosa*, *Erlangea ugandensis*, *Galisonga parviflora*, *Senecio discifolius*, *Vernonia amygdalina*, *Vernonia auriculifera*, *Cassia hirsute*, *Cleome gynandra*, *Commelina benghalensis*, *Kyllinga bulbosa*, *Acalypha ornate*, *Hoslundia opposite*, *Ocimum gratissimum*, *Crotalaria brevidens*, *Polygonum setosulum*, *Rumex abyssinicus*, *Triumfetta tomentosa*, *Triumfetta rhomboidea*, *Cyphostemma adenocaule*, etc. Extension workers should be able to teach farmers how to propagate such plant species. For those species that produce seeds, farmers should learn how to collect seeds and plant them in field margins few weeks later after crops have emerged such as they can flower at time when crops are not in bloom. Farmers are recommended to cultivate annual, bi-annual and perennial flowering plants in field margins to flower when crops are not in bloom. Augmenting wild floral resources in field margins can be a major step towards the provision of food source to bees in supplementation to cultivated annual crops. Alternate growing periods of crops and wild floral resources can guarantee year-round availability of floral resources. Improving field margins with more nectar-pollen rich plant species can help to fill the pollinator food gap which may be created when perennial crops are not flowering in the farm-landscape.

The enrichment of field margins with mass producing pollen-nectar plant species can therefore ensure continuous local nectar-pollen flow during rainy and dry season periods of the year.

Management of roadside, track-side and stream-side habitats

Roadsides, trackside and streamside represent approximately 3% of semi-natural features found in farmlands (Munyuli, 2010) of central Uganda (Appendix 3c: Plate 11). Roadsides are important habitats for pollinators, particularly bees and butterflies. Roadsides support a variety of pollen and nectar sources and unlike agricultural fields, are un-ploughed, and therefore can provide potential nesting sites for ground nesting bees. Hence good management practices of roadsides can enhance pollinator diversity in rural landscapes. Proper management of semi-natural grasslands of roadside verges (rotational mowing schemes/weeding regimes) increases flower abundance and diversity, as well as attracting or promoting the diversity and abundance of insect-flower-visitor communities (Noordijk et al., 2009). Suitable road habitats for bees must include a diversity of flowering species and nesting substrates because of the range of specialized floral and nesting requirements of bees. Management practices such as the improvement and restoration of roadside habitats can enhance bee diversity in the rural landscapes, particularly if they increase floral resources and nesting sites within the roadside habitats. Roadside habitat restoration or management for the benefit of pollinators can (Haaland et al., 2010) create suitable habitat and floral resources for diverse pollinator species. Functional attributes, such as plant–pollinator interactions, are essential for ecosystem recovery.

Restoration of roadside vegetation can also serve as protective corridors through which pollinators could move in highly modified landscapes and agricultural landscapes. Plant-pollinator interactions restoration on roadsides (Garcia-Robledo et al, 2010) in Uganda may involve planting native plant species to yield better results. Improving roadside-vegetation and related greenways by sowing within wildflower strips along their margins can also enhance significantly pollinator biodiversity visiting these habitats. Overall, the species richness and abundance of wild bees respond rapidly to restoration measures (Exeler et al., 2009). In agricultural landscapes of Uganda, sides of road and water bodies (Lakes, streams, rivers) are good and suitable nesting and foraging habitats for bees because these habitats are relatively undisturbed by anthropogenic activities (Munyuli, 2010).

Often butterflies and bees forage in these habitats that are sometimes populated by diverse floral resources of plant species flowering at a time when other wild plants and crop species in adjacent fields are not in bloom. Several butterfly species forage around streams. In central Uganda, it is common to find out that streamside habitats always have plant species in bloom throughout the year, providing nectar for butterflies. Awareness campaigns are necessary to sensitize farmers about the role played by these habitats in maintaining pollinators in the farmlands.

Farmers should avoid farming practices leading to the destruction of such habitats. For example, permanent and intensive grazing activities in these habitats may endanger pollinators (destruction of nesting sites of ground nesting bee species). Vegetation colonizing these habitats should be viewed as supportive to pollinators that are very vital to crop production. If found necessary to cut or weed such habitats, it should be done on an irregular interval basis.

The ideal solution would be to leave such habitats as natural as possible so that pollinators can use them as refugia.

Management strategies of non-linear features of un-cropped areas in agricultural landscapes

Management of fallows

In many farming systems in Uganda, a cropping period is generally followed by a fallow period. The fallow period conventionally serves to restore soil fertility (Montagnini and Mendelsonh, 1996), suppress weeds and protect soils. Fallows are the most important features in the conservation of pollinators in agricultural landscapes in Uganda (Munyuli, 2010). Fallows represent approximately 30% of semi-natural features (Munyuli, 2010) found in farmlands of central Uganda (Appendix 3c: Plate 12). Two main fallow systems occur in central Uganda: natural bush fallows and improved fallows. In most cases, short-fallows are not improved by farmers. These types of fallows are colonized by undesired plant species such as "*Imperata cylindrca* fallows". Such fallows are also poor nesting or foraging habitats for bees. In contrast, the majority of long-fallows are generally good and suitable habitats for pollinators. Generally, farmers improve such fallows for increased crop productivity by introducing fast growing trees/shrubs and herbs (*Calliandra colothyrsus, Indigofera* sp., *T. diversifolia*, *Acacia* sp., *Mucuna pruriens, Centrosema* sp., *Pueraria phaseoloides*, *Vernonia* spp., *Cajanus cajan*). It is rare to observe improvement of fallows that are purposely made to protect pollinators in central Uganda. However, fallows represent a source and stable foraging and nesting habitat for bees. Even, several butterflies do use some plant species within bush fallows as host or forage plants.

There are different age-categories fallows in central Uganda: Young fallows (< 1 to 2 years aged), old fallows (2 to 5 years) and very old fallows (forest fallows: >5 years). Young, old and very old fallows represent respectively 60, 30 and 10% of the fallow population occurring in central Uganda. Young fallows are characterized or colonized by a vegetation population composed essentially by short (<40 cm height) herbs, grass, weeds and few scattered shrubs trees. Herbaceous vegetation strongly dominates young fallows. Old fallows harbor mixed vegetation (60% grasses and herbs/weeds/lianas + 40% trees/shrubs). These types of fallows are colonized by *Lantana camara, Erlangeya tomentosa*, *Vernonia* spp., *Bridelia bridelifolia* etc. In some cases, these fallows are mixed with crops (sweet potato). Contrastingly to young fallows, several abandoned gardens in central Uganda do harbour remnants of the crops previously grown in these plots. During a study conducted on pollinator biodiversity in central Uganda (Munyuli, 2010), it was observed that old fallows were suitable foraging and nesting habitats for a diverse community of both solitary and social bees. Several termite mounds and wooden-nests were found in such fallows. Very old (>5 to 6 years) fallows ("forest fallows") are also excellent foraging/nesting habitats for bees. Similarly, several butterfly species were observed breeding in these "forest fallows". Forest fallows are dominated by trees/shrubs (60%) including forest remnant trees although in some case, they may be colonized by herb (40%) and grass species. Despite the fact that forest fallows are not common in farm-landscapes of central Uganda, highly diverse bee community was observed to be associated with fields adjacent to them. Forest fallows offer good nesting site opportunities of similar quality as forest patches. Some stingless bee species (*Plebeina hildebrandti*, *Meliponula bocandei*, *Meliponula ferruginea*) were observed to frequently nest in forest fallows (Munyuli, 2010).

In terms of habitat management, the only sound management that can be recommended for fallows is the increase of the fallowing period to enable "young fallows" becoming at least "old fallows". Fallowing for less than a year may not enable the establishment of some bee species (habitat specialist) but it is possible to maximize nests establishment in old to very old fallows. In the planning of management of different lands, it is important for a given land that has been put under fallow system to be kept and treated just as fallow and not as a land that can be used to serve other interests of the farmer. Small-scale farmers are recommended to avoid as much as possible transforming fallows into grazing plots because animals grazing in a fallow can disturb, interrupt or destroy nesting sites of certain bee groups (solitary bee species in particular). Also, some butterfly species can found their larval host plants within fallows and the grazing of these fallows habitats can destroy different immature stages of butterflies. Fallows should not be considered as waste land but as a land that can provide various benefits and services to agriculture and to farmers. Management of fallows should also aim at improving the vegetation quality to make them being able to harbor different flowering plant species that can bloom at different periods of the year.

Management of woodlands and forest plantations

One strategy that potentially facilitates the maintenance or recovery of biodiversity within agricultural landscape is the establishment of native forest plantations on degraded agricultural lands (Mosquera-Losada et al., 2009). Planting trees or leaving tree plantations in agricultural landscapes may contribute to conserving and restoring biodiversity by offering habitats for birds and other animals and by enhancing seed dispersal into agricultural landscapes (Harvey and Haber, 1999; Montagnini, 2001; Paritsis and Aizen, 2008). Tree plantations are common features in areas where natural forest (including secondary forests) has declined across. Tree plantations of non-native species, often but not always are established to help meet increased demand for timber, fuel wood and pulp. Plantations are of limited value for native tree species, and species richness in other taxa is generally low compared to forest ecosystems. However, if established near to mature forests, tree plantations can provide more suitable habitat (for forest species, rare species) than savannah for some species (animal, plant). Coniferous plantations with more open canopy can favor biodiversity by increasing individual abundance and species richness of different understory functional assemblages (Paritsis and Aizen, 2008; Kanowski et al., 2005). In Uganda, woodlands are "secondary forests" that have naturally evolved from savannahs and that are colonized by complex vegetations dominated by a variety of wild shrub and tree species. They are sometimes called "savanah forests"; whereas, woodlots are forests deliberately planted by humans.

Woodlands and woodlots (here considered as "forest plantations") represent approximately 1 to 2% of semi-natural features found in farmlands of central Uganda (Munyuli, 2010). Plantations are generally dominated by one to two tree species. The predominant forest plantation tree species found in central Uganda is *Eucalyptus* followed by *Pinus* species (Appendix 3c: Plate 14) and *Cupressus lusitanica.* There are several private and individuals companies growing pines and Eucalyptus in Uganda. Monoculture plantations of Pine/Eucalyptus dominate polyculture and mixed native species plantations; the later ones may be able to attract and host a rich animal diversity than monoculture plantations. Practically, mixed plantations are more biodiversity-friendly (more valuable for biodiversity) than mosaic of monoculture plantations in a given landscapes, although they are rare in Uganda. Selecting only the fastest growing species for firewood or timber production is similar to planting highly-selected monocultures for agricultural production. The classic *Eucalyptus* or *Pine* plantations do not present the best solutions in most situations, neither short-term nor long-term since these plants are selected for only a few important characteristics (that is, maximum rate of biomass production). Similar to the planting of hedges, forest plantations can be established near agricultural fields. Just like natural forests, forest plantations can provide a multitude of uses in addition to that of maintaining some pollinator species in the farm landscape. For example, in Israel and in Australia, *Eucalyptus* is the main forage for long-distance flying bee species. In tropical environments, *Eucalyptus* are suitable for a few number of bee species. Even though most *Eucalyptus* species provide abundant nectar, their pollen is deficient in nutrients and very few companion plants can grow in the understoy of these trees. Thus, there are no sources of cover, forage or alternative food for many kinds of animals in monospecies forest plantations.

In contrast, there are many fast-growing indigenous tree species that permit various other uses of the land

and the tree crop. Carefully selected species can even improve soil conditions through nitrogen fixation and organic matter deposition, as well and providing foraging and nesting opportunities for diverse pollinator communities. Higher diversity contributes to sustainability of future crops and a higher quality of environmental conditions in general. By planning multiple uses (multi-purposes) native tree species wisely, it is possible for farmers from Uganda to gain some cash or income at the same moment providing nesting and foraging opportunities to pollinators. For example, several known native apiary tree species (*Markhamia lutea*, etc) that are rated as good producers of nectar and or pollen, can be used when establishing forest plantations. It is possible that several native species may be fast-growing (*Terminalia ivorensis, Thevetia peruviana, Artocarpus heterophyllus, Solanum wrightii, M. lutea, Entandrophragma angolense, Celtis africana, Celtis mildbraedii, Trema orientalis, Maesopsis eminii*) species that can be used in forests plantation since they are good producers of pollen and nectar for pollinators. It may be interesting for farmers to try native tree species and to associate these native tree species with exotic tree species (*Eucalyptus, Pinus* sp, *Cuppressus lusitanica*) while establishing forest plantations in marginal lands. Once the planted trees are well established, grazing activities can take place in these plantations. It should be advised to control the grazing regimes or intensity. Large animals should not be allowed to graze continuously in such plantations because their movements may destroy bee nests. Selective tree harvesting is recommended for woodlots and plantations in order to minimize ecological disturbances.

Woodlots and tree plantations are suitable nesting and foraging habitats for several bee species because they are semi-natural habitats that can maintain relatively perennial their ecological characteristics. Pine (*Pinus* sp.) and *Eucalyptus* plantations are generally logged after 5 to 20 years of establishment. Synchronizing harvesting and planting of tree species is recommended to owners of plantations in Uganda. For the benefit of pollinators, it is recommended to policy-makers, land-use planners and to all other stakeholders interested (involved) in continuing increasing the number of forest plantations to develop collaborative strategies with the National Forest Authority and the national environmental management Authority. Overall, efforts to protect or preserve currently established woodlots and establishing new plantations up to 30% cover of agricultural landscapes in central Uganda, may be very important and these woodlots can perform similar roles as “natural forest patches” that are disappearing at alarming rates. Increasing woodlots and plantations cover in Uganda can also markedly contribute to increase pollinator populations and stabilize pollination services in farmlands and this can have a great impact on crop yields increase and stability. It is recommended to land-use planners and policy-makers to plan afforestation of marginal public lands and strengthening community forestry for forest plantations (“woodlots“) establishment up to 10 to 30% cover of the rural landscapes (Munyuli, 2010) to maximize multiple benefits to the community.

The deliberate planting and management of native trees on-farm by rural communities is one of the best farming practices to promote community forestry as they enhance landscape connectivity and heterogeneity (Boffa et al., 2005). Such practices can in turn increase nesting opportunities, particularly for wood-nester bee species that deliver pollination services to some crops like cucurbits commonly grown in central Uganda.

Management of grasslands and pasturelands

Here, grazed lands or grazing plots that are fenced are considered as non linear features. Grasslands and pastures represent approximately 10% of semi-natural features found in farmlands of central Uganda (Munyuli, 2010). Living and dead materials used for fencing cattle paddocks have been frequently observed being used as nesting habitats by some bee species of the genera *Megachile, Lipotriches*, *Lasioglossum* and *Ceratina* in several sites (Masaka, Mukono and Kamuli districts) of central Uganda (Munyuli, 2010). Also, butterflies and bees were observed visiting several grass and legume plant species that are naturally or deliberately grown in grazing plots by cattle keepers. However, these habitats were considered as fragile and unstable nesting habitats for pollinators although they may serve as suitable foraging habitats during certain periods of the year, especially when crops are not in bloom. Grasslands in central Uganda are dominated by few grass plant species such as *Imperata cylindrica, Digitaria sp.* and *Hypparrhenia* sp. It was not clear why grasslands were conserved in agricultural landscapes of central Uganda (Munyuli, 2010). However, a few farmers reported that the existence of grasslands was due to the fact that the owners of such lands were living out of the country (Munyuli, 2010).

Interestingly, a good proportion of grasslands occurred in government lands. In farmlands of central Uganda, grasslands were found to be ideal nesting habitats for several species belonging to Certinini, Halictini and to some Megachilini bee groups (Munyuli, 2010) that are among good and effective solitary bee species of crops of beans, sim-sim, cowpea, egg plants, cucurbits, avocado.

Quiet often, nesting sites of bees belonging to these groups could be inventoried in these habitats (Munyuli, 2010). However, grasslands are not suitable foraging habitats for bees. No appropriate management practices of grassland can be proposed for instance because the management involves legal issues, especially when owners do not stay in the country. However, maintaining grasslands not cultivated for a long period is likely to make them to be good reservoirs of a diverse bee community that pollinate crops in fields found nearby because they will be colonized by various plant species including trees, shrubs and herbs tat attract pollinators. Using grasslands as permanent grazing areas should be avoided as much as possible by farmers. In fact, it is generally admitted that grazing intensity (stocking density of animals) can affect the pollinator species richness, abundance and visitation frequency to flowering plants through changing the structure, composition and phenology of preferred bee-food plants (Xie et al., 2008).

Mitigating fire frequency and grazing intensity in grasslands and ranchlands can help in protecting pollinator nesting sites in these habitats.

POLLINATOR-FRIENDLY NATURAL HABITAT MANAGEMENT PRACTICES

Management of natural forests

Forest resources represent approximately 6 to 7% of natural habitats found in farmlands of central Uganda (Munyuli, 2010). There exist almost no large primary forests in central Uganda. However, there are approximately 15 small forest patches that have been gazetted (Appendix 3c: Plate16) by the national forest authority (NFA) as “forest reserves” within central Uganda. Un-gazzetted forest fragments were only encountered in Nakaseke district. Forest reserves are the most suitable habitats for most bee and butterfly species in farmlands of central Uganda (Munyuli, 2010). Social bees prefer forest habitats more than do solitary bees (Munyuli, 2010). In central Uganda, the population density of social bees is higher than that of solitary bee species although the species richness of solitary bee is higher and not necessarily located in forest ecosystems (Munyuli, 2010). Natural forest habitats may not be ideal foraging habitats for some bee species, especially if the forest does not allow the emergence of a diverse undergrowth plant community that is used by the majority of bees. Not all bees can forage in the canopy. It is important that currently existing natural forest reserves in agricultural landscapes of Uganda are conserved. Preventing these forest patches from degradation may enable the conservation of both specialist and generalist bee species. Where need arises, some of these forest fragments have undergone serious degradation (for example Kifu forest in Mukono district), it is important that restoration management of these forest fragments are envisaged (Baranga et al., 2010). The presence of forest fragments in agricultural matrices is thus necessary for increasing yields of several crops through diversification of pollinator communities and stabilization of pollination services delivered. There is evidence showing that meliponine bees (the most economically important bee groups that pollinate several crop species in Uganda) are strongly associated not only with flowering plant community but also with forests in tropical countries mainly because of cavity tree nesting opportunities (Munyuli, 2010).

The destruction of termite mounds and forest logging can lead to disappearance of these important bees. Mitigating charcoal burning, grazing intensity, systematic and intensive timber harvests in forest reserves can help to save wood-nest sites for various pollinator species. Also, the majority of butterflies visiting coffee-banana agroforests, are forest-dependent species”, probably because they visit farmlands for nectar but they breed in forest patches where there are a diversity of larval host plants (Munyuli, 2010). Proximity to a rainforest fragments can lead not only to increased yields of crops grown in adjacent fields but also can lead to higher honey yield from beekeeping enterprises established in buffer zones of these forest ecosystems. A study conducted around Arabuko Sokoke dry coastal forest in Kenya indicated that honey yield increased with proximity to forest with honey yield almost doubled in hives placed less than 1 km from the forest compared to those placed more than 3 km from the forest. The study demonstrated that the conservation of tropical forest ecosystems can have real local economic benefits or community living in the surroundings. It was suggested that documentation of the services provided by nearby natural areas should help make conservation of these areas a priority, even for the local communities (Sande et al., 2009).

Similar trends are observed in western part of Uganda (around Bwindi Impenetrable national park) where it was observed that small-scale farmers who had their beehives established in the margins of the forests harvested three to five times more honey than farmers who had placed their hives far way from the edge of the forested national park (Munyuli, 2011).

Protection of riparian forest and forest edge/ecotone habitats

Forest boundaries (“ecotone zones”) provide a narrower, yet similar habitat to forest that should not be neglected while planning pollination services conservation in rural landscapes. Through minimal maintenance such as periodic cutting and selective clearing, a rich flora and beneficial fauna can be maintained. Forest edges (Appendix 3c: Plate 15) can be improved by nectariferous plant species within the area. However, whether they receive minimum management or not, forest edges are good nesting and foraging habitats for certain pollinator species? For example, butterfly species that can be classified as “agricultural matrix avoiders” can exploit these habitats. These habitats are also important for bees. In central Uganda, it was quiet frequent to observe nests of Anthophorini, Lithurgini and certain Ceratinini bees in forest edges (Munyuli, 2010). Efforts should be made by farmers to avoid overuse and misuses of these habitats. If crops have to be established in the vicinity of forest habitats, the boundaries of the fields should be marked at least 10 to 30 m far from forest edges. Riparian forests are those forests growing in the immediate vicinity of a Lake or river. Riparian forests growing along streams, rivers and lakes comprise less than 0.5 to 1% of the forested areas found in rural landscapes in central Uganda (Munyuli, 2010). They have special ecological functions in the landscape. They receive water and nutrients from the upslope areas, and they are important habitats for pollinator biodiversity, they also have large soil carbon stores, although they may emit more greenhouse gases than the uplands. They offer nesting opportunities for diverse bee communities that can easily forage in fields found in the surrounding.

Vegetable production is flourishing activities in swampy and reclaimed wetland habitats located alongside Lake Victoria and River Nile (Munyuli, personal observation). These crops are visited by several bee species from riparian forests located in the sides of Lake Victoria and River Nile. The protection of these riparian forests is thus crucial to maintain the productivity of vegetable and fruit production in zones that are located nearby riparian forests everywhere in central Uganda. Policy should be developed to protect these habitats that support pollinators of most vegetable crops consumed on various markets in central Uganda including Kampala.

Management of wetlands and swamps

Wetlands cover 13 to 14% of Uganda territory and they play several ecological and socio-economic roles in the country (Munyuli, 2010). Most of wetlands found in Uganda are preferred habitats for some specific wildlife. Wetlands are very good foraging and nesting habitats for pollinators, particularly when they harbour “wetland forests”. In terms of nesting, trees and shrubs located in the middle and at the edges of wetlands are suitable nesting sites for meliponini bee group. During field work conducted in 2006 to 2008 in central Uganda, nest of five stingless bee species were recorded in wetland vegetations (Munyuli, 2010). In Nakaseke district, it was observed during surveys conducted in 2006 to 2008 (Munyuli, 2010) that cucurbits, groundnut, sunflower and cowpea crops grown in the vicinity of wetlands received pollination services from a diverse bee community than did crops grown just 1000 m way from wetlands. Several nests of Megachilidae were counted in the sides (“banks”) of Nakaseke-Semuto wetland during the survey of 2006 to 2008 (Munyuli, 2010). In Kalagi (Mukono district), *Meliponula nebulata* was found nested in *Papyrus* leaves. Together with forests, wetlands harbour not only generalists but also specialist bee species. Therefore, policies that help in conserving wetlands/swamp habitats are likely to protect a rich community of pollinators in these habitats. The disappearance of wetlands may lead to the decline of some specialist bee species. In Uganda, most cucurbits grown nearby wetlands are pollinated by some habitat specialist Halictid bees (*Lipotriches* sp., *Patellapis*,) that prefer nesting in wetlands and dense forest habitats than in farmland habitats. However, outside of such environment (wetlands), grown curcurbits are reported to be visited by various bees including Halictidae, Megachildae, Apidae (Apinae, Xylocopinae, Meliponinae, Ceratininae, etc) in Uganda and in other parts of sub-Sahara such as Kenya and in Cote D’ Ivoire (Kouonon et al., 2009).

Plant/crop species with rare and specialized biotic vectors are more vulnerable to anthropogenic changes than plant/crop species characterized by abiotic (for example wind) or biotic common (abundant) pollinator species. In farmlands of Uganda, cucurbit species seemed to be vulnerable crop species given the fact they are mainly grown nearby wetlands where they rely on a limited number of bee groups (for example *Patellapis, Lipotriches, Nomia, Megachile, Meliponula*) for pollination.

The absence of these pollinators in the environment may lead to high pollination deficiency and to yield failures in these crops with high market value in the country. Wetlands are protected as stipulated in the wetlands policy and other reports released by the national environmental management authority (NEMA). However, the wetlands policy does not contain an article stipulating the conservation of pollinators. There exist no documented information on the abundance and distribution of different pollinator species in wetlands. Swampy habitats represent approximately 2 to 3% of semi-natural features found in farmlands of central Uganda (Munyuli, 2010). However, swamps are like “old fallows” since they are often colonized by complex native vegetation (herbs, grasses, trees, shrubs). Undisturbed swampy habitats are excellent and suitable foraging/nesting habitats for bees and other beneficial insects.

In central Uganda, it is frequent to see some crop species in swampy habitats. Therefore, it is recommended that swampy habitats are protected as natural as possible. In terms of management practices, it is recommended to farmers to avoid reclamation or complete destruction of these habitats to maximize pollination services delivery nearby.

POLLINATOR-FRIENDLY FIELD MANAGEMENT AND FARMING PRACTICES

Managing floral resources within agricultural fields

Bees are entirely dependent on pollen and nectar for food, suggesting that floral abundance profoundly influence the bee fauna of given habitat (Cane et al., 2006) or landscape. There are several factors limiting bee populations but the conservation and restoration of bee habitats in farmlands has to offer adequate floral and nesting resources to bees. Effective restoration and conservation of pollinators require the knowledge of factor(s) most often limit population size in a given a habitat, so that these factor (s) can be restored or so that management can be done to offer optimal conditions for the survival of bees in farmlands. The resources bees require to complete their life cycle can be roughly divided into those related to nesting (the appropriate substrate, such as bare soil, stems, or cavities, and for some species the materials necessary to create the nest interior, such as leaves or resin), and those related to foraging on flowers (pollen and nectar). Managing crop plots to be hospitable to a wide array of pollinator species is very challenging in tropical rural landscapes. It is challenging to determine best farming practices for pollinator community and populations. A first step, towards conservation and maximization of in-field attraction of pollinators and services delivery to crops on farmlands, is to determine which plants are most suitable for providing foraging resources at different times of the growing season. This calls for a need for combining plantings of highly suitable plants that provide overlapping bloom periods through the growing season.

Combined floral planting can be tested for its use in conserving beneficial insects within agricultural settings, with the ultimate aim of improving sustainable pollination of crops that depend on bees for reaching their potential yield (Tuell et al., 2008; Julier and Roulston, 2009). If wild bee populations are supported throughout the season by the addition of flowering plants into farmland, farmers may receive greater pollination services from wild bees when the crop is in bloom. Perennial flowering plants have the potential to be a relatively low maintenance way to incorporate additional floral resources into the landscape, as opposed to the multiple sowings per season necessary if one relies on annual plants for this purpose. Native bees endemic to agricultural landscapes, which are active beyond the bloom period of pollinator-dependent crops, necessitate farm management practices that will provide flowering plants throughout the growing season. It has been shown (Munyuli, 2010) that wild bees may be affiliated to mass blooming of weeds/herb species and other native perennial plants with overlapping bloom periods. Therefore, in Uganda the selection and use in agricultural settings of weed/herb plants, within fields, may be suitable for beneficial insects (bees and natural enemies), and can promote both pollination and biological control, the two main ecosystem services provided to agriculture by arthropods (Tuell et al., 2008). Many of the options for increasing the diversity and abundance of floral resources on farms to accommodate the needs of a diverse pollinator community do not necessarily reduce farming productivity, and they can even improve productivity by providing additional benefits beyond pollination services, such as nectar for natural enemies of crop pests.

Some farming practice related to sustainable agriculture and sustainable use of natural resources (long-term crop rotation, using legume crops in rotation, growing cover crops, mixture of crop varieties, promotion of polycultures or mixed cropping systems, not burning residues after harvest, avoiding early and excessive grazing of rangelands and common grazing places such as field margins, pasture grazing rotation, protection of natural habitats in the farm-landscape including pastures and fallows, judicious use of fallows, afforestation and reforestation of less advantaged farm environment, proper use of chemical fertilizers and pesticides, etc) can be beneficial to pollinators (increasing availability of nesting and floral resources) if government develop proper policies and incentive mechanisms for farmers to adopt and implement them properly at their farms. Different conservation management of the farm landscape affects pollinator communities differently. Generally, management regimes such as traditional farming systems that promote polycultures and floral resources-enrichment of field margin habitats are likely to increase visitations by a diverse bee community, thus increasing the reproduction success of cultivated and wild insect-pollinated plants in the farm landscape.

Some of the field management strategies, practices and options likely favoring the persistence of pollinators and services on-farms are outlined as follows:

1) Growing polycultures rather than monocultures in a field can results in a more diverse set of floral resources. Including flowers that bloom at different times of the year provides for and attracts a greater number of pollinator species, including those with long flight seasons. Cropping systems (Malézieux et al., 2009) diversification can also help in attracting high number of pollinator on-farms. For example, polyculture systems that consist of mixing beans, maize and cassava are likely to attract a different bee community than maize sole grown; and such situation can be beneficial especially if crops are planted such as they can flower at different periods of the year. Growing pollinator-dependent local crop varieties may be advantageous. Polycultures dominate Uganda cropping systems and this should be encouraged since they present advantageously more pollination friendly attributes than monoculture systems.
2) Tolerating weeds along crop borders can provide a diverse and abundant set of floral resources, at no cost to the farmer.
3) Insectary strips planted within crop fields or in field margins and in buffer strips can provide abundant pollen and nectar sources and attract bees to the field.
4) Planting cover crops on resting fields or allowing cover crops to bloom before ploughing them under, can provides green manure that benefits both pollinators and soil fertility.
5) Planting within fields perennial hedgerows of native

perennial herbs and shrubs ("field temporarily fallows") can provide nest sites and preferred pollen and nectar sources for a diverse community of pollinators in the spaces between fields. Generally, enhancing biodiversity in fields involves: (i) the use of legume-based crop rotations and mixed pastures, (ii) intercropping or strip-cropping annual crops where feasible, (iii) mixing varieties of the same crop (iv) use of varieties that carry many genes-rather than just one or two-for tolerating the same disease and varieties with different floral traits, (v) growing cover crops in crop fields, and planting plant species capable of attracting pollinator species (vi) leaving strips of wild vegetation at field edges (vi) providing corridors for pollinators and other beneficial insects (viii) practice agroforestry: where possible, combine trees or shrubs with crops or livestock to improve habitat continuity for pollinators, (ix) planting microclimate-modifying trees and native plants as windbreaks or hedgerows, (x) providing a source of water for bees (xi) leaving areas of the farm untouched as habitat for plant and animal diversity, (xii) enhancing landscape diversity with biological corridors, vegetationally diverse crop-field boundaries or mosaics of agro-ecosystems (Altieri, 1999).

6) The promotion of conservation agriculture technologies and practices can create nesting opportunities within farm landscapes.

7) Placing massively beehives within farm landscape is a farming practice that should be encouraged. It is also important that researchers in collaboration with farmers initiate meliponiculture, "xylocopiniculture" and "ceratiniculture" as novelty approaches that can increase crop visitations, particularly in areas where honeybees may not be sufficiently available or have been reduced in number by disease such as Varroa mite.

8) In-field habitat and plant resources manipulation (Jones and Gillett, 2005; Landis et al., 2000, 2005; Fiedler et al., 2008) can increase within farm heterogeneity, thus enhancing pollinator attractions, visitations and conservation in farm landscapes.

9) The interspacing of cereal lines with legume lines in the field can also help in attracting and enabling easy movements of pollinators within farm-landscape.

10) Crop varieties mixture during planting can help in attracting and easy movement of pollinators in the field. The association of pollinator-dependent and non-pollinator crop species during planting is good farming practice that is recommended to all farms for adoption.

11) The conservation of plant genetic resources is important in the attraction and maintenance of pollinators in fields and in the study of plant-pollinator dynamics. The decline in plant genotypic diversity can lead to decline in pollinators due to reduced plant diversity in both agricultural and natural ecosystems (Genung et al., 2010). Crop breeding and crop selection are important to obtain varieties that have desired characters to attract pollinators. Crops with floral attractiveness and rewards for insects can be used to enhance pollinator conservation as well as crop yield and yield stability. It might be possible for breeders from Uganda and those working in sub-Saharan national research institutes to select and distribute to farmers crop varieties that do not require external pollination agents like insects. However, those crop varieties that will continue to require pollinating insects need to be made more attractive to pollinators. This means that plant breeders have to pay more attention to flowering times and duration, nectar secretion and /or pollen attractiveness and to shape and colour of flowers such as they can attract a diverse bee community when in bloom. Within the agricultural ecosystem, the services provided by pollinators and services provided by crops are interdependent. Hence, the need to increase the number of functional traits and to facilitate the interactions among crop and pollinators in the pollination network that can positively affect both services. Consequently, breeders should work on the improvement of functional floral traits of different pollinator-dependent crop species and increase the ability of crops to benefit from associative relationships with beneficial species such as insect pollinators.

Besides, promoting such a breeding approach might give significant economic benefit to growers by promoting wild bee populations that enhance seed production and yield stability. In this way, breeder can contribute significantly in the development of pollinator-friendly varieties that respond positively to bee visitations.

Management to provide bee nesting sites within agricultural fields

Among resources bees require to complete their life cycle in rural landscapes include nesting substrates. There are several factors limiting bee populations but the conservation and restoration of bee habitats in farmlands has to offer adequate nesting resources to bees. Methods are available for providing or protecting nest sites and substrates for bee species in the agricultural fields; and many of them do not interfere with crop farming. They range from simple, low-cost measures to more complex and expensive methods. The protection of bees in farmland of Sub-Sahara Africa consists of managing agricultural fields to create nesting sites opportunities for ground-nesting bee species and wood-nesting bee species within fields. The process of providing naturally or artificially nesting opportunities to various guild of bees require proper understanding the biology and nesting requirements and adaptation ability of different species to farmland habitats. For example, in central Uganda, several bee species were observed to nest in termite mounds (Appendix 3b: Plate 9) located in hedgerows or in field margins or in woodlands/woodlots/ grasslands. In areas where farmers have been sensitized about the importance of termite as habitat for bees that pollinate their crops, it was frequent to observe some structure build around termite mounds to prevent their destruction by children (Appendix 3b: Plate 10) and vagrant animals. Other bee species were observed frequently using different types of standing tree stumps and logs as nesting sites (Appendix 3b: Plates 5 and 6). Tree-nester species were observed to nest in holes in living tree species in the landscape (Appendix 3b: Plate 7).

Also several nest sites were counted alongside irrigation canals in the sugar cane plantations that have been maintained almost undisturbed for a while.

Stem bundles that are available and stored in sheltered and dry areas nearby fields are good wood-nesting sites for several solitary bees in farmland of central Uganda. Hollow stems such as those of bamboos are frequently used by several types of bees in Uganda. Human and livestock buildings were also observed to frequently being used by several solitary bee species in central Uganda. Different types of bee species were recorded in wooden materials located in the wall or in the roof of animal kraals (Appendix 3b: Plate 8) particularly in Jinja district (Munyuli, 2010). Houses are also some times inhabited by certain bee species in central Uganda, particularly bees from the Xylocopini and Ceratinini bee groups. Therefore, farmers are advised to avoid destruction of critical habitats for bees such as termite mounds. In addition, the storage of dead wooden and stamps materials in sheltered microhabitats within field margin habitats may provide nesting opportunities for various bee species.

Also mixing hedgerows and related field margin habitats or promoting agroforestry systems that incorporate native tree species that are generally known to be used as nesting habitats for various bee species is important to facilitate pollinator nesting in the farmland. For example, during the study conducted in 2006 to 2008 (Munyuli, 2010), few tree species were observed to be nest tree species for a variety of solitary, social and parasitic bee species occurring in farmland of central Uganda.

These included: *Senna occidentalis, M. lutea, Maesa lanceolata, V. amygdalina, Psidium guajava, Ficus saussureana, Persea americana, Mangifera indica, Eucalyptus grandis, Theobroma cacao, Erythrina abyssinica, Grevillea robusta, S. wrightii, Cassia spectabilis, C. lusitanica, Ficus mucuso, Leucaena leucocephala, Spathodea campanulata, Citrus lemon, Funtumia africana, C. calothyrsus, Jacaranda mimosifolia, Bridelia micrantha, Ficus thonningii, Kigelia africana, Macaranga schweinfurthii, Sesbania sesban,* etc.

Consequently, the integration of such tree species in the agroforestry systems may be very important to provide nesting opportunities on a long term-basis since many bee species uses hallows in these tree species when living or when dead.

Providing breeding sites to butterflies within agricultural fields

Butterflies lay their eggs on plant leaves that are suitable for their caterpillars to eat, whereas bees create a nest in a secure location and stock it with food for their offspring. Young stages of butterflies need host plants whereas adult need a diversity of nectaring plant species. If there is no host plant (trees/shrubs) in a farm landscape, there may almost be no butterfly remaining in the farmland to pollinate wild plants and crop species that require pollination by butterflies. Caterpillar host plants are a vital component of butterfly habitats in rural landscapes. In other worlds, host plants on which caterpillars can feed are a critical part of butterfly habitats. It is often a lack of host plants rather than nectar plants that limit the presence of a butterfly species in most agricultural landscapes (Munyuli, 2010). Some butterflies are very particular about which host plants they use as food and as host for laying their eggs. However, the majority of butterflies are less choosy about where to lay eggs, because their caterpillars will eat several plants. Actions and strategies to successfully conserve and enable the persistence of butterflies in the farm landscape involves mainly the preservation of larval host plants in relatively stable habitat located nearby crop fields. To a great extent, good host plant areas are the same as good foraging areas. Diverse forage patches almost certainly include a variety of host plants for various butterfly species. In farmlands of central Uganda, it was observed that caterpillars of many butterflies feed on trees and shrubs. Few of these plant species were inventoried and are generally forest remnant tree species. Approximately 56 tree species were inventoried to be butterfly host plants in the Myrtaceae, Asteraceae, Rubiaceae families (Munyul, 2010). Also some native species (*Ficus* spp., *Mesopsis eminii, B. micrantha, B. bridelifolia, Vernonia* spp., *S. campanulata*, *Cassia* sp., *Hibiscus* sp., etc) used in the agroforestry systems were frequently observed to host caterpillars of various butterfly species during some specific periods of the year (May to July, November to December).

Few species in the Nymphalidae family (*Junonia eonone, Junonia chorimene*) were observed using *Erlangea ugandensis* (Asteraceae) as larval host plant species whereas *Acraea acerata* used sweet potato (*Ipomoea batatus*) as larval host plant essentially (Munyuli, 2010). In terms of landscape management, host plants population density should be increased in crop fields and in semi-natural habitats to complement forest remnant tree species, although the majority of butterfly species encountered in farmland of central Uganda were observed to be “forest–dependent species”, meaning that they had to use or to find forest patches to lay eggs while common and farmland users butterfly species were adapted to various tree species available in areas far from the forest fragments. Butterflies were observed to be regularly associated with semi-natural features and natural habitats in central Uganda (Munyuli, 2010). Protecting, enhancing, restoring or creating butterfly habitats is the key to increase butterfly pollinator populations in the farm landscape. Such practices may involves: (i) first, increasing the available foraging habitat to include a range of plants (preferably native species) blooming at different times in order to provide nectar and pollen throughout the season; (ii) second, plant caterpillar host plants appropriate for the butterfly species in different semi-natural habitat types. Major butterfly food plants (nectar plants) encountered in different semi-natural habitats in central Uganda included *A. pubescens, A. gangetica, J. flava, Amaranthus hybridus, Ageratum conyzoides, A. africana, B. pilosa, C. vitellinum, E. javanica, E. tomentosa* and *E. ugandensis*. For instance, the overall checklist of larval host plants and nectaring plant species found in agricultural areas of central Uganda is not yet published, but this should be the basic step towards consolidating landscape and habitat management techniques the protection of Lepidoptera-derived pollination services in farm landscapes in Uganda.

The pollination efficiency of different butterfly species as effective pollinators of crops in on-going and findings will help to improve the knowledge about role of butterfly in crop pollination in sub-Sahara Africa.

POLLINATOR-FRIENDLY LANDSCAPE MANAGEMENT PRACTICES AND STRATEGIES

Land cover and land use surrounding fragmented habitat can greatly impact species persistence by altering resource availability, edge effects, or the movement of individuals throughout a rural landscape (Banks, 2004; Robertson and Swinton, 2005). The type of matrix surrounding habitat patches does matter because it influences the diversity, abundance and distribution of pollinator species. However, the quality of the matrix to pollinators may depend also on the size, structure, composition and position of habitat patches within the fragmented landscape. Because matrix matters much (Perfecto and Vandermeer, 2008; Tscharntke et al., 2005; Dorrough et al., 2007; Green et al., 2005), transforming farm-landscapes to become agricultural mosaic landscapes (Lindenmayer et al., 2008; Mattison and Norris, 2005; Aviron et al., 2009a) is a key to successful protection of pollinators and services in tropical agricultural landscapes (Lovell and Johnston, 2009). General guidelines and principles for sustainable land-use management to benefit pollinators were previously highlighted by Dale et al. (2000). Later, Fischer et al. (2006) defined ten guiding principles to help maintain biodiversity, ecosystem functions and resilience in production mosaic landscapes or to balance food production with biodiversity conservation in farmlands. Because local land management directly affects floral resource and nesting site availabilities, it is therefore important that management of pollinators at the landscape level aims at creating structurally complex and heterogeneous landscapes with corridors that promote movement of pollinators, or creating a mosaic landscape with high-habitat matrix or with high cover of natural and semi-natural vegetation.

With greater engagement of agro-ecologists in the process of ecological landscape design towards forming a mosaic landscape, designing multifunctional landscape can provide multiple ecosystem services and a range of environmental, social, and economic functions, and services while considering the interests of landowners and users (Lovell and Johnston, 2009). Forming mosaic landscapes mimicking natural systems to benefit diverse pollinator communities and to enhance-mediated ecosystem services delivery, can be very challenging. However, this is highly needed to shape landscape and in order to enable them to be more “wildlife friendly” (Green et al., 2005; Ewers et al., 2009). Wildlife friendly systems (such as complex agroforestry systems) represent, not only habitat for biodiversity, but also a high-quality matrix that permits the movement of forest organisms among patches of natural vegetation (Perfecto and Vandermeer, 2008). Diverse low-input agro-system types are probably the best option for a high-quality matrix to support biodiversity while maintaining optimal crop yield productivity in tropical regions (Perfecto and Vandermeer, 2008; Duffy, 2009; Sayer, 2009). It seems that wildlife friendly farming approach is appropriate, particularly for the protection of pollinators for crop yield increase and stability in central Uganda. Therefore, policy guidelines for conservation of pollination services in agricultural landscapes are proposed to be based on the scientific foundation behind wildlife-friendly farming system that is refereed to as pollinator-friendly farming practices and landscape habitat management systems. Creating landscape matrixes dominated by productive agro-ecological systems that facilitate inter patch migration while promoting a sustainable and dignified livelihood for rural communities is recommended in central Uganda. Because there is need for setting measures that preserve and increase agro-ecosystem viability in farmlands of Uganda, policy guidelines should be developed for agricultural practices that maintain and increase heterogeneity and habitat connectivity of the farmlands. This includes maintenance of forest remnants, scattered trees, semi-natural features and crop diversity.

Habitat connectivity is essential to maintain not only abundant and diverse bee communities, but also plant-pollinator interactions in economically important crops and endangered wild plants and wildlife. Hence, management strategies that increase habitats connectivity can also help in ensuring long-term survival of both generalist and habitat-specialist pollinator species in rural landscapes. There are substantial benefits from conservation of parcels of lands which are connected or contiguous to each other than those that are isolated or not very contiguous. Habitat characteristics determining bee diversity and abundance include: floral diversity and abundance, quality and quantity of energy available (nectar and pollen), and availability of nesting substrates and nest building materials (Kremen and Ostfeld, 2005). This implies that, landscape management practices in favour of pollinators, needs to be addressed at the ecosystem-level to conserve and restore natural and semi-natural habitats and optimize pollinator services in agricultural systems (Kremen and Ostfeld, 2005; Murray et al., 2009). For example, in tropical agroforestry systems, local bee density and diversity are generally high compared to primary forests (Hoehn et al., 2010) due to increased floral density of herbs (herbaceous food resources), including cash crops due to high management diversity (Hoehn et al., 2010) of the habitats that offer both floral rewards and suitable nesting sites for wood-nesting bee species (Hoehn et al., 2010). In a small-scale mosaic landscape, the species-richness and abundance of wild bees is particularly high, as their demands for nesting places, food-plants and hiding places are satisfied in such a landscape (Ricketts et al., 2008). An agricultural mosaic landscape or complex agricultural landscape is likely to allow breeding or reproduction of pollinators including highly specialized species, as well as offering diversity of feeding places and a variety of refugia (Samways, 2007). For example, butterflies have got different habitat demands for the larvae, pupae and adults. A host plant that larvae feed on is not necessarily the same that adult will visit for nectar collection. Different life stages may require different habitats for the insect to persist in the landscape. However, to be able to meet all these insect requirements for a habitat, the landscape need to be mosaic diverse with many different types of habitats and different types of agricultural matrices.

In terms of landscape management practices, wild bees could be favoured by preserving and restoring the mosaic structure of the landscape and identifying this structure as a natural feature in its own right (Duartea et al., 2008; Hranitz et al., 2009). The optimal farm design for creating pollinator diversity is the best strategy for effective provision of pollination services in agricultural landscapes (Brosi et al., 2008) of Uganda. Keeping >10 to 30%<60% of the farmland as uncultivated areas to serve as reservoir (Brosi et al., 2008) for pollinators is key to sustain pollinator and pollination services in agricultural landscapes of Uganda (Munyuli, 2010). Overall, promoting the conservation of pollinator diversity in rural landscapes that are actively managed or modified by people is a key to guarantee the provision of pollination services and sustainability of rural livelihoods. Landscape heterogeneity and connectivity favour increase of species richness and abundance in an area (Holzschuh et al., 2009). Greater heterogeneity of a landscape favour biodiversity enhancement in agricultural landscapes (Shuler et al., 2005; Nelson et al., 2009). In addition, heterogeneous landscapes offer a greater range of resources and microclimates, which can buffer populations against climatic variation and generate more stable population dynamics (Oliver et al., 2010). Heterogeneous landscapes that contain a variety of suitable habitat types are generally associated with high pollinator species-rich communities with more stable population dynamics (Oliver et al., 2010). Practically, landscape management strategies that increase floral and nesting resources in an area are likely to have significant effects on pollinator population viability, pollinator richness, on multiple pollination services delivery and crop yield increase. Therefore, policy decisions and land-use planning (Chan et al., 2006; Daily et al., 2009) that promote pollination conservation and service delivery in agricultural landscapes in central Uganda must ensure temporal and spatial availability of sufficient nesting and floral resources for pollinators to be able to deliver pollination services of high quality in farms (Lonsdorf et al., 2009). Participatory and multidisciplinary approaches in landscape research and management are needed here in Sub-Saharan Africa.

Lasting conservation efforts demand new alliances among conservation biologists, agroecologists, agronomists, farmers, indigenous peoples, rural social movements, foresters, social scientists, and land managers to collaborate in research, co-design conservation programs and policies, to manage human-modified landscapes in ways that enhance pollinator biodiversity conservation and promote sustainable livelihoods in the region. Crop pollination being an essential ecosystem service, provided by wild and managed pollinator species, can be negatively affected by human activities at a landscape scale level. Various pollinator species can be affected by landscape factors and/or act at different spatial scales. Many crop pollination services are, provided by a wide range of taxa in addition to bees, and these taxa may respond differently to landscape changes. Thus, a diversity of pollinator taxa may help to reduce the negative effects of land-use change on the pollination success of crops. Different species operate at different scales, thereby reinforcing services/functions across scales. Scale-dependent effects depend on the spatial scale at which organisms interact with landscape structures by dispersal most managed and wild bees depend on those different landscape factors (scale factors), since they possess different dispersal abilities. Different pollinator groups exhibit correlations with different landscape metrics at different spatial scales. For example, the abundance of some bee species may decrease with increasing distance from hives (pollinator reservoir) and/or with increasing abundances of the other pollinators (Taki et al., 2010; Carvalheiro et al., 2010). The abundance of social bees may increase with increasing the area of forest cover and/or with decreasing the abundances of the other pollinators. The abundance of other pollinators may increase with increasing area of natural and semi-natural land cover and/or with decreasing the abundances of honeybee species. Overall, these varying responses of different pollinators differentially affect the fruit/seed set of most cultivated and wild plant species (Taki et al., 2010). Therefore, appropriate management targeting landscape factors at different spatial scales may enhance services delivered by pollinators, thus increasing crop yields (Taki et al., 2010). Incorporating different ranges of landscape scales into a management plan may increase pollinator populations and visitations and insure more crop yield. Practically, management at a more local scale may be more applicable in many cases. Thus, the creation of natural and semi-natural land cover at local and landscape scales would provide habitats pollinators and other beneficial insects through enhancement of nest and food resources. Some specific and promising landscape management practices can be recommended given the fact that they may contribute to the conservation of pollinators in Uganda and in countries with similar habitats in sub-Sahara Africa. These include: (i) management of hedgerows as corridors enabling connectivity of forest fragments with semi-natural habitat features and with crop fields for easy movements and persistence of diverse pollinator communities within agricultural matrices; (ii) promoting agroforestry systems with multi-purpose tree species likely offering abundant and stable nesting and floral resources opportunities to various pollinator species (Bhagwat et al., 2008; Sileshi et al., 2007; Philpott and Armbrecht, 2006) as well as maintaining current simple, complex and very complex traditional agroforestry systems (Appendix 3c: Plate 17), (iii) conservation of remnant and other primary forest trees in pastures and in agriculture fields as nesting sites for various bee species and (iv) relay cropping and improved fallow systems, which involve use of perennial legume shrubs (Sileshi et al., 2007) to benefit pollinators. The agro-forestry sub-sector, which is the integration of trees, food crops and/or animals in an interactive manner, is of great significance to the agriculture sector in Uganda as one of the most popular agricultural practices.

Agroforestry as a production system can be one of the best management tool that can enable farmers to earn money, stop forest degradation, stop degradation of environmental resources. It can be a good model of pollinator-friendly sustainable land management in an overpopulated country with anthropogenic, environmental and socio-economic pressures.

COMPENSATION OF FARMERS FOR SUSTAINABLE CONSERVATION OF POLLINATORS IN AGRICULTURAL LANDSCAPES

Providing investments and incentives are necessary steps in (reversing current trends) ending environmental degradation in rural areas as well contributing to the improvement of the environmental quality and provision of ecosystem services. Incentives for the provision of environmental services are therefore crucial in providing benefits to people and in improving livelihoods. Payment for environmental services is not necessarily of a financial nature, but is largely a voluntary transaction in the form of compensation flows for a well-defined environmental service likely to secure it (Pascual and Perrings, 2007). Payments/rewards for environment services are often designed to address problems related to the decline in some environmental services, such as the provision of water, soil conservation and carbon sequestration by upland farmers who manage forest-lands in upper watersheds (Pascual and Perrings, 2007). The process of assessing and rewarding farmers for environmental services involves: (i) measuring the actual amount of environmental services being provided, so that appropriate payments can be made; (ii) providing payments in a way that results in the desired change in land use; (iii) and avoiding the creation of perverse incentives (for example, for land users to cut down existing trees so as to qualify for additional payments for tree planting). Generally, payments are provided to farmers proportionally to the level of services provided and evaluated in terms of indices of the biodiversity conservation and carbon sequestration services that different land uses provide (Pagiola et al., 2005). For example, paying US$75/ha per incremental environmental service (for example increase in the number of trees planted and maintained per farm per year) is a commonly practice in the environmental services rewards in Latin America (Pagiola et al., 2005) and for US$3 to 15/ton carbon sequestered. For biodiversity conservation to be able to play a key role in environmental sustainability and provide benefits to future generations, particularly in region with agricultural systems with high degree of poverty of local populations, it is important that incentive measures (for example payment for multiple environmental/ecosystem services delivered) are put in place to maintain the viability of farmers' seed systems; to maintain complex pollination systems and to maintain wildlife conservation within agricultural areas (Jackson et al., 2010).

Incentive mechanisms can be efficient tools for the conservation of biodiversity in agricultural landscapes (Pascual and Perrings, 2007). Payment for environmental service programs are expected to compensate land users who adopt practices that generate environmental services (Pagiola et al., 2005; Aviron et al., 2009a) for themselves and the community or his neighbors. Paying or rewarding farmers for delivering ecological (environmental) services to themselves and to their communities can be a critical incentive measure to enhance pollinators and services in farmlands of Uganda.

Paying services provided by farmers to agricultural ecosystems may involve the valuation of the services delivered by the farmers and translate the value of the services in monetary rewards to be paid as an incentive to continue generating such important services to the community. Many crops grown in central Uganda rely on services provided by neighboring ecosystems (and specifically those harboring beneficial insects) for integrated pest control or pollination. These wild insect populations originate principally from public lands or from neighbor lands, while their dispersal and utilization are affected by land use decisions on individual farms. There is a need for establishing and designing public environmental service interventions in agricultural landscapes of Uganda. Prior to that, it is particularly useful first to identify which agricultural practices should be eligible for compensation for producing ecosystem goods and services. In rural landscapes of Uganda, pollination services from managed bees (hives) and those from wild bees inhabiting in semi-natural habitats managed by some farmers, need to be recognized by farmers, extension services, local leaders, government and policy-makers. The value of such public service offered should be determined and people providing such services have to be compensated so that they can continue caring for the maintenance of such service in the rural area. There exist various ways of creating incentives that can be used to promote pollinators conservation in agricultural areas in Uganda.

Overall, all incentives have to be made to influence positively farmers' decisions in implementing any farming practices likely to benefit pollinators. These include: (i) setting collaborative and participatory pollination experiments resulting in the attachment of monetary value to pollination services delivered to crops: Conducting collaborative pollination experiments where farmers participate in the demonstration and evaluation of pollination services to their different crops and varieties is one of the best incentives to convince farmers of the contribution of pollinators to their crops. Pollination experiments present good opportunities to capture the value of pollinators to crops. Once farmers are convinced that pollinators can increase yield of their crops, then, it can be easier to educate them and provide to them basic information about the identification, management and conservation of pollinators. (ii) Rewarding small-scale farmers for providing ecosystem services to the community. In central Uganda, some small-scale farmers combine beekeeping and crop/animal production in their compounds. Those farmers having more than 10 beehives in their compounds are likely to provide pollination services to their neighbours. Such farmers should be identified and special prize should be allocated to them for providing environmental services of good quality to themselves and their neighbours. (iii) Direct compensation payments for farmers implementing best pollinator-friendly land-uses and farming practices for example. Efforts should be made to compensate small scale farmers who deliberately use best practices for pollinator conservation. Overall, policy should be developed to encourage farmers to maintain wild land on their farms for crop productivity stability in Uganda. Incentives for pollination services should be developed as for carbon sequestration correctly available worldwide. "Payment for ecosystem services" is an effective pollination services management option. For example, in Costa Rica, ecosystems valuation methods have been used to determine the monetary value of forest protection, based on the ecosystem functions of carbon sequestration and water purification. Landowners are paid approximately US$50/ha/year to maintain forest cover on their properties.

In Uganda for the sake of maintaining the stability of agricultural productivity of crops, similar incentives should be determined based on the mean productivity of small scale farmers. For example, a price that is the equivalent of the contribution of pollination services in the value of the crop can be adopted. A regular monitoring program should be developed to continuously determine and evaluate farmers' practices against recommended best practices. Such ecosystem service payment mechanisms have to involve government bodies for transparency. An incentive scheme for rural area of central Uganda has been proposed based on calculated economic value of some conservation practices (Munyuli, 2010). For example, paying small-scale farmers: (i) US$64/ha/year for owning and protecting natural fragments of natural forests and wetlands in their village, (ii) US$816/ha/year for engaging in forest plantations, (iii) US$250/ha/year for engaging in protection of semi-natural habitats (fallows, hedgerows), (iv) US$200/ha/year for abstaining from destroying bee nests (termite mounds) in the village, (v) US$300/ha/year for running successful traditional complex agroforestry systems based on native trees, fruit trees, and medicinal plants. These compensation measures can help in slowing environmental degradation in rural areas, adding monetary value to agroforestry systems, on-farm biodiversity and enhancing understanding of the economic and social contribution of natural ecosystems. On a long-term, incentives to enhance ecosystem services (pollination services) can have significant on livelihoods of people (providing additional income to people), create positive attitude towards environmental conservation as well as influencing the development of other environmental markets-for freshwater enhancement, soil conservation, on-farm biodiversity conservation, etc.

Improving rural landscape environmental quality (for example restoring, protecting, and conserving natural forests against degradation, promoting complex agro-forestry systems using native tree species), through making good decision making by policy makers, can generates substantial co-benefits in the form of pubic goods and services of high economic values. For example, the investment in central Uganda for 5 years may cost the government of Uganda around US$ 1.5 billion but this could save and generate long-term net benefits flows from those investments of about US$ 13.2 billion per year (Munyuli, 2010). It is important to ensure that people who benefit from a particular ecosystem service compensate those who provide the service, giving the latter group an incentive to continue doing so. This calls for making a wide-country strategy for pollinator biodiversity ecosystem service conservation for sustainable development of the agricultural sector. Such a program require setting a national program that can remunerates small-scale farmers who invest in protection of natural and semi-natural habitats that are reservoirs of pollinators and for providing carbon sequestration and hydrological (watershed protection) services as well as for preserving on-farm biodiversity and landscape beauty. Other strategies for conservation of pollinators and services in agricultural landscapes may include:

1) Development of human resources, institution strengthening and grass-root communities' capacity building in pollination management (for example “meliponiculture”).
2) Empowering farmers and extension service agents with basic knowledge on pollination services management through establishment of “farmers' field schools” and demonstration programs to disseminate best pollinator–friendly farming practices.
3) Reviewing curricular of formal education system to integrate pollination aspects. There is a need for the scope of agricultural education to include pollination in a more thorough-going manner, including the role of wild pollinators and the management actions, costs and benefits needed to promote their services.
4) Strengthening research and development institutions by investing in training in pollinator taxonomy and management at all levels.
5) Mainstreaming and increasing mechanisms for information-sharing that fully engage various public actors, scientists and farmers.
6) Promoting public awareness and education about the importance and significance of pollinators for crops yield stability and food security.

Raising public awareness by growing advocacy campaigns and education initiatives about pollinators and their economic values can also contribute to the conservation of pollinators in rural landscapes. Awareness campaigns aim at obtaining a change in farmer behaviour towards the increased friendly-farming practices for the conservation and utilisation of bees for their pollinating services. Influencing the change of attitudes of farmers, towards consideration of pollination as a “free service” granted by nature through increase of farmers' level of awareness about the role of pollinators in increasing crop yields and revenues can also be very important in mainstreaming conservation of pollinator in farmlands. Farmers need to be trained on how to protect the bees in the farmland, particularly on how to conduct local and landscape management of natural and semi-natural habitats and vegetation structures found within surrounding agricultural matrices. Local institutions strengthening and regular community training workshops for different categories of stakeholders should be conducted in order to increase awareness on importance of bees and other pollinators.

Policies for conservation of pollinators in agricultural landscapes

The socio-economic and ecological importance of pollinators and the issue of their declines around the world have not been recognized in most mainstream research and development efforts. Because the needs of people must be balanced with the needs of preserving species and ecosystems, strategies and incentives (derived from scientific evidences) have to be developed for the public (including farmers), policy-makers and decision makers ;and implementers must be convinced that managing and conserving pollination services in agricultural landscapes will have large economic payoffs in the future. For that, scientific community needs to respond to policy needs by increasing communication of scientific findings to decision-makers in a range of policy processes and media accessible and easily interpretable by policy-makers. Interactions between scientists and policy/decision-makers should be increased through convening regular communication and dialogues between these two groups. In this way, scientist can fill the gap in knowledge about pollination services and bring emerging issues to the attention of policy-makers. This also require to build pollination capacity to support scientific contributions to policy processes, and to mainstream pollinator biodiversity services for human-well-being into policy processes in Uganda. It is also important that farmers, extensions workers, land managers and policy makers are better informed of economic values of pollinator biodiversity, so that they can appropriately account for and address pollination services in their decision-making processes. Apparently, most people including farmers and policy makers are generally unaware of the services pollinators provide to natural and agroecosystems in Uganda. To effectively address this issue, it is necessary to bring pollination concerns into the policy, research and development mainstream through promoting their integration into agricultural research policies, extension and outreach activities. However, getting bees and butterflies into policy-mainstreaming is not easy. There is a dearth of information for promoting awareness among planners and policy makers. Sustainable conservation of pollinators needs development of policies at individual farmer, community, national, regional, and global levels (Byrne and Fitzpatrick, 2009). Hence, the need for influencing modification of current public policies and institutions and stimulate the formulation of new public policies that largely address the issue of pollinator diversity protection in rural landscapes.

Promoting institutions reforms and policy changes is needed for the protection of pollinators in agricultural landscapes in Uganda in most sub-Saharan Africa countries. Policy changes that address the roots of problems and protect people's rights are always much needed. Taking into account knowledge, need and production targets of farmers when formulating public policies can largely favour pollinator populations and services conservation in rural landscapes of Uganda. The incorporation of farmers' local/indigenous ecological knowledge, practices and experimentation is advantageous in efforts to formulate policy that encourage pollinator biodiversity conservation and sustainable use. A farmer-friendly approach is essential to the successful implementation of change. An understanding of farmers' knowledge and incorporation of their strategies and local indigenous knowledge can enhance or increase the chances of success. Also, policy changes that benefit the public, especially the poor farmers are likely to have strong impact. Therefore, development of locally-adapted pollinator conservation policies requires collaboration of scientists, entrepreneurs, policy-makers (politicians) and educators to enhance their adoption by small-scale farmers in Uganda. Thus is a need to make policy makers and other stakeholders to understand that conserving pollinator biodiversity and agricultural production development are naturally linked. People need to be informed about the strong links between agriculture, biodiversity protection, and incentives should be developed to make people appreciate the value of biodiversity for livelihoods improvement/maintenance and economic prosperity. Once decision makers are made aware of the value of pollination services, they are likely to make decision that promote environmentally sound farming systems, particularly those decision that take into account the valuable knowledge of traditional agriculture in the use and preservation of agro-biodiversity. Globally, it is recognised that, on a practical level, conservationists and land managers have few guidelines for pollinator management plans and no d irect policy framework in place to introduce them and to conserve plant-pollinator systems. Policy-makers that are more likely to include pollination services within existing sectoral and governmental legislation, thus mainstreaming of pollinators into existing policies at global, regional and national levels are supportive (Byrne and Fitzpatrick, 2009). Because pollination service is very critical for food security in Uganda, they therefore, deserve special attention from local policy/decision makers. There exist several policies in Uganda that can take care of pollination services, but they lack specific pollinator conservation measures.

The current policy frameworks implemented under various sectors do not have strong measures for the protection of pollinators. these include among others, the National Forest Policy, National Environmental Policy, National Wetlands Policy, Plan for Modernization of Agriculture in Uganda (PMA), and National Biodiversity Strategy and Action Plan. At the national level, a strategy for the integration of pollination and pollinators into national biodiversity strategies and action plans (NBSAPs) is of paramount importance for on-farm biodiversity protection, crop yields stability and livelihoods improvements. Effective strategies to incorporate pollinators into national plans would emphasise their roles and services delivered and improve the chances of effective enforced conservation strategies. Reviews of different laws, acts and regulation measures under these different policies to incorporate laws, rules and regulations for the protection of pollinators in farmlands are needed. There is also a need to review agricultural research and investment policies aimed at developing specific guidelines for conserving pollinators in agricultural landscapes. In order to cater for the interests of various stakeholders, such reviews should involve: (i) raising public awareness, (ii) balancing the interests of multiple stakeholders when setting policy-priorities, (iii) engaging public participation in science-policy dialogue throughout the process.

DISSEMINATION STRATEGIES OF INFORMATION ON POLLINATORS

Although, there is still much to be learned about how to convey scientific knowledge in user-friendly language to rural and urban audiences (Frankie et al., 2009a, b) several dissemination strategies of information on pollinators can be used to promote the development of an informal pollinator-friendly policy in addition to the formal policy for the conservation of pollinators in agricultural landscapes. There is a need for scientists in Uganda to organize and communicate their evidences in ways that will be useful not only to other scientists, but to others stakeholders involved in the policy process. Involving some investors and businessmen in the research process may be significant since many of these businessmen are in permanent dialogue with politicians and leaders. For example, involving Mukwano industries company (company dedicated in the production of all types of vegetable cooking oils among others) in an experiment aiming at assessing the relevance of bees to palm oil, groundnut, sunflower and sim-sim (*Sesmum* sp.) can be very relevant, particularly if the experiments can lead to highly derived monetary benefits. Establishing and maintaining a pollinator database that is accessible by all can be very relevant. Also, publishing leaflets (targeting different audience) with contribution of different pollinator taxa (species) to the economic value of different crops (particularly those interesting the industrial sector) can create an investment opportunity for the conservation of pollinators in Uganda. Creating such market incentives mechanisms can also significantly promote pollinators importance awareness. Certification and labeling represents a regulated market mechanism with the potential to stimulate ecologically based agricultural research, extension and investment. Ecolabelling has the potential to promote the adoption and increase of consumption of agricultural products free of pollution. Labeling crop products as products obtained after natural pollination by wild bees can increase consumption provided public awareness is prior created (Munyuli, 2011). Also, market-based ecolabels can promote on-farm conservation for a wide variety of species diversity, ecosystem services and other ecological settings.

Successful ecolabeling campaigns and certification of pollinator-safe agricultural products such as fruits, vegetables and legumes will contribute significantly to the protection of pollinators in Uganda, particularly when consumers will be buying agricultural products with a label "pollinator-friendly product", just as it is currently done for "organically produced food products" in supermarkets worldwide". To achieve such an objective, there is a need for scientists to collaborate or liaise with businessmen, advertising agencies particularly those involved in "organic labeling" or agencies and private organizations involved in" food certification labeling" to catalogue pollinator produced crops. Such organizations can be empowered to develop and provide certification for a pollinator protector label. There is also a need to create a mechanism that bring together "seekers and providers" of pollinator goods, services, raw information/data on pollination management. Such actions are also important, and they should be of major priority for the benefit of informing policy makers at national level.

MONITORING POLLINATOR COMMUNITIES IN RURAL LANDSCAPES

Pollinator decline has been declared worldwide. There are several drivers both environmental and anthropogenic that are causing erosion of bees in the world including Uganda. In fact recent bee surveys conducted in central Uganda (Munyuli, 2010) suggest potential previous (historical) non documented decline in bee species and numbers in Uganda. Pollinators are critical to agriculture in Uganda. Pollinators are critically important for healthy and productive agriculture on which the majority of population depends on in Uganda (Munyuli, 2010). A high number of crops grown in Uganda depend on pollinators, mainly bees. Some crops like cucurbits, passion fruits and water melon require the visit of certain specialized bee species to be able to set seeds/fruits. The disappearance of these key bee species may cause yield failure in these crops leading to high food insecurity. It is therefore important to develop basic protocol for conducting faunistic surveys, research and monitoring of pollinators in natural and agricultural landscapes in Uganda. It is important to develop, invest and implement monitoring survey programs for the protection of pollinators in Uganda. Developing a basic guideline to monitor pollinators will help in maintaining spatio-temporal stability of crop yields by preventing further bee declines. Developing monitoring guidelines can also help in alerting policy makers to develop their own strategies to help in reducing/avoiding/preventing total disappearance of pollinators in local environments. A well developed monitoring program would help in regularly updating the public and policy-makers on the status and trends of pollinators in Uganda.

Major aims of such a program would be: (i) to detect differences in bee diversity and population density in disturbed and undisturbed habitats over time across all ecological and climatic zones of Uganda, and (ii) to detect changes and evaluate native population fluctuations (trends and patterns) and (iii) to guide decision-making for pollination services conservation actions, practices and management. The monitoring program should be designed to collect data across all climatic and ecological zones of Uganda. Key parameters to be collected during the monitoring process include: (i) landscape, land-cover and habitats (land-uses) data, study site geographic coordinates, (ii) response variables (pollinator species and population densities), (iii) pollinator species foraging behaviours and activities and efficiency, (iv) floral resources abundance, (v) local, landscape, anthropogenic and environmental drivers, (vi) meteorological data (macro-climatic and microclimatic factors), and (vii) socio-economic factors and farmers perceptions and attitudes. Research- intensive field surveys (1 to 4 years) and extensive monitoring programs (>5 years) are keys to produce baseline information and ensure the future of sustainable management of pollinators and services in Uganda. Long-term monitoring of pollinator populations in specific areas or sites is important for assessing pollinator diversity and abundance patterns that may be affected by nearby anthropogenic activities or by land-use/climate change. Monitoring of pollinators in specific sites and regions (north, eastern, western, southern) can also provides information on changes in species diversity and abundance, especially in areas close to intensive human habitation (Byrne and Fitzpatrick, 2009). Pollinator monitoring programs should include information on anthropogenic measures such as nearby human population increases, type and amount of natural habitats destroyed in immediate vicinity of monitoring sites, and whether suitable bee-floral and-nesting resources remain intact or are added subsequent to disturbance/removal of natural habitats. This information is important for interpreting impacts of human activities on patterns of pollinators and their services (Frankie et al., 2009b).

Spatio-temporal pollinator species richness and population variability and drivers of the variability are essential to monitor in order to understand responses and degree of vulnerability (susceptibility) of species and individuals to pressure and disturbance regimes; such information is critical for setting effective conservation and management strategies. Overall, monitoring (changes in response to disturbance) is essential to understand responses and for assessing the effectiveness management practices. The sampling frame in such a monitoring should be designed to cover as much as possible all different ecological/ climatic zones of Uganda. Systematic sampling should be required in pollinator monitoring programs in Uganda. It may be desirable to have a monitoring program with sampling efforts and frequency of monitoring clearly defined to achieve pre set objectives. For example monitoring activities carried out on a bi-annual basis across sites, dry and wet seasons in each ecological/ climatic zone may yield good data collection. Sampling should be using line transect or belt methods in combination with pantrapping, handneting and visual observation methods in all monitoring work to assure quality data. There is a need to develop permanent or regular monitoring programs using classical/standard methods and tools for pollinator biodiversity surveys. Such programs need to follow standard sampling protocols for different pollinator taxa and their drivers. For example, bee monitoring programs may involve, netting bees at flowers, pan trapping and transect-counting. Monitoring activities can only be carried out efficiently by developing or building research capacity. There is thus a need to empower current researchers and research organizations to carry out pollinator monitoring activities.

A national pollinator monitoring program is necessary in Uganda (as well as in other sub-Saharan African countries) in order to document patterns in the communities of pollinators occurring in different ecological zones of the country. This call for pollinator specimens should be identified and stored in the museums. Cybertaxonomy, digital methods (for example lucid keys) for rapid species description and DNA barcoding work can be easily facilitated by good collection of specimens from diverse biogeographical zones of the country. After all regions of the country are surveyed and mapped for their richness and abundance in pollinators, a national checklist can be developed, as well as simple identification keys, guides, leaflets targeting different audiences. These should be disseminated widely using available media and dissemination networks. There is a need to develop monitoring program that is back-stopped by the creation of good database managed by well trained database managers. Running a pollinator monitoring program in Uganda may requires that not only well trained database managers are available but also it may require (apart from field and laboratory equipments) great investment in training and capacity building in pollinator systematic using morphological and molecular techniques. A national database system for pollinators can be developed based on the national checklist. Bioinformatics development is strongly backed by the development of database of good quality. For example, space should be created to accommodate pollinators in the national biodiversity databank at Makerere University. Such scientific collections can provide the primary scientific evidence for the existence and identification of different species, and possess reliable documentation of past extinctions. In the future, the database can be used to provide information on abundance and distribution of different pollinator species and some insight about the history of the areas of collection, as well as enabling diagnosis of past drivers of pollinator communities.

Making museum collections is one of the ways of linking taxonomy to conservation and livelihood improvement. Once the information is well collected and stored in museums, it is possible to mobilize that taxonomic information to support human well-being and ecosystem health through field visits, demonstration, and training of farmers, extension workers and parataxonomists. Taxonomy is a field in which it is often difficult to attract new or young researchers, yet this is important as taxonomic capacity is essential to pollinator identification, conservation and management. There are a number of dimensions to the challenges that need to be addressed in a targeted effort to surmount the taxonomic impediment: the adequacy and accessibility of identification services, the status of taxonomic knowledge, the provision of tools to assist non-experts in identification. Most museums charge fees for identification services. Currently, there is increasing recognition that support for taxonomy and identification services are legitimate and critical components of pollinator biodiversity conservation programs in Uganda and in Sub-Sahara Africa. Training field data collectors and taxonomists and parataxonomists is therefore important to mitigate taxonomic impediments. Having fully employed researchers working on different pollinator taxonomic matters can also be very important, although difficult to achieve. So far, there is no professional pollinator taxonomist in Uganda and building taxonomic capacity is a long-process. However, Uganda need to build capacity to carry out surveys (inventories) of pollinator diversity and distribution in order to optimize their management, through, inter alia, the training of taxonomists and parataxonomists of bees and other pollinators.

There is also a need to promote applied research on pollination in agricultural ecosystems through massive training of postgraduates. Pollinator conservation should be integrated into agroecosystem research and policy. This requires the strengthening national research institutes and universities to promote and support taxonomy of bees and other pollinators. The development of partnerships of stakeholders can also promote taxonomic capacity building for the conservation of pollinators in Uganda. Funding and teaching to increase the taxonomic capacity is very fundamental in developing strategies for pollinator conservation (Eardley et al., 2009). An important step in building capacity is the development of targeted educational and outreach materials for dissemination. Internet can be used as an important tool in aggregating and facilitating information sharing appropriately (Byrne and Fitzpatrick, 2009). Finally, the development of taxonomic expertise and research networks, and the sharing of ideas, with the effective utilisation of the internet, is generally encouraged as a tool to effectively obtain pollinator conservation (Byrne and Fitzpatrick 2009; Eardley et al., 2009) becoming a reality in Uganda and in other sub-Saharan African countries.

POLLINATOR-UNFRIENDLY FARMING PRACTICES

Use of pesticides

Pesticide application causes a lot of damage to wildlife and ecosystem biodiversity (Tegtemeier and Duffy, 2004). They are capable of completely destroying both honey and wild bee populations because of their degree of toxicity to Apoidea (Pimentel, 2005; Shuler et al., 2005; Brittain et al., 2010; Chauzat et al., 2011). The annual external cost of honey bee and pollination losses from pesticide applications in USA was estimated to be of US$ 409.8 million in 2002 (Tegtemeier and Duffy, 2004) and of $4 billion in 2005 (Pimentel, 2005). Like other beneficial insects, bees respond negatively to various types of pesticides (herbicides acaricide, fungicide, insecticide, nematicide, molluscicide, etc), they are positively sensitive insecticides (carbamates, nicotinoids, organophosphates, carbamates, endosulfan, paraquat, organochlorines, organophosphates, pyrethroids, etc) although different insects including bees present different degree of sensitivity to individual insecticides (Maini et al., 2010; Chauzat et al., 2009). Although pesticides are documented to be potentially the most damaging agrochemicals for pollinators (Byrne and Fitzpatrick, 2009; Scott-Dupree et al., 2009; Batley and Hogendoorn, 2009; Valdovinos-Núňez et al., 2009; Freitas et al., 2009); little is known about the impacts of pesticides (and pest management programs used in pre-and post crop blooms) on different wild pollinator species in the field in Sub-Sahara Africa. The effect of insecticides on pollinator populations has not been documented in Uganda, but some social and solitary bees are estimated to be currently under threat in the country (Munyuli, 2010). For example, the application of permethrine for control of mosquitoes is highly poisonous for honey bees and stingless bees that are abundantly found in farmlands of Uganda. Insecticide (for example Malathion, Diazinon, Dimethoate, Cybermetrin) applications reduced the number of species and the total numbers of individuals after spraying watermelon and cowpea in Kumi district in Uganda in 2007.

Pesticide poisonings of pollinators is a serious problem in areas where people are using systematic spray of insecticides to control mosquitoes and crop pests in Uganda (Munyuli, 2011a). Practically, over-use of pesticides (insecticides/herbicides/fungicides) can lead to pollinators' demise. The conservation of pollination systems involves also minimizing agricultural chemicals (Byrne and Fitzpatrick, 2009) by increasing recognition by small-scale farmers of pollination as an agricultural input to crop productivity along with pesticides, herbicides and fertilizers. The type, quantity and time of pesticide application as well as the application regimes have significant impacts on pollinator populations and species richness at different spatio-temporal scales. Minimizing hazards to beneficial insects from agrochemicals may include limits of application rates, timing, scale and methods. Insecticide application before crop bloom has ceased is likely to have a greater impact on social bee species than on the solitary species (Tuell and Isaacs, 2010). Also, wise use of pesticides consist of timing the period of use and or using them when necessary to reduce intoxication of pollinators (bees) visiting the targeted or main crop/plant species. Even when, natural pesticides such as essential oils and related agrochemicals, have to be applied to control crop pests, there is a need to conduct more research to find out how these different effective pesticides can influence pollinator foraging behavior (flight intensity, visitation frequency, etc) and effectiveness (Abramson et al., 2007) in rural landscapes of Uganda. Currently, there is a need for wise and judicious use of pesticides (insecticides, fungicides, and herbicides) by farmers can help in avoiding extirpation/decline of pollinators in agricultural landscapes in Uganda. It is recommended to farmers to use pesticides only when necessary and incorporate other non-chemical management practices when available. Among farming practices that can lead to great control of pests and enhance field pollination visitations, there is "application of biological control agents" (Maini et al., 2010). The application of organic product and biological control (natural enemies) may help to control several crop pests and cause no harm to pollinators. Management practices that enhance beneficial insects are likely to be beneficial to pollinators. In other words, habitat manipulation to enhance ecological services provided by beneficial insects can also enhance pollination services delivery in the field. Not only that the wise use of insecticides is advocated for but also it is generally recommended to avoid the use of broad-spectrum insecticides. Selecting least toxic insecticides for application during times of the growing season, when insect pollinators are not exposed, can lessen the impact of the insecticide application. If possible, insecticide applications should be avoided during plant bloom periods to minimize insecticide poisoning. Using pesticides at times when pollinators are likely to be not active in the field is a key to sustain and maintain viable population of bees in agricultural landscapes in Uganda. It is important for farmers to know when to expect bees to be foraging on a crop so that if pesticides are needed to be applied, pollinator-pesticide interactions can be reduced. This requires having good knowledge of foraging peak time of important pollinators. In other words, it is important to known the exact time interval of the day when the greatest density of different bee species can be recorded on the crops (Wang et al., 2009). It is generally recommended that if spraying must be done during the blooming period, then applications should be restricted to the period after dark or very early morning in order to reduce mortality to diurnal bees that may be visiting the blooms (Mineau et al., 2008).

In central Uganda, pesticide applications should be safely applied before 06:00 h and after 19:00 h as recommended (Nderitu et al., 2007). Daily activity patterns and seasonal phenology may also determine the level of risk of bee exposure to pesticides and other agrochemicals. Alternating the timing of pesticide application from mid-day to early morning or late evening can ensure that the window of maximum toxicity does not overlap with the times when bees are foraging on crops. Insecticide application timing and spraying regimes are important factors determining the relative vulnerability of different pollinator species (Brittain et al., 2010). Farmers may apply pesticides at different times of the day (early morning or late in the evening). However, it is likely that early applications can pose a greater threat to flower visiting insects than to late (evening) applications. Overall the application of pesticides that are toxic to bees may be recommended for evening periods than in the early morning periods of the day because in Uganda, most pollinating species are more active in the early morning hours than in the evening moments of the day. In summary, farmers from Uganda and sub-Sahara Africa can reduce risks to pollinators from pesticides by choosing the appropriate pesticides and by not using insecticides that are toxic to bees on flowering crops and by and adopting integrated pest management (IPM) technologies to minimize the unnecessary use of agrochemicals to reduce the decline of wild and managed bees in local agro-ecological zones (Maini et al., 2010). Herbicides are considered relatively not very toxic to honeybees (Roy et al., 2003) but can have an indirect effect on native bee communities. Although insecticides do vary in toxicity towards bees, most of them induce mortality or sublethal effects for foraging bees; whereas herbicides eliminate weed species which may be important sources of pollen and nectar for native and managed bees (Cuthbertson and Brown, 2009).

Herbicide use reduces the amount of nectar and pollen available by killing wild flowering plants and also by causing displacement of nectar-and pollen-rich plants by herbicide-tolerant plants that are not rich resources for bees. Maintaining the abundance of wild flowering plants in the open edge areas around fields may help in mitigating the effect of herbicides within farms. Avoiding herbicide spraying can be achieved. Controlling weeds with herbicides when typical pollinator-food plants are not in flower can be an ideal farming practice. Similarly, modifying the types and application regime of herbicides can facilitate the maintenance of diverse flower communities within intensive agro-ecosystems. Chemical weeding regimes should be carefully practiced and minimized. It is important for farmers to apply hand hoe-weeding of their farms. It may be more useful for farmers to alternate their weeding activities by dividing the field into several plots that are weeded at two weeks interval to avoid pollinators missing food in the field. Such a weeding strategy may be important to be applied, particularly when crops are not in bloom in cropping systems with perennial crops (for example coffee-banana agroforestry system).

Cultivation of genetically modified crops (GMOs)

Genetically modified (GM) crops are becoming an increasingly important feature of agricultural landscapes, particularly in developed countries (Conner et al., 2003). The effects of genetically modified (GM) crops on bees have been largely reviewed (Aviron et al., 2009b; Prendeville and Pilson, 2009; Malone and Pham-Delègue, 2001; Ramirez-Romero et al., 2008). Crops modified for insect resistance could harm bees if the relevant proteins are both toxic to bees and expressed in pollen. Several GM crops have been introduced in the African environment with and or without consent of local leaders and populations, through humanitarian NGOs distributing seeds as food aid but that at the end being cultivated/ grown by local farmers. Much as no studies has been conducted to assess the status of GM crops in farmlands compared to local landraces, there is a concern that these GM crops are widely being distributed in many villages in Sub-Sahara Africa and in Uganda. Growing genetically modified crops is likely affecting negatively the effectiveness of beneficial insects including pollinators and bees in Uganda. It is advised to farmers to slow the adoption and utilization of genetically modified seeds they receive through humanitarian agencies as seed aid. Research is needed also needed to assess the potential impact of GM crops on beneficial insects including bees before they are released to farmers by humanitarian organizations and related extension agents.

Introduction of alien invasive species

Alien species are recognised as important drivers of global environmental change (Kenis et al., 2009; Shapiro, 2002; Hanley and Goulson, 2003; Parker and Engel, 2002) because of their widespread effects on agriculture, forestry, fisheries, human health, and natural ecosystems (Eardley et al., 2006; Vilà et al., 2009; Pejchar and Mooney, 2009; Parker and Engel, 2002; Totland et al., 2005; Crowl et al., 2008; Kadoya et al., 2009; Padrón et al., 2009). However the effect of alien mutualists on the architecture of plant–pollinator webs remains largely unexplored (Aizen et al., 2008). Most alien invasion species affects pollinator behaviour (for example flower visitation rates, switches to alien flowers) and pollinator populations and diversity (Bartomeus et al., 2010; Morón et al., 2009; Morales and Traveset, 2009; Montgomery et al., 2009). Because pollinators perform a vital ecosystem function, impacts of alien species invasion can have knock-on effects on entire communities (Dohzono and Yokoyama, 2010; Walther-Hellwig et al., 2006). There exist, direct and indirect impacts of invasive alien species (focusing on plants and insects) on native bees worldwide (Stout and Morales, 2009). Valuable resources (nectar and pollen) provided by invaded plants may be inappropriate for some native pollinators morphologically (pollinators may not be able to access rewards from flowers), physiologically (they may be nutritionally poor, or even contain toxins and phenologically (there may be temporal miss-matches between flower rewards supply and native pollinator demand), (Nienhuis et al., 2009).

Alien plant invasion can cause a change in the native plant community by altering the spatial distribution of floral resources or even displacing important native plant species (Memmott and Waser, 2002) invasive alien plants have the potential to indirectly impact both generalist and specialist taxa that utilise these native plants (Stout and Morales, 2009; Livanis and Moss, 2009). Invasive Africanized honey bee is known to impact on native solitary bees (megachilds, C*entris*) in Mexico (Roubik and Villanueva-Gutiérrez, 2009; Goulson et al., 2002) through competition that has caused changes in local pollination ecology (shifts in floral hosts by native bees). Invasive species have destructive effects on biodiversity due to competitive exclusion of native species for floral resources (Paini, 2004; Moritz et al., 2005). Invasive bee species can lead to decline of native bee species through strong competition for flower resources and nest sites utilization (Inoue and Yokoyama, 2010; Goulson and Sparrow, 2009; Steffan-Dewenter and Tscharntke, 2000; Flanaganet et al., 2011; Dohzono and Yokoyama, 2010; Goulson, 2003a, b; Shavit et al., 2009; Lach, 2008) in natural and rural landscapes. Because of the negative effects on plant-pollinator interactions, farmers from Uganda (and farmers from other parts of Sub-Sahara Africa) are encouraged to identify and eliminate invasive plants in their gardens. Research is also needed on the potential interacting effects of invasive species with climate changed on pollinators and crop yields.

CONCLUSION AND POLICY/RESEARCH RECOMMENDATIONS

Much as pollinators (bees) are known to pollinate most of the world's wild plant species and provide economically valuable pollination services to crops, their knowledge of strategies for conservation biology, lags far behind other beneficial taxa such as parasitoids and predators (Winfree, 2010; Menz et al., 2010) in Uganda and in most sub-Saharan countries. The objective of this mini-review was to provide landscape and habitat management strategies for the conservation of pollinators and their services in rural landscapes. A list of conservations strategies and practices were listed and described. These conservation strategies may guide the creation and conservation of "protected areas for pollinators" or "pollinator corridor zones" managed within farmed landscapes in Uganda and in Sub-Sahara Africa. No laws or policies directly address the conservation of bee pollinators in Uganda. However, national environmental management policies and policies governing protected areas are recommended to play a key important role in conservation of bees. Developments of good agricultural practices codes, standards and regulations were found to be likely to be promising since such practices may help to protect bees and butterflies in farmlands of Uganda.

Critically needed landscape and habitat management strategies for the conservation of pollinators and services in Uganda include and in sub-Sahara Africa: (i) the protection from degradation forest fragments and semi-natural habitats (fallows, hedgerows, field margins, roadside, woodlands, grasslands, forest plantations), (ii) increasing landscape and habitat connectivity/heterogeneity, (iii) field manipulation of plants and habitats for spatio-temporal provision of good nesting sites and floral resources to pollinators (forage management to ensure the bees have nectar and pollen all year round), (iv) encouraging farmers to adopt pollinator-friendly farming practices (increasing percentage of on-farm trees cover, judicious application of pesticides, management of pesticide sprays to avoid bee poisoning, avoiding the destruction of pollinator refugia, keeping uncultivated 20 to 30% of the farm as pollinator reservoir, avoiding the introduction of alien invasive species and the cultivation of genetically modified crops; practising multi-purposes simple, complex traditional agroforestry systems, etc); (v) provide water to bees and managing bee pests and diseases, (vi) awareness-raising among local people to increase their understanding of the value of conserving wild bees, (vii) sensitizing policy-makers, land-use planners, forest managers about importance of protecting pollinators for crop productivity and ecosystem health enhancements, livelihood improvement and food security strengthen, (viii) llaunching awareness campaigns for grass-root communities (farmers) about the importance of conserving pollinator for crop yields and food security, (ix) advocating for policy-changes and for development of national policy that address properly the issue of sustainable conservation of pollinators in agricultural landscapes, (x) building taxonomic capacity and develop a good monitoring plan, (xi) develop good communication strategy to disseminate information on pollinators to the public, and (xii) setting rewarding schemes for pollination services providers. These proposed conservation strategies are valid for other African countries, particularly those located around the equator and with similar rural environmental characteristics (Kenya, Tanzania, DRC, Ghana, Nigeria, Gabon, Cameroon, Congo-Brazzaville, Togo, Benin, Rwanda, Burundi, Angola, etc).

The lack of public awareness on roles of pollinators to agricultural and ecosystems health makes it difficult for governments and other agents to support pollinator related projects. However, conservation of pollinators is necessary for food security, poverty alleviation and biodiversity in general. In order to conserve Ugandan bees, there is a need for information on all these aspects. For example, there is a need to attract public interests and attach economic values to pollination services. Such information will help governments, policy makers, researchers and the general public to contribute to mitigate the impacts of loss of pollinators in the country. Making farmlands more suitable for pollinators benefits both agriculture and nature conservation (Carvalheiro et al., 2010). There is a high economic gain for farmers to adopt pollinator-friendly practices in crop production systems. Striking gaps in pollinator conservation, restoration and management are immense (Winfree, 2010). Briefly, there is a clear need for studies of bees and climate change in relationships to different conservation strategies above listed in order to develop effective mitigation measures. There is also lack of basic scientific information about the population biology of different bee species in different regions of Uganda. It may be interesting to have a life table analysis or population viability analysis for different bee species (need to know the reproduction behaviour of different bee species). The effectiveness of a habitat management strategy/restoration in conserving bee biodiversity and enhancing other ecosystem services is needed to be conducted to provide important information for conservation planning and policy (Winfree, 2010) in Uganda.

More research will be greatly needed in many agro-ecological zones of Uganda to determine the effectiveness of different strategies and options available for the conservation of pollinators in farmlands, looking at few parameters such as comparing basic pollinator population biology, ecology, reproduction, nesting opportunities and spatio-temporal availability of floral resources; as well as determining/identifying drivers of pollinators in these habitats and develop a map of distribution of disturbance-sensitive bee species at the national levels. There is also a need for deep investigations about the effects of different pesticides, genetically modified, climate change, global (regional, local) environmental change on pollinator diversity, effectiveness and pollination services delivery to crops and forecast these changes over time and the consequence for food security and livelihoods. Social and economic drivers behind farmers' decision to adopt pollinator-friendly farming practices need to be examined for proper planning of effective conservation of pollinators in rural landscapes.

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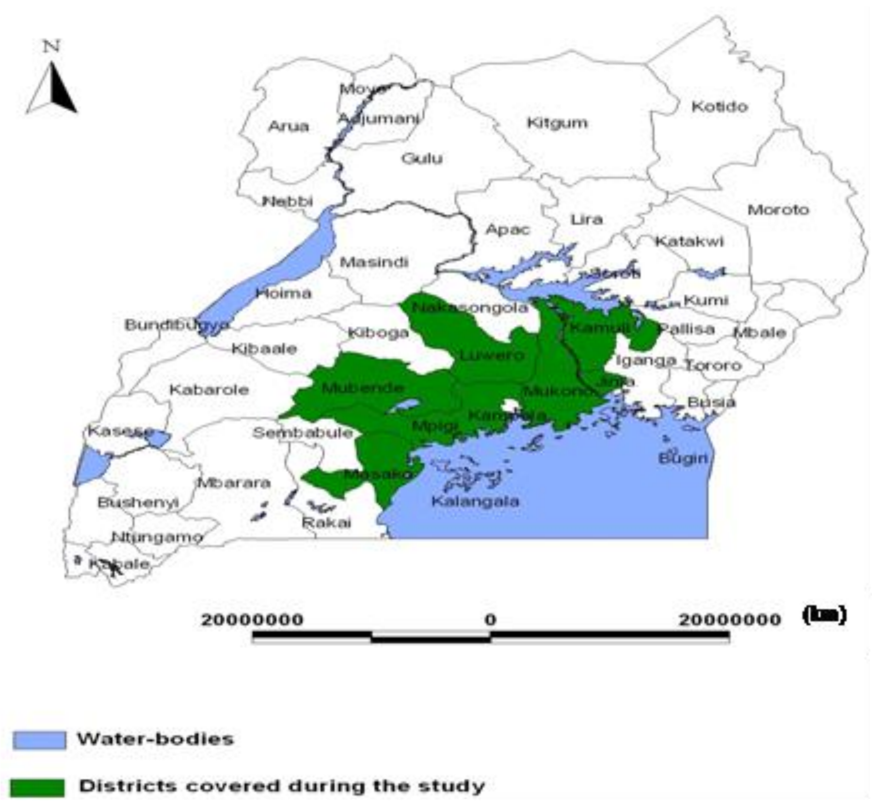
Appendix 1. The 2006 to 2008 study was conducted in the banana-coffee system of Lake Victoria Arc covering various districts in central Uganda (Figure 1). The Lake Victoria Arc is characterized by ferrisoils with high to medium fertility level and receives on average 1000 to 1800 mm of rains on a bimodal pattern (rainy seasons: March to May, September to November; semi-dry to dry seasons: June to August, December to February) with 22 to 28ºC and 60 to 75% of mean annual temperature and relative humidity respectively. The study zone belonged to the Lake Victoria phytochorion with shrubs of *Acacia* spp, legume trees, melliferous plant species, *Papyrus* and palms ranging from 2 to 15 m high dominating the remnant secondary vegetation. Several oily, food and cash crops are grown, mainly cassava (*Manihot esculentum* L.), sweet potato, (*Ipomoea batatus*, L.), maize (*Zea mays*), beans (*Phaseolus vulgarus* L.), groundnut (*Arachis hypogea* L.); tomato (*Lycopersicon esculentum*), watermelon (*Citrullus lanatus*), pumpkin (*Cucurbita moschata*), cucumber (*Cucumis sativus*), melon (*Cucumis melo*); chilies (*Capsicum* spp.), and several other fruits, vegetables and horticultural crops (cabbage, onion etc, egg plants, sim-sim, etc). The majority of these crops are grown in small-scale monoculture and or polyculture fields that are integrated into the coffee-banana agroforest production systems where coffee and banana are the heading corps.



Appendix 1. Districts of Uganda covered during the course study conducted from 2006 to 2008.

Coffee (*Coffea canephora*) is the cash crop of economic importance at national level, mainly produced in this region, while banana is the main staple food crop. However, some large commercial monocultures and Estates of industrial crops (tea, sugar, and coffee) are found in the study zone. Traditional agroforestry systems found here are those with multipurpose tree species such as avocado (*Persea americana*), papaya (*Carica papaya*), mango (*Mangifera indica* L.), jackfruit, citrus trees, anonas (*Annona* spp.). These tree species are maintained in simple and complex traditional agroforestry systems (integrating several native/indigenous tree species and forest remnant species), indicating the diversity of farming systems in these farm landscapes. Rural central Uganda is mosaic landscape where "islands" of patches of natural habitats (forest fragments, forest reserves, wetlands, woodlands) are found scattered within agricultural matrices dominated by linear and no-linear features of semi-natural habitats (fallows, hedgerows, grasslands, woodlots, cattle pastures or rangelands) that are displayed as field boundaries of the diversity of small-scale fields. Compared to other regions (districts) of Uganda, central Uganda area is characterized by high demographic pressure, limited access to arable lands, continuous cultivation and over-exploited lands. Different study sites (2 to 4 four sites per district) were intentionally selected in the different districts based on assumptive criteria of drivers that may potentially be responsible for differences in pollinator communities across different localities found within the study area (Figure 1). A total of 26 sites were selected to represent a range of habitats types of varying degrees of anthropogenic disturbances, and management intensities. These included human population densities; farm management practices, agriculture modernization intensity (traditional small-scale farms versus large and intensively managed plantations or estates); natural and semi-natural habitats, gradient of vegetation complexity and structures (strata) found within and between agricultural fields.

Detailed environmental and landscape vegetation characteristics of the 26 sites and clusters are presented in Appendix 2. Bees and butterflies were sample in different semi-natural habitats/land-uses (Appendix 3a, plates 1-4; Appendix 3c: Plate 13 and 18) alongside line transects established in each of the the 26 study sites using 3 complementary methods (plates 19-21): transect counts, handnet, pantraps (for bees) or banana bait traps (for butterflies and moths) that lead to detection of more than 600 bee species (Appendix-5) and more than 300 butterfly species (Appendix-4); with few common species (Appeindix 3d, plates:22-23) and a high number of rare and unique species of bees, butterflies, hoverflies and moths.

Appendix 2. Characteristics of the study sites. All study sites (altitude: 800 to 1100 m above the sea levels) in the different clusters are dominated by small-scale fields that are extensively managed with exception to sites from Kaweri (Nonve, Luwunga: coffee plantations) and Lugazi (sugar plantations and Kasaku tea plantations) clusters which are large scale plantations that are intensively managed. Types of dominant vegetations and habitats found within, between and nearby (surrounding) agricultural mosaic landscapes of each study site are highlighted. These are vegetation structures (0.01 to >10 ha size) with high frequency of occurrence within the farmed landscape as observed on line transects during pollinator censuses conducted in 2006 to 2008. Eye estimation of the farmland environmental habitat heterogeneity/connectivity was done based on the number and abundance of vegetation types and microhabitats, connected or not, but frequently encountered with high occurrence on linear transects while sampling farmland pollinators (butterflies, bees).

Cluster names (mean annual temperature and rainfall). The mean data is for 8 years: 2000 to 2007	Study site names (land-use intensity gradients)	Type of dominant forest plantations and similar natural vegetation types found within and between sites	Types of dominant semi-natural vegetation found within and between study sites	Types of dominant man-made vegetations found within study sites	Type of vegetation structure strata (layers) found alongside line transects within each farm landscape study site	Estimation of connectivity and heterogeneity gradients of the different types of microhabitats as found alongside line transects within each study site	Type of natural habitats and natural forests found nearby or in vicinity of study sites
Bujaggali	Namizi-east (high)	Wetland fragments	Young fallows Grasslands, Cattle pastures	Multi-species agro-ecosystems Coffee shaded trees	Weeds/Herbs strata (ground layer)	Very low habitats heterogeneity and connectivity	
Temperature: 25.8°C	Namizi-west (high)	Forest fallows	Old fallows, Grazing fields Swampy	Complex shaded banana-coffee agroforests Multistrata agroforests	Coffee trees layer Wood/Shrub layer Coffee shrubs layer	High habitats heterogeneity and connectivity	Large swampy habitats
Rainfall: 1405.6 mm	Nawangoma (high)	Conifer plantations Pine/Eucalyptus plantations	Hedgerows, Field margins Alley cropping	Simple shaded banana-coffee agroforests Invasive tree species	Tin woody trees in the lower layer Large native trees (canopy layer)	Medium habitats heterogeneity, low connectivity	
	Bukose (high)	Woodlands Shrub-lands	Young fallows Field margins	Fruit trees Simple and diverse shade tree species	Ruderal vegetation layer Deciduous trees	Low habitat heterogeneity, Medium connectivity	
Kamuli Temperature: 25.8°C	Namulekya (high)	Wood-shrub grasslands	Young fallows	Complex shaded banana-coffee agroforests	Weeds/Herbs strata (ground layer)	Very low heterogeneity, connectivity	Large swampy habitats
Rainfall: 1405.6 mm	Naikesa (high)		Old fallows Grazing fields Swamps	Complex agroforests Fruit trees	Coffee trees layer Ruderal vegetation	Low habitat heterogeneity and connectivity	
Kalagi Temperature: 23.8°C Rainfall: 1698.6 mm	Kimwanyi (intermediate)	Eucalyptus plantations Wood-shrub grasslands	Young fallows Hedge rows Field margins Cattle pastures	Simple shaded coffee-banana agroforests	Weeds/Herbs strata (ground layer) Coffee shrubs in the upper layer	Medium habitats heterogeneity, High habitat connectivity	Large wetlands

Appendix 2. Contd.

	Kiweebwa (intermediate)	Forest fallows Swampy forest Wooded grasslands	Young fallows Hedgerows Grazing fields	Fruit trees Diverse shade trees Invasive tree species Complex agroforests	Weeds/Herbs strata (ground layer) Coffee shrubs in the upper layer	High habitats heterogeneity and connectivity	Small swampy habitat
	Bamusuta (intermediate)	Forest fallows	Young fallows Hedgerows	Complex agroforests Simple shade trees	Ruderal vegetations Coffee shrubs in the upper layer	Medium habitats heterogeneity and connectivity	
	Kifu (intermediate)	Swampy forests Eucalyptus plantations	Grasslands Cattle pastures Marshlands	Multistrata agroforests Coffee shaded trees Complex agroforests Indigenous trees	Tin woody trees/tall herbs in lower layer Coffee shrubs in the upper layer	Very high habitats heterogeneity and connectivity	Small swampy habitat Cleared forests
Masaka	Kasaala (intermediate)		Young fallows Old fallows	Simple agroforests Diverse shade trees	Weeds/Herbs strata (ground layer)	Low habitat heterogeneity and connectivity	
Temperature: 27.3°C	Katwadde (intermediate)		Young fallows Hedgerows Grazing plots	Fruit trees Diverse shade trees Complex agroforests Medicinal plants	Weeds/Herbs strata (ground layer) Coffee shrubs in the upper layer	Low habitat heterogeneity, Medium habitats connectivity	
Rainfall: 1026.3 mm	Kiwaala (intermediate)	Wood/-Shrub grasslands Grasslands	Old fallows Hedgerows Cattle pastures	Simple shade trees	Weeds/Herbs strata Coffee shrubs in the upper layer	High habitats heterogeneity and connectivity	Wetlands Forest reserves
	Mpugwe (intermediate)	Shrublands	Young fallows Old fallows Grasslands	Diverse fruit and indigenous tree species; Diverse shade trees	Coffee shrubs. Tin woody trees Tall herbs	Medium habitat heterogeneity and connectivity	
Mpigi Temperature: 23.8°C	Lukalu (intermediate)	Eucalyptus plantations Forest fallows	Young fallows Cattle pastures Hedgerows	Coffee shaded trees Indigenous tree species	Weeds/Herbs strata Coffee shrubs layer Tall herbs layer	High habitats heterogeneity, medium connectivity	Forest patches Forest remnants

Appendix 2. Contd.

Rainfall: 1698.6 mm	Mpanga (intermediate)	Forest fallows Wood-Shrub grasslands	Young fallows Grazing fields	Complex agroforests Large native trees Forest remnant trees	Weeds/Herbs strata Coffee shrubs layer Tin woody trees	Very high habitats heterogeneity and connectivity	Large natural forest reserves (Mpanga forest)
Kaweri Temperature: 24.2°C	Luwunga (very high)			Simple planted shade tree species	Coffee shrubs in the upper layer	Very low habitats heterogeneity, no habitat connectivity	Forest corridors
Rainfall: 1322.3 mm	Nonve (very high)			Diverse trees species Forest remnants	Coffee shrubs in the upper layer	Low habitats heterogeneity and connectivity	Forest corridors, Forest fragments
Mabira Temperature: 23.8°C	Bulyasi (intermediate)	Ecotones Forest fallows	Young fallows Grazing fields	Shad tree stands Forest remnant trees	Weeds/Herbs strata Coffee shrubs layer	Medium low habitats heterogeneity, but very high connectivity	Large natural forest reserves
Rainfall: 1698.6 mm	Kinoni (intermediate)		Young fallows Old fallows Grazing fields	Diverse shade trees Forest remnants Simple agroforests	Weeds/Herbs strata Coffee shrubs layer Large native trees	Low habitats heterogeneity and connectivity	
Lugazi Temperature: 23.8°C	Sugar (very high)				Weeds/Herbs strata (ground layer)	Very low habitats heterogeneity, no single habitat connectivity	
Rainfall: 1698.6 mm	Kasaku tea (very high)	Swamps Irrigation channels			Weeds/Herbs strata (ground layer)	Very low habitats heterogeneity and connectivity	Large reclaimed Wetlands
Nakaseke Temperature: 22.4°C	Kimuli (low)	Ecotones Forest clear-cuts Forest fallows	Cattle pastures Old fallows Grasslands	Multistrata agroforests Complex agroforests Semi-forest coffee trees	Weeds/Herbs strata. Large native trees (canopy layer)	Very high habitats heterogeneity and connectivity	Secondary forests; Swampy habitats
	Segalye (low)	Woodlands	Old fallows	Shade tree stands Complex agroforests	Weeds/Herbs strata Large native trees	Very high habitats heterogeneity and connectivity	Degraded natural forests
	Kyetume (low)	Woodlands	Young fallows Cattle pastures	Forest remnant trees Complex agroforests	Weeds/Herbs strata Large native trees	Very high habitats heterogeneity and connectivity	Primary and secondary forests
Rainfall: 1498.3 mm	Lukumbi (low)	Forest fallows	Young fallows Grazing fields	Coffee shaded trees Complex agroforests	Weeds/Herbs strata Large native trees	High habitats heterogeneity, Medium connectivity	Secondary forests Large wetlands

Appendix 3a. Plates showing a variety of land-uses visited by pollinators in farmlands of central Uganda: Plates 1 to 4.

Plate 1. Coffee and banana-based pollinator foraging habitats. A = banana + lablab, B = banana + cassava; C = coffee monoculture; D = coffee polyculture. These habitats are visited by bees and butterflies when they harbour blooming plants/crops.

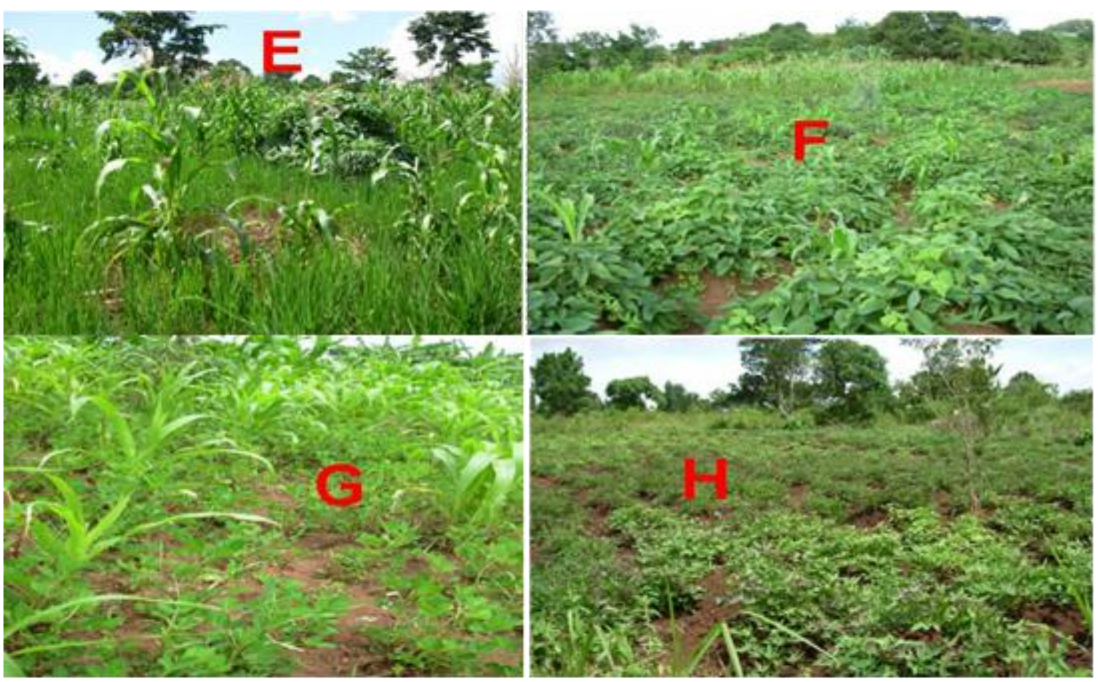


Plate 2. Polycultures crop fields. E = Rice + maize, F = cowpea + maize, G = Groundnut + maize, H = Sweet potato. These different types of crop-associations are visited by bees when crops are in bloom.

Plate 3. Small-scale grazed fields with high grazing intensity (T). These different fields grazed by cattle are visited by bees and butterflies when wild plants are in bloom.

Plate 4. Small-scale home-gardens (U). Home-garden fields are visited by bees of all functional groups and butterflies because they frequently harbour mass blooming vegetable plants/crops.

Appendix 3b. Plates showing a variety of structures used as nesting sites by Apoidea community inhabiting farmlands of central Uganda, Plates 5 to 10.

Plate 5. Sprouting stumps (standing-up stumps), dead stumps (standing-up), decomposed logs (stumps laying on the ground) and dry logs (A) that have been left un-destroyed, after forest fragments were cleared (cut) for the establishment of new crop fields. These structures are used by bees as refugia in farm landscapes.

Plate 6. Different types of standing-stumps used by bees as refugia from which they emerge to harvest crop floral resources (pollen/nectar) within and in nearby fields (B).

Plate 7. Different types of living trees with holes used by bees as nesting sites within farmlands (E).

Plate 8. House walls and wooden materials in human buildings that are used as nesting sites by different types of bees (D) mainly from *Meliponini, Xylocopini, Ceratinini* and *Megachilini.*

Plate 9. F = traditional beehives set in an old fallows; H = modern beehive set in a coffee plantations (Kaweri) to pollinate coffee G = protected termite mounds in woody vegetation are frequently preferred by stingless bees as nesting habitats; K = non-protected termite mounds are used by several solitary bees (Halictidae: *Halictus, Ceratina, Lasioglossum, Nomia, Lipotriches*).

Plate 10. Termite mounds that have been protected by farmers to favour bees pollinating crops nearby.

Appendix 3c. Diversity of nesting/breeding habitats used by pollinators (bees, butterflies, hoverflies) as refugia-habitats within farmlands: Plate 11 to 18.

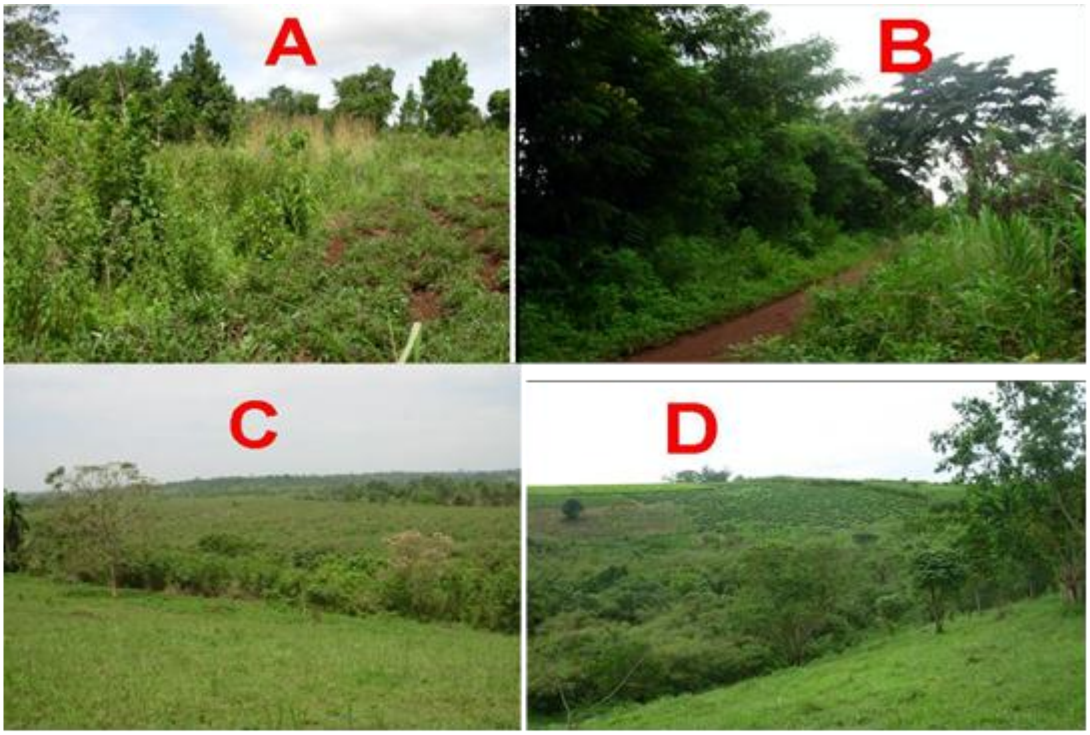


Plate 11. A = field margins (“field-sides”/“field-edges”); B = road-sides (track-sides) mainly used as refugia (nesting/breeding sites) and some time used as foraging habitats by bees and butterflies; C = wetland-edge. Sometimes, stingless bees establish their nests in leaves and flowers of *Pypyrus* sp. found at the edge of wetlands; D = swampy habitats with different shrub (*Acacia* sp.) and tree (*Ficus* sp.) are used as refugia (nesting/breeding sites) and some time used as foraging habitats by bees and butterflies.

Plate 12. Different types of linear hedgerows (L) with living trees and livestock fences (O) mainly used as nesting sites by different solitary bee species and as a breeding/resting site by different butterfly species found in rural landscapes of Uganda.

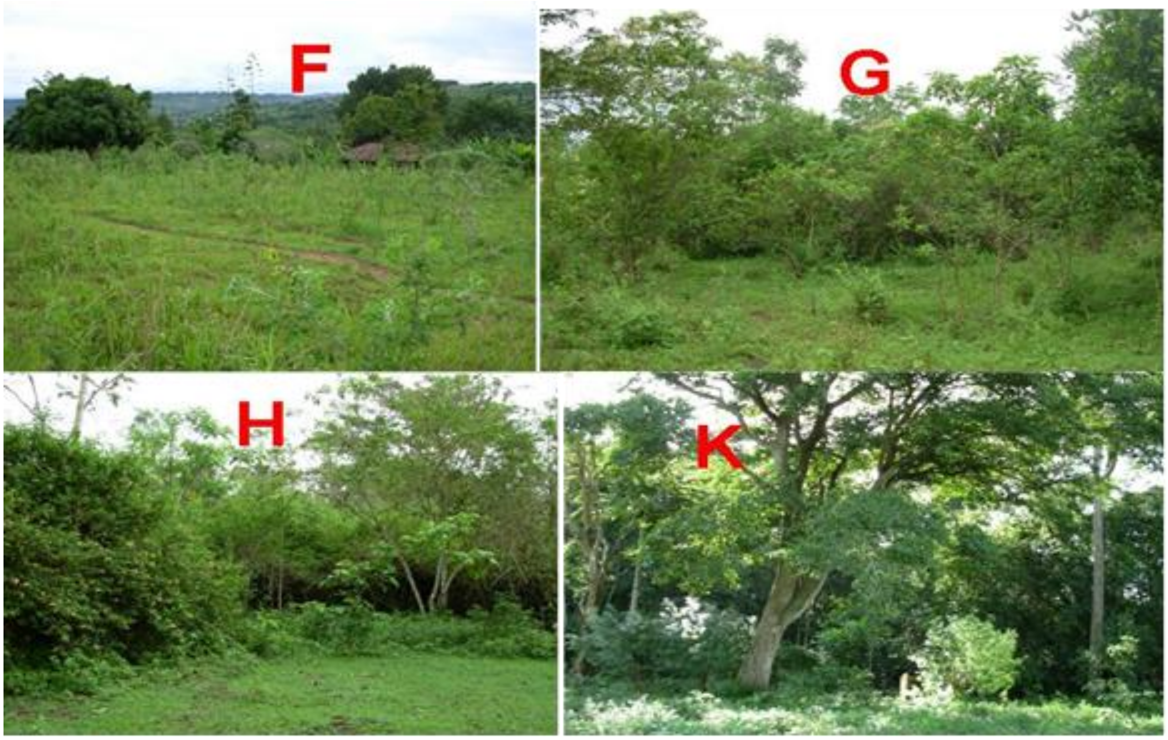


Plate 13. Different types fallows: F = young fallows (<1 to 2 years old); G, H = mature fallows (2 to 5 years old); K = forest fallows (>5 years old). These different types of fallows are the main refugia (nesting/breeding sites) for bees and butterflies in farmlands. They are sometime used as foraging habitats by different butterfly species and bee species.

Plate 14. Different types of plantations (U-1) = Eucalyptu; U2 = Pine plantations (U-2). These tree plantations serve both as refugia (nesting/breeding sites) and as foraging habitats by different species of bees and butterflies.

Plate 15. Different types of “forest-edges” that serve both as refugia (nesting/breeding sites) (P) and as foraging habitats by different species of bees and butterflies.

Plate 16. Different types of gazetted forest reserves (R) that serve both as refugia (nesting/breeding sites) and as foraging habitats by different butterfly species of bees and butterflies delivering pollination services to wild and cultivated plants nearby them.

Plate 17. Traditional agroforest fields with different shading regimes. N = simple agroforestry field; M = complex agroforestry field, S, T = very complex agroforestry fields. These different agroforestry fields serve mainly as foraging habitats and in some case as refugia (nesting in mature native shading tree species) habitats by different bee species.

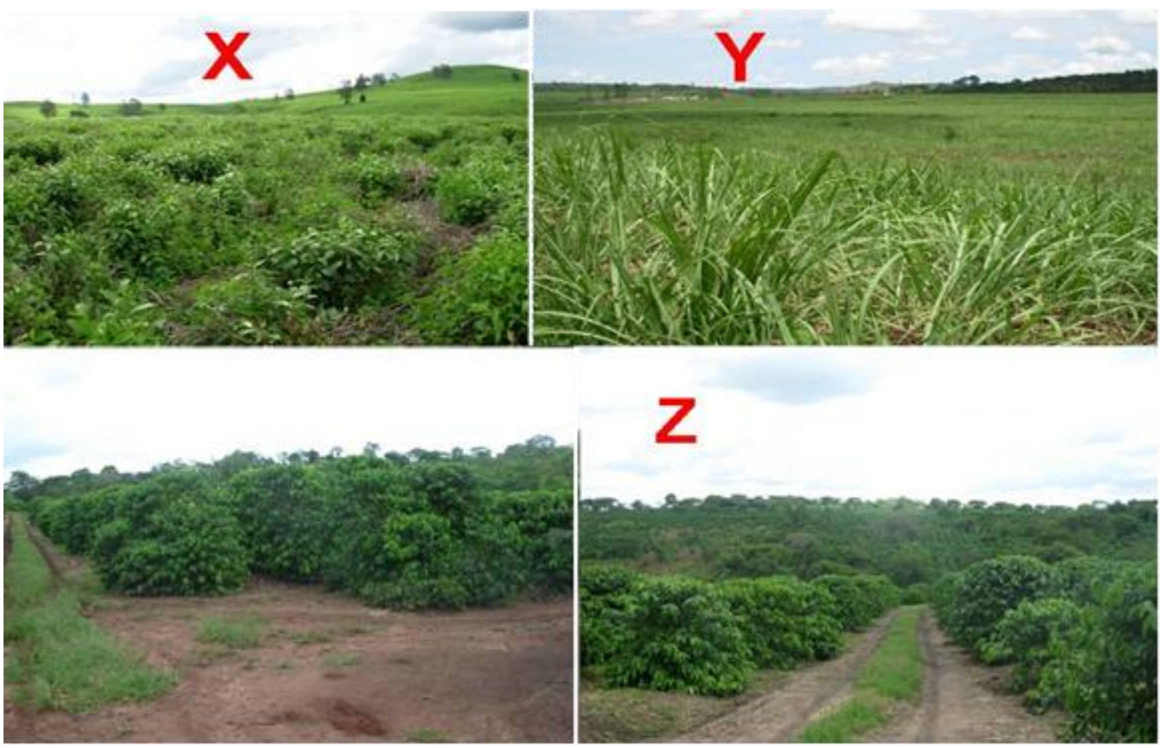


Plate 18. Large monocultures: X = Teas estates, Y = sugar cane plantations, Z = large coffee plantations. These different large plantations were observed being used as refugia (nesting/breeding sites) and as foraging habitats by different species of bees and butterflies.

Appendix 3d. Different methods (approaches) to sample pollinators.

Plate 19. Setting different pantraps (A) at the flower height in different habitats (land-uses).

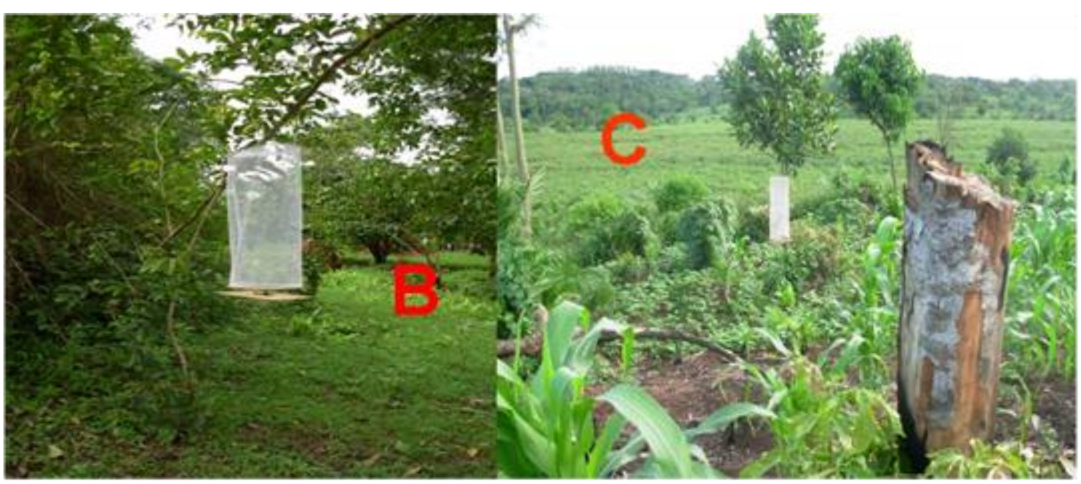


Plate 20. Placing banana-bait traps in different environments: setting a trap in shaded environment (B) and in sunny-environment (C).

Plate 21. Transect counts (F, H) and hand-netting techniques (G, K) applied as sampling methods.

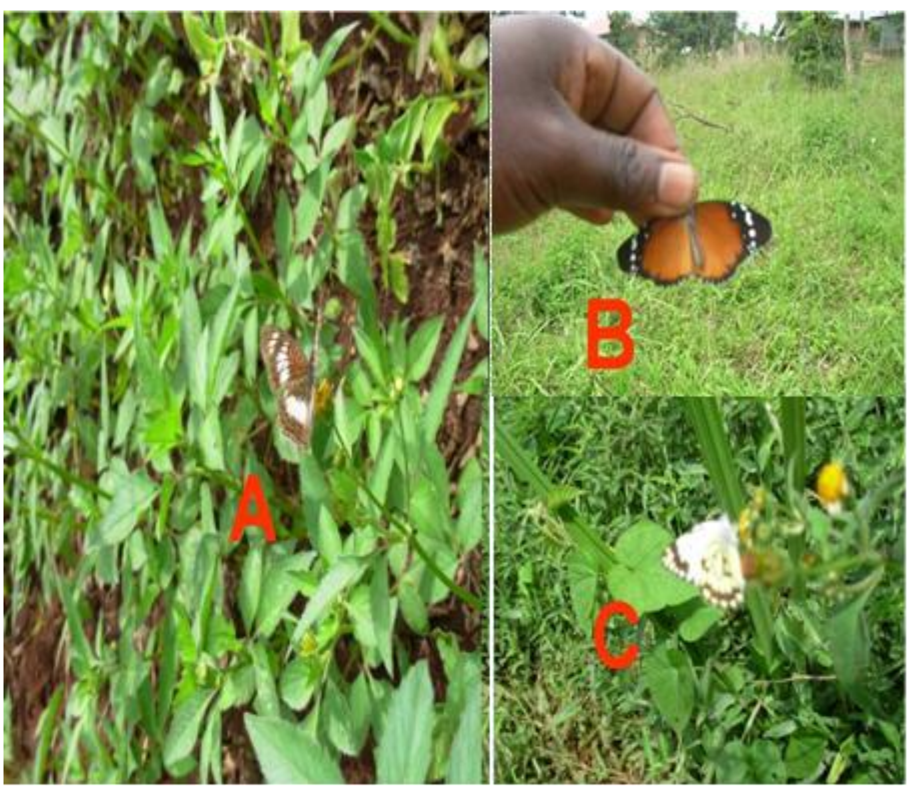


Plate 22. Some common farmland butterflies: *Junonia* sp. (A), *Danaus* sp. (B) and *Belenois* sp. (C).

Plate 23. Some common farmland stingless bee species: *Plebeina hildebrandti* (A) emerging from a termite mound and *Meliponula ferruginea* (B).

Appendix 4. Checklist of bee species collected in farmlands of central Uganda in 2006.

Family	Species	Family	Species
Andrenidae	*Andrena africana* (Friese, 1909)	Halictidae	*Lasioglossum somereni* (Cockerell, 1945)
Andrenidae	*Andrena notophila* (Cockerell)	Halictidae	*Lasioglossum stellatifrons* (Cockerell, 1945)
Andrenidae	*Melitturga penrithorum* (Eardley, 1991)	Halictidae	*Lasioglossum trichardti* (Cockerell)
Andrenidae	*Meliturgula braunsi* (Friese, 1903)	Halictidae	*Lasioglossum ugandicum* (Cockerell, 1937)
Andrenidae	*Meliturgula eardleyana* (Patiny, 2000)	Halictidae	*Lasioglossum zonaturum* (Cockerell)
Andrenidae	*Meliturgula flavida* (Friese, 1913)	Halictidae	*Lassioglossum simulator* (Cockerell, 1935)
Andrenidae	*Meliturgula rozeni* (Eardley, 1991)	Halictidae	*Lipotriches ablusa* (Cockerell)
Andrenidae	*Meliturgula scriptifrons* (Walker, 1871)	Halictidae	*Lipotriches amatha* (Cockerell, 1935)
Andrenidae	*Meliturgula wilmattae* (Cockerell, 1932)	Halictidae	*Lipotriches angustifrons* (Cockerell)
Apidae	*Afromelecta bicuspis* (Stadelmann, 1898)	Halictidae	*Lipotriches armatipes* (Friese, 1930)
Apidae	*Allodape armatipes* (Friese, 1924)	Halictidae	*Lipotriches aureotecta* (Cockerell, 1931)
Apidae	*Allodape brachycephala* (Michener, 1971)	Halictidae	*Lipotriches aurifrons* (Smith, 1853)
Apidae	*Allodape ceratinoides* (Gribodo, 1884)	Halictidae	*Lipotriches brevipennis* (Friese, 1915)
Apidae	*Allodape collaris* (Vachal, 1903)	Halictidae	*Lipotriches clavata* (Cockerell)
Apidae	*Allodape exoloma* (Strand, 1915)	Halictidae	*Lipotriches collaris* (Vachal)
Apidae	*Allodape friesei* (Strand, 1915)	Halictidae	*Lipotriches cubitalis* (Vachal)
Apidae	*Allodape interrupta* (Vachal, 1903)	Halictidae	*Lipotriches dentipes* (Friese, 1930)
Apidae	*Allodape macula* (Strand, 1912)	Halictidae	*Lipotriches digitata* (Friese, 1909)
Apidae	*Allodape microsticta* (Cockerell, 1934)	Halictidae	*Lipotriches ethioparca* (Cockerell , 1935)
Apidae	*Allodape punctata* (Lepeletier & Audinet-Serville, 1825)	Halictidae	*Lipotriches flavitarsis* (Friese)
Apidae	*Allodape quadrilineata* (Cameron, 1905)	Halictidae	*Lipotriches friesei* (Magretti, 1899)
Apidae	*Allodape rufogastra* (Lepeletier & Audinet-Serville, 1825)	Halictidae	*Lipotriches gratiosa* (Strand)
Apidae	*Allodape tridentipes* (Cockerell, 1933)	Halictidae	*Lipotriches guluensis* (Cockerell)
Apidae	*Allodapula acutigera* (Cockerell, 1936)	Halictidae	*Lipotriches hirsutula* (Cockerell)
Apidae	*Allodapula hessei* (Michener)	Halictidae	*Lipotriches inaequalis* (Cockerell)
Apidae	*Allodapula jucunda* (Smith, 1879)	Halictidae	*Lipotriches kampalana* (Cockerell, 1935)
Apidae	*Allodapula maculithorax* (Michener, 1971)	Halictidae	*Lipotriches longipes* (Strand)
Apidae	*Allodapula melanopus* (Cameron, 1905)	Halictidae	*Lipotriches macropus* (Friese)
Apidae	*Allodapula monticola* (Cockerell, 1933)	Halictidae	*Lipotriches meadewaldoi* (Brauns, 1912)
Apidae	*Allodapula palliceps* (Friese, 1924)	Halictidae	*Lipotriches natalensis* (Cockerell, 1916)
Apidae	*Allodapula rozeni* (Michener, 1975)	Halictidae	*Lipotriches notabilis* (Schletterer)
Apidae	*Allodapula variegata* (Smith, 1854)	Halictidae	*Lipotriches nubecula* (Smith, 1875)
Apidae	*Amegilla acraensis* (Fabricius,1793)	Halictidae	*Lipotriches oberthurella* (Saussure)
Apidae	*Amegilla africana* (Friese,1905)	Halictidae	*Lipotriches orientalis* (Friese, 1909)
Apidae	*Amegilla albocaudata (*Dours,1869)	Halictidae	*Lipotriches patellifera* (Westwood, 1875)

Appendix 4. Contd.

Apidae	*Amegilla atrocincta* (Lepeletier,1841)	Halictidae	*Lipotriches picardi* (Gribodo)
Apidae	*Amegilla bothai* (Friese)	Halictidae	*Lipotriches reichardia* (Strand, 1911)
Apidae	*Amegilla calens* (Lepeletier,1841)	Halictidae	*Lipotriches rubella* (Smith)
Apidae	*Amegilla capensis* (Friese)	Halictidae	*Lipotriches rufipes* (Smith, 1875)
Apidae	*Amegilla eritrina* (Friese, 1915)	Halictidae	*Lipotriches ruwenzorica* (Cockerell, 1935)
Apidae	*Amegilla fallax* (Smith, 1879)	Halictidae	*Lipotriches sessensis* (Cockerell)
Apidae	*Amegilla madecassa* (Saussure)	Halictidae	*Lipotriches sjoestedti* (Friese, 1909)
Apidae	*Amegilla mimadvena* (Cockerell, 1916)	Halictidae	*Lipotriches speculina* (Cockerell, 1942)
Apidae	*Amegilla natalensis* (Friese, 1922)	Halictidae	*Lipotriches spinulifera* (Cockerell)
Apidae	*Amegilla nila* (Eardley,1994)	Halictidae	*Lipotriches tanganyicensis* (Strand, 1913)
Apidae	*Amegilla niveata* (Friese, 1905)	Halictidae	*Lipotriches viciniformis* (Cockerell, 1939)
Apidae	*Amegilla nubica* (Lepeletier, 1841)	Halictidae	*Lipotriches vulpina* (Gerstäcker, 1857)
Apidae	*Amegilla obscuriceps* (Friese, 1905)	Halictidae	*Lipotriches welwitschi* (Cockerell, 1908)
Apidae	*Amegilla penicula* (Eardley, 1994)	Halictidae	*Lipotriches whitfieldi* (Cockerell, 1942)
Apidae	*Amegilla punctifrons* (Walker, 1871)	Halictidae	*Nomia amabilis* (Cockerell, 1908)
Apidae	*Amegilla rapida* (Smith, 1879)	Halictidae	*Nomia atripes* (Friese, 1909)
Apidae	*Amegilla regalis* (Cockerell, 1946)	Halictidae	*Nomia bouyssoui* (Vachal, 1903)
Apidae	*Amegilla rufipes* (Lepeletier, 1841)	Halictidae	*Nomia brevipes* (Friese, 1914)
Apidae	*Amegilla sierra* (Eardley, 1994)	Halictidae	*Nomia candida* (Smith, 1875)
Apidae	*Amegilla somalica* (Magretti)	Halictidae	*Nomia chandleri* (Ashmead, 1899)
Apidae	*Amegilla terminata* (Smith, 1879)	Halictidae	*Nomia clavicauda* (Cockerell)
Apidae	*Anthophora vestita* (Smith,1854)	Halictidae	*Nomia elephas* (Strand, 1911)
Apidae	*Anthophora armata* (Friese, 1905)	Halictidae	*Nomia ethiopica* (Pauly, 2000)
Apidae	*Anthophora basalis* (Smith)	Halictidae	*Nomia felina* (Cockerell)
Apidae	*Anthophora braunsiana* (Friese,1905)	Halictidae	*Nomia forbesii* (W. F. Kirby, 1900)
Apidae	*Anthophora diversipes* (Friese, 1922)	Halictidae	*Nomia garambensis* (Pauly, 2000)
Apidae	*Anthophora glaucopis* (Friese, 1905)	Halictidae	*Nomia granulata* (Vachal, 1903)
Apidae	*Anthophora rufolanata* (Dours)	Halictidae	*Nomia lutea* (Warncke, 1976)
Apidae	*Anthophora rufovestita* (Cockerell)	Halictidae	*Nomia maculata* (Friese)
Apidae	*Anthophora schultzei* (Friese, 1909)	Halictidae	*Nomia marginata* (Pauly, 1990)
Apidae	*Anthophora strucki* (Eardley & Brooks, 1989)	Halictidae	*Nomia nigrociliata* (Cockerell, 1932)
Apidae	*Anthophora wartmanni* (Friese, 1905)	Halictidae	*Nomia politula* (Cockerell)
Apidae	*Anthophora xanthostoma* (Cockerell, 1932)	Halictidae	*Nomia postscutellaris* (Strand, 1914)
Apidae	*Apis mellifera adansonii* (Linnaeus,1758)	Halictidae	*Nomia pretoriensis* (Cockerell, 1946)
Apidae	*Apis mellifera scutellata* (Latreille,1804)	Halictidae	*Nomia rozeni* (Pauly, 2000)
Apidae	*Braunsapis facialis* (Gerstäcker, 1857)	Halictidae	*Nomia rufosuffusa* (Cockerell, 1935)
Apidae	*Braunsapis albipennis* (Friese, 1909)	Halictidae	*Nomia senticosa* (Vachal, 1897)

Appendix 4. Contd.

Apidae	*Braunsapis albitarsis* (Friese, 1924)	Halictidae	*Nomia somalica* (Friese, 1908)
Apidae	*Braunsapis angolensis* (Cockerell,1933)	Halictidae	*Nomia stageri* (Pauly, 2000)
Apidae	*Braunsapis bouyssoui* (Vachal, 1903)	Halictidae	*Nomia theryi* (Gribodo, 1894)
Apidae	*Braunsapis flavitarsis* (Gerstaecker)	Halictidae	*Nomia viridicincta* (Meade-Waldo)
Apidae	*Braunsapis foveata* (Smith, 1854)	Halictidae	*Nomia whiteana* (Cameron, 1905)
Apidae	*Braunsapis gorillarum* (Cockerell, 1936)	Halictidae	*Nomia zonaria* (Walker, 1871)
Apidae	*Braunsapis leptozonia* (Vachal)	Halictidae	*Nomioides micheneri* Pesenko & Pauly
Apidae	*Braunsapis minutula* (Friese, 1914)	Halictidae	*Patellapis aberdarica* (Cockerell, 1945)
Apidae	*Braunsapis natalica* (Michener, 1970)	Halictidae	*Patellapis albofasciata* (Smith, 1879)
Apidae	*Braunsapis neavei* (Vachal, 1910)	Halictidae	*Patellapis benoiti* (Pauly)
Apidae	*Braunsapis rhodesi* (Cockerell, 1936)	Halictidae	*Patellapis bilineata* (Friese)
Apidae	*Braunsapis strandi* (Masi, 1930)	Halictidae	*Patellapis communis* (Smith, 1879)
Apidae	*Braunsapis vitrea* (Vachal,1903)	Halictidae	*Patellapis disposita* (Cameron, 1905)
Apidae	*Ceratina aliceae* (Cockerell, 1937)	Halictidae	*Patellapis flavofasciata* (Friese, 1915)
Apidae	*Ceratina armata* (Smith, 1854)	Halictidae	*Patellapis flavorufa* (Cockerell, 1937)
Apidae	*Ceratina braunsi* (Eardley and Daly, 2007)	Halictidae	*Patellapis glabra* (Pauly, 1989)
Apidae	*Ceratina excavata* (Cockerell)	Halictidae	*Patellapis gowdeyi* (Cockerell, 1937)
Apidae	*Ceratina labrosa* (Friese, 1905)	Halictidae	*Patellapis hargreavesi* (Cockerell)
Apidae	*Ceratina lineola* (Vachal, 1903)	Halictidae	*Patellapis harunganae* (Pauly, 1989)
Apidae	*Ceratina lunata* (Friese, 1905)	Halictidae	*Patellapis kivuensis* (Pauly, 1989)
Apidae	*Ceratina minuta* (Friese, 1905)	Halictidae	*Patellapis macrozonia* (Cockerell)
Apidae	*Ceratina moerenhouti* (Vachal)	Halictidae	*Patellapis minima* (Friese, 1909)
Apidae	*Ceratina nasalis* (Friese,1905)	Halictidae	*Patellapis minutior* (Friese, 1909)
Apidae	*Ceratina nigriceps* (Friese, 1905)	Halictidae	*Patellapis mosselina* (Cockerell)
Apidae	*Ceratina nilotica* (Cockerell, 1937)	Halictidae	*Patellapis neavei* (Cockerell, 1946)
Apidae	*Ceratina paulyi* (Daly, 1988)	Halictidae	*Patellapis nomioides* (Friese, 1909)
Apidae	*Ceratina penicillata* (Friese, 1905)	Halictidae	*Patellapis obscurescens* (Cockerell)
Apidae	*Ceratina rufigastra* (Cockerell, 1937)	Halictidae	*Patellapis partita* (Cockerell, 1933)
Apidae	*Ceratina ruwenzorica* (Cockerell)	Halictidae	*Patellapis patriciformis* (Cockerell, 1933)
Apidae	*Ceratina speculifrons* (Cockerell, 1920)	Halictidae	*Patellapis perineti* (Benoist, 1954)
Apidae	*Ceratina tanganyicensis* (Strand,1911)	Halictidae	*Patellapis perpansa* (Cockerell, 1933)
Apidae	*Ceratina viridifrons* (Cockerell, 1934)	Halictidae	*Patellapis pondoensis* (Cockerell)
Apidae	*Ceratina viridis* (Guérin-Méneville, 1844)	Halictidae	*Patellapis retigera* (Cockerell)
Apidae	*Ceratina whiteheadi* (Eardley and Daly, 2007)	Halictidae	*Patellapis ruwensorensis* (Strand, 1911)
Apidae	*Cleptotrigona cubiceps* (Friese, 1912)	Halictidae	*Patellapis schultzei* (Friese, 1909)
Apidae	*Compsomelissa nigrinervis* (Cameron, 1905)	Halictidae	*Patellapis spinulosa* (Cockerell)
Apidae	*Compsomelissa nigrinervis* (Cameron,1905)	Halictidae	*Patellapis terminalis* (Smith, 1853)

Appendix 4. Contd.

Apidae	*Ctenoplectra albolimbata* (Magretti)	Halictidae	*Patellapis tshibindica* (Cockerell)
Apidae	*Ctenoplectra antinorii* (Gribodo, 1884)	Halictidae	*Patellapis vittata* (Smith, 1853)
Apidae	*Ctenoplectra armata* (Magretti, 1895)	Halictidae	*Pseudapis aliceae* (Cockerell, 1935)
Apidae	*Ctenoplectra polita* (Strand, 1912)	Halictidae	*Pseudapis anomala* (W. F. Kirby, 1900)
Apidae	*Ctenoplectra terminalis* (Smith, 1879)	Halictidae	*Pseudapis anthidioides* (Gerstäcker, 1857)
Apidae	*Ctenoplectra ugandica* (Cockerell, 1944)	Halictidae	*Pseudapis armata* (Olivier, 1812)
Apidae	*Ctenoplectrina politula* (Cockerell, 1930)	Halictidae	*Pseudapis flavicarpa* (Vachal)
Apidae	*Dactylurina schmidti* (Stadelmann, 1895)	Halictidae	*Pseudapis kenyensis* (Pauly, 1990)
Apidae	*Dactylurina staudingeri* (Gribodo)	Halictidae	*Pseudapis patellata* (Magretti, 1884)
Apidae	*Epeolus amabilis* (Gerstäcker, 1869)	Halictidae	*Pseudapis rhodocantha* (Cockerell)
Apidae	*Epeolus corniculatus* (Bischoff)	Halictidae	*Pseudapis rugiventris* (Friese, 1930)
Apidae	*Epeolus friesei* (Brauns, 1903)	Halictidae	*Pseudapis schubotzi* (Strand)
Apidae	*Epeolus natalensis* (Smith, 1879)	Halictidae	*Seladonia africana* (Friese)
Apidae	*Hypotrigona gribodoi* (Magretti, 1884)	Halictidae	*Seladonia jucundus* (Smith)
Apidae	*Liotrigona bottegoi* (Magretti,1895)	Halictidae	*Seladonia jucundus* (Smith,1853)
Apidae	*Macrogalea candida* (Smith, 1879)	Halictidae	*Seladonia valligensis* (Cockerell, 1937)
Apidae	*Meliponula bocandei* (Spinola, 1853)	Halictidae	*Spatunomia filifera* (Cockerell)
Apidae	*Meliponula ferruginea* (Lepeletier, 1836)	Halictidae	*Sphecodes abyssinicus* (Sichel)
Apidae	*Meliponula lendliana* (Friese, 1900)	Halictidae	*Sphecodes braunsi* (Blüthgen)
Apidae	*Meliponula nebulata* (Smith, 1854)	Halictidae	*Sphecodes centralis* (Cockerell)
Apidae	*Nomada africana* (Friese, 1911)	Halictidae	*Sphecodes dilutus* (Cockerell)
Apidae	*Nomada aurantifascia* (Eardley & Schwarz, 1991)	Halictidae	*Sphecodes fimbriatus* (Blüthgen)
Apidae	*Nomada eximia* (Eardley and Schwarz, 1991)	Halictidae	*Sphecodes hagensi* (Ritsema)
Apidae	*Nomada gigas* (Friese, 1905)	Halictidae	*Sphecodes luteiventris* (Friese)
Apidae	*Nomada whiteheadi* (Eardley & Schwarz, 1991)	Halictidae	*Sphecodes punctatus* (Sichel, 1865)
Apidae	*Pachymelus abessinicus* (Friese, 1913)	Halictidae	*Sphecodes punctiscutum* (Eardley and Urban)
Apidae	*Pachymelus bettoni* (Cockerell)	Halictidae	*Sphecodes ugandae* (Blüthgen, 1928)
Apidae	*Pachymelus ciliatus* (Friese, 1922)	Halictidae	*Sphecodes woodi* (Cockerell)
Apidae	*Pachymelus claviger (*Benoist, 1962)	Halictidae	*Thrinchostoma bequaerti* (Blüthgen)
Apidae	*Pachymelus conspicuus* (Smith, 1879)	Halictidae	*Thrinchostoma emini* (Blüthgen, 1930)
Apidae	*Pachymelus festivus* (Dours, 1869)	Halictidae	*Thrinchostoma mwangai* (Blüthgen)
Apidae	*Pachymelus reichardti* (Stadelmann, 1898)	Halictidae	*Thrinchostoma sjoestedti* (Friese, 1909)
Apidae	*Pasites appletoni* (Cockerell, 1910)	Halictidae	*Thrinchostoma torridum* (Smith)
Apidae	*Pasites barkeri* (Cockerell, 1919)	Halictidae	*Thrinchostoma ugandae* (Blüthgen, 1930)
Apidae	*Pasites braunsi* (Bischoff, 1923)	Halictidae	*Thrinchostoma umtaliellus* (Cockerell, 1937)
Apidae	*Pasites carnifex* (Gerstäcker, 1869)	Halictidae	*Thrinchostoma wissmanni (Blüthgen, 1930*
Apidae	*Pasites dichroa* (Smith, 1854)	Halictidae	*Systropha ugandensis* (Cockerell)

Appendix 4. Contd.

Apidae	*Pasites friesei* (Cockerell, 1910)	Megachilidae	*Afranthidium braunsi* (Friese, 1904)
Apidae	*Pasites humecta* (Eardley, 1997)	Megachilidae	*Afranthidium junodi* (Friese,1904)
Apidae	*Pasites jenseni* (Friese, 1915)	Megachilidae	*Afranthidium sjoestedti* (Friese, 1909)
Apidae	*Pasites jonesi* (Cockerell, 1921)	Megachilidae	*Afranthidium tanganyicola* (Strand, 1911)
Apidae	*Pasites rotundiceps* (Bischoff, 1923)	Megachilidae	*Afroheriades larvatus* (Friese, 1909)
Apidae	*Pasites rufipes* (Friese, 1915)	Megachilidae	*Afroheriades reicherti* (Brauns, 1929)
Apidae	*Pasites somalicus* (Eardley, 1997)	Megachilidae	*Anthidiellum bipectinatum* (Pasteels, 1984)
Apidae	*Plebeina hildebrandti* (Friese, 1900)	Megachilidae	*Anthidiellum eritrinum* (Friese, 1915)
Apidae	*Sphecodopsis aculeata* (Friese, 1922)	Megachilidae	*Anthidiellum rubellum* (Friese, 1917)
Apidae	*Sphecodopsis capensis* (Friese, 1915)	Megachilidae	*Anthidium abjunctum* (Cockerell, 1936)
Apidae	*Sphecodopsis capicola* (Strand, 1911)	Megachilidae	*Anthidium basale* (Pasteels, 1984)
Apidae	*Sphecodopsis minutissima* (Cockerell, 1933)	Megachilidae	*Anthidium cordiforme* (Friese, 1922)
Apidae	*Sphecodopsis vespericena* (Eardley, 1997)	Megachilidae	*Anthidium niveocinctum* (Gerstäcker, 1857)
Apidae	*Tetralonia boharti* (Eardley,1989).	Megachilidae	*Anthidium pontis* (Cockerell, 1933)
Apidae	*Tetralonia caudata* (Friese, 1905)	Megachilidae	*Anthidium severini* (Vachal, 1903)
Apidae	*Tetralonia macrognatha* (Gerstäcker, 1870)	Megachilidae	*Coelioxys aurifrons* (Smith)
Apidae	*Tetralonia obscuriceps* (Friese, 1916)	Megachilidae	*Coelioxys caffra* (Friese)
Apidae	*Tetralonia penicillata* (Friese, 1905)	Megachilidae	*Coelioxys cherenensis* (Friese)
Apidae	*Tetralonia ruficollis* (Friese, 1911)	Megachilidae	*Coelioxys foveolata* (Smith)
Apidae	*Tetralonia trichardti* (Cockerell, 1933)	Megachilidae	*Coelioxys nasuta* (Friese)
Apidae	*Tetraloniella apicalis* (Friese, 1905)	Megachilidae	*Coelioxys natalensis* (Cockerell, 1920)
Apidae	*Tetraloniella aurantiflava* (Eardley, 1989)	Megachilidae	*Coelioxys odin* (Strand, 1912)
Apidae	*Tetraloniella braunsiana* (Friese,1905)	Megachilidae	*Coelioxys recusata* (Schulz)
Apidae	*Tetraloniella brevikeraia* (Eardley, 1989)	Megachilidae	*Coelioxys torrida* (Smith)
Apidae	*Tetraloniella capensis* (Lepeletier, 1841)	Megachilidae	*Coelioxys ultima* (Pasteels)
Apidae	*Tetraloniella elsei* (Eardley, 1989)	Megachilidae	*Coelioxys verticalis* (Smith, 1854)
Apidae	*Tetraloniella friesei* (Meade-Waldo, 1914)	Megachilidae	*Eoanthidium rothschildi* (Vachal)
Apidae	*Tetraloniella junodi* (Friese, 1909)	Megachilidae	*Euaspis abdominalis* (Fabricius)
Apidae	*Tetraloniella katangensis* (Cockerell, 1930)	Megachilidae	*Euaspis abdominalis* (Fabricius, 1773)
Apidae	*Tetraloniella michaelseni* (Friese, 1916)	Megachilidae	*Heriades arnoldi* (Friese)
Apidae	*Tetraloniella minuta* (Friese, 1905)	Megachilidae	*Heriades bequerti* (Cockerell)
Apidae	*Tetraloniella nanula* (Cockerell, 1932)	Megachilidae	*Heriades bouyssoui* (Vachal, 1903)
Apidae	*Tetraloniella paulyi* (Eardley, 2001)	Megachilidae	*Heriades capicola* (Strand, 1912)
Apidae	*Tetraloniella sierranila* (Eardley, 1989)	Megachilidae	*Heriades eximius* (Friese)
Apidae	*Tetraloniella simpsoni* (Meade-Waldo, 1914)	Megachilidae	*Heriades fumipennis* (Cockerell)
Apidae	*Tetraloniella sjoestedti* (Friese, 1909)	Megachilidae	*Heriades humilis* (Cockerell)
Apidae	*Tetraloniella whiteheadi* (Eardley, 1989)	Megachilidae	*Heriades rufifrons* (Cockerell, 1932)

Appendix 4. Contd.

Apidae	*Thyreus abyssinicus* (Radoszkowski, 1873)	Megachilidae	*Heriades scutellatus* (Friese, 1922)
Apidae	*Thyreus albomaculatus* (DeGeer, 1778)	Megachilidae	*Heriades speculiferus* (Cockerell)
Apidae	*Thyreus axillaris* (Vachal, 1903)	Megachilidae	*Hoplitis infrapicta* (Cockerell, 1916)
Apidae	*Thyreus bouyssoui* (Vachal, 1903)	Megachilidae	*Lithurgus pullatus* (Vachal, 1903)
Apidae	*Thyreus calceatus* (Vachal, 1903)	Megachilidae	*Lithurgus spiniferus* (Cameron)
Apidae	*Thyreus delumbatus* (Vachal, 1903)	Megachilidae	*Lithurgus spiniferus* (Cameron, 1905)
Apidae	*Thyreus interruptus* (Vachal, 1903)	Megachilidae	*Megachile abessinica* (Friese, 1915)
Apidae	*Thyreus meripes* (Vachal)	Megachilidae	*Megachile accraensis* (Friese, 1903)
Apidae	*Thyreus neavei* (Cockerell, 1933)	Megachilidae	*Megachile aculeata* (Vachal, 1910)
Apidae	*Thyreus niloticus* (Cockerell, 1937)	Megachilidae	*Megachile admixta* (Cockerell, 1931)
Apidae	*Thyreus oxaspis* (Cockerell, 1936)	Megachilidae	*Megachile afra* (Pasteels, 1965)
Apidae	*Thyreus pretextus* (Vachal)	Megachilidae	*Megachile albocincta* (Radoszkowski, 1874)
Apidae	*Thyreus scotaspis* (Vachal, 1903)	Megachilidae	*Megachile aliceae* (Cockerell, 1932)
Apidae	*Thyreus somalicus* (Strand, 1911)	Megachilidae	*Megachile altera* (Vachal)
Apidae	*Thyreus stellifera* (Cockerell)	Megachilidae	*Megachile apiformis* (Smith, 1853)
Apidae	*Xylocopa africana* (Fabricius, 1781)	Megachilidae	*Megachile attenuata* (Vachal, 1910)
Apidae	*Xylocopa albiceps* (Fabricius, 1804)	Megachilidae	*Megachile aurifera* (Cockerell)
Apidae	*Xylocopa apicalis* (Smith, 1854)	Megachilidae	*Megachile basalis* (Smith, 1853)
Apidae	*Xylocopa braunsi* (Dusmet & Y Alonso, 1924)	Megachilidae	*Megachile battorensis* (Meade-Waldo, 1912)
Apidae	*Xylocopa caffra* (Linnaeus, 1767)	Megachilidae	*Megachile beniticola* (Strand, 1912)
Apidae	*Xylocopa calcarata* (Le Veque, 1928)	Megachilidae	*Megachile bilobata* (Friese, 1915)
Apidae	*Xylocopa calens* *(*Lepeletier, 1841)	Megachilidae	*Megachile boswendica* (Cockerell)
Apidae	*Xylocopa erythrina* (Gribodo, 1894)	Megachilidae	*Megachile burungana* (Cockerell)
Apidae	*Xylocopa flavicollis* (DeGeer, 1778)	Megachilidae	*Megachile capitata* (Smith, 1853)
Apidae	*Xylocopa flavorufa* (DeGeer, 1778)	Megachilidae	*Megachile chrysopogon* (Vachal)
Apidae	*Xylocopa gaullei* (Vachal, 1898)	Megachilidae	*Megachile cincta* (Fabricius)
Apidae	*Xylocopa gribodoi* (Magretti, 1892)	Megachilidae	*Megachile cognata* (Smith, 1853)
Apidae	*Xylocopa hottentota* (Smith, 1854)	Megachilidae	*Megachile congruens* (Friese)
Apidae	*Xylocopa imitator* (Smith, 1854)	Megachilidae	*Megachile coniformis* (Friese, 1922)
Apidae	*Xylocopa inconstans* (Smith,1874)	Megachilidae	*Megachile cornigera* (Friese,1904)
Apidae	*Xylocopa lateritia* (Smith, 1854)	Megachilidae	*Megachile crassitarsis* (Cockerell, 1920)
Apidae	*Xylocopa mixta* (Radoszkowski, 1881)	Megachilidae	*Megachile curtula* (Gerstaecker, 1857)
Apidae	*Xylocopa modesta* (Smith, 1854)	Megachilidae	*Megachile devexa* (Vachal, 1903)
Apidae	*Xylocopa nigrita* (Fabricius, 1775)	Megachilidae	*Megachile digiticauda* (Cockerell, 1937)
Apidae	*Xylocopa olivacea* (Fabricius, 1778)	Megachilidae	*Megachile discolor* (Smith)
Apidae	*Xylocopa praeusta* (Smith, 1854)	Megachilidae	*Megachile dolichognatha* (Cockerell)
Apidae	*Xylocopa pubescens* (Spinola, 1838)	Megachilidae	*Megachile dorsata* (Smith, 1853)

Appendix 4. Contd.

Apidae	*Xylocopa senior* (Vachal, 1899)	Megachilidae	*Megachile edwardsiana* (Friese, 1925)
Apidae	*Xylocopa torrida* (Westwood, 1838)	Megachilidae	*Megachile ekuivella* (Cockerell, 1909)
Apidae	*Xylocopa ustulata* (Smith, 1854)	Megachilidae	*Megachile erythrura* (Pasteels, 1970)
Apidae	*Xylocopa varipes* (Smith, 1854)	Megachilidae	*Megachile eupyrrha* (Cockerell, 1937)
Apidae	*Xylocopa villosa* (Friese, 1909)	Megachilidae	*Megachile eurymera* (Smith, 1864)
Apidae	*Xylocopa wellmani* (Cockerell, 1906)	Megachilidae	*Megachile excavata* (Cockerell)
Colletidae	*Colletes eardleyi* (Kuhlmann)	Megachilidae	*Megachile fastigiata* (Vachal)
Colletidae	*Colletes opacicollis* (Friese)	Megachilidae	*Megachile felina* (Gerstäcker, 1857)
Colletidae	*Colletes reginae* (Cockerell)	Megachilidae	*Megachile fimbriata* (Smith, 1853)
Colletidae	*Colletes rothschildi* (Vachal)	Megachilidae	*Megachile flavipennis* (Smith, 1853)
Colletidae	*Colletes rufitarsis* (Friese)	Megachilidae	*Megachile fulva* (Smith, 1853)
Colletidae	*Colletes schultzei* (Friese)	Megachilidae	*Megachile fulvitarsis* (Friese, 1910)
Colletidae	*Colletes somereni* (Cockerell)	Megachilidae	*Megachile fulvohirta* (Friese, 1904)
Colletidae	*Hyaeus tinctulus* (Cockerell)	Megachilidae	*Megachile funebris* (Radoszkowski, 1874)
Colletidae	*Hylaeus alfkeni* (Friese, 1913)	Megachilidae	*Megachile garambana* (Pasteels)
Colletidae	*Hylaeus braunsi* (Alfken, 1905)	Megachilidae	*Megachile gastracantha* (Cockerell)
Colletidae	*Hylaeus fortis* (Cockerell)	Megachilidae	*Megachile globiceps* (Pasteels)
Colletidae	*Hylaeus heraldicus* (Smith, 1853)	Megachilidae	*Megachile gowdeyi* (Cockerell, 1931)
Colletidae	*Hylaeus lineaticeps* (Friese, 1913)	Megachilidae	*Megachile gratiosa* (Gerstäcker, 1857)
Colletidae	*Hylaeus magrettii* (Vachal)	Megachilidae	*Megachile griseola* (Cockerell)
Colletidae	*Hylaeus neavei* (Cockerell, 1942)	Megachilidae	*Megachile hecate* (Vachal)
Colletidae	*Hylaeus scutispinus* (Alfken)	Megachilidae	*Megachile hirticauda* (Cockerell)
Colletidae	*Hylaeus subfortis* (Cockerell)	Megachilidae	*Megachile hopilitis* (Vachal, 1903)
Colletidae	*Hylaeus ugandicus* (Cockerell, 1939)	Megachilidae	*Megachile ikuthaensis* (Friese)
Colletidae	*Scrapter albitarsis* (Friese, 1909)	Megachilidae	*Megachile invenita* (Pasteels)
Colletidae	*Scrapter algoensis* (Friese, 1925)	Megachilidae	*Megachile junodi* (Friese, 1904)
Colletidae	*Scrapter amplispinatus* (Eardley, 1996)	Megachilidae	*Megachile laminata* (Friese)
Colletidae	*Scrapter amplitarsus* (Eardley, 1996)	Megachilidae	*Megachile leucospila* (Cockerell, 1933)
Colletidae	*Scrapter armatipes* (Friese, 1913)	Megachilidae	*Megachile lineofasciata* (Pasteels, 1965)
Colletidae	*Scrapter aureiferus* (Cockerell, 1932)	Megachilidae	*Megachile luteociliata* (Pasteels)
Colletidae	*Scrapter avius* (Eardley, 1996)	Megachilidae	*Megachile mabirensis* (Cockerell)
Colletidae	*Scrapter basutorum* (Cockerell, 1915)	Megachilidae	*Megachile mackieae* (Cockerell, 1937)
Colletidae	*Scrapter bicolor* (Lepeletier & Audinet-Serville, 1825)	Megachilidae	*Megachile maculosella* (Pasteels, 1965)
Colletidae	*Scrapter caesariatus* (Eardley, 1996)	Megachilidae	*Megachile manyara (*Eardley & Urban)
Colletidae	*Scrapter calx* (Eardley, 1996)	Megachilidae	*Megachile masaiella* (Cockerell, 1930)
Colletidae	*Scrapter capensis* (Friese, 1909)	Megachilidae	*Megachile meadewaldoi* (Brauns, 1912)
Colletidae	*Scrapter catoxys* (Davies, 2005)	Megachilidae	*Megachile mimetica* Cockerell

Appendix 4. Contd.

Colletidae	*Scrapter chloris* (Eardley, 1996)	Megachilidae	*Megachile mixtura* (Eardley and R. P. Urban, 2005)
Colletidae	*Scrapter chrysomastes* (Davies, 2005)	Megachilidae	*Megachile nasalis* (Smith, 1879)
Colletidae	*Scrapter erubescens* (Friese, 1925)	Megachilidae	*Megachile natalica* (Cockerell, 1920)
Colletidae	*Scrapter flavipes* (Friese, 1925)	Megachilidae	*Megachile neavei* (Vachal, 1910)
Colletidae	*Scrapter flavostictus* (Cockerell, 1934)	Megachilidae	*Megachile nigroaurea* (Pasteels)
Colletidae	*Scrapter glarea* (Davies, 2005)	Megachilidae	*Megachile niveicauda* (Cockerell, 1920)
Colletidae	*Scrapter heterodoxus* (Cockerell, 1921)	Megachilidae	*Megachile niveofasciata* (Friese, 1904)
Colletidae	*Scrapter leonis* (Cockerell, 1934)	Megachilidae	*Megachile panda* (Cockerell)
Colletidae	*Scrapter luridus* (Eardley, 1996)	Megachilidae	*Megachile paupera* (Pasteels, 1965)
Colletidae	*Scrapter niger* (Lepeletier & Audinet-Serville, 1825)	Megachilidae	*Megachile perfimbriata* (Cockerell, 1920)
Colletidae	*Scrapter nitidus* (Friese, 1909)	Megachilidae	*Megachile postnigra* (Cockerell)
Colletidae	*Scrapter pallidipennis* (Cockerell, 1920)	Megachilidae	*Megachile pulvinata* (Vachal)
Colletidae	*Scrapter pruinosus* (Davies, 2006)	Megachilidae	*Megachile pyrrhothorax* (Schletterer, 1891)
Colletidae	*Scrapter pyretus* (Davies, 2006)	Megachilidae	*Megachile rosarum* (Cockerell)
Colletidae	*Scrapter rufescens* (Friese, 1913)	Megachilidae	*Megachile rufa* (Friese, 1903)
Colletidae	*Scrapter ruficornis* (Cockerell, 1916)	Megachilidae	*Megachile rufigaster* (Cockerell, 1945)
Colletidae	*Scrapter striatus* (Smith, 1853)	Megachilidae	*Megachile rufipennis* (Fabricius, 1793)
Colletidae	*Scrapter viciniger* (Davies, 2006)	Megachilidae	*Megachile rufipes* (Fabricius, 1781)
Colletidae	*Scrapter whiteheadi* (Eardley, 1996)	Megachilidae	*Megachile scindularia* (du Buysson)
Halictidae	*Ceylalictus muiri* (Cockerell)	Megachilidae	*Megachile selenostoma* (Cockerell)
Halictidae	*Eupetersia similis* (Benoist)	Megachilidae	*Megachile semiflava* (Cockerell, 1937)
Halictidae	*Evylaeus kampalensis* (Cockerell)	Megachilidae	*Megachile silverlocki* (Meade-Waldo)
Halictidae	*Evylaeus latesellatus* (Cockerell)	Megachilidae	*Megachile simulator* (Cockerell)
Halictidae	*Evylaeus microsellatus* (Cockerell)	Megachilidae	*Megachile sinuata* (Friese, 1903)
Halictidae	*Evylaeus nigritulinus* (Cockerell)	Megachilidae	*Megachile striatula* (Cockerell, 1931)
Halictidae	*Evylaeus semilucidus* (Cockerell)	Megachilidae	*Megachile torrida* (Smith, 1853)
Halictidae	*Halictus bidens* (Cameron)	Megachilidae	*Megachile truncaticeps* (Friese)
Halictidae	*Halictus chalybaeus* (Friese, 1908)	Megachilidae	*Megachile ungulata* (Smith, 1853)
Halictidae	*Halictus fascialis* (Smith)	Megachilidae	*Megachile utra* (Vachal)
Halictidae	*Halictus frontalis* (Smith, 1853)	Megachilidae	*Megachile venustella* (Cockerell)
Halictidae	*Halictus harveyi* (Cockerell)	Megachilidae	*Megachile vittatula* (Cockerell, 1920)
Halictidae	*Halictus jonesi* (Cockerell)	Megachilidae	*Megachile wahlbergi* (Friese, 1901)
Halictidae	*Halictus obscurifrons* (Cockerell, 1945)	Megachilidae	*Megachile waterbergensis* (Strand, 1911)
Halictidae	*Halictus picaninus* (Cockerell)	Megachilidae	*Noteriades tricarinatus* (Bingham)
Halictidae	*Halictus placatus* (Cockerell)	Megachilidae	*Othinosmia braunsiana* (Friese)
Halictidae	*Halictus rugicollis* (Friese)	Megachilidae	*Othinosmia globicola* (Stadelmann, 1892)
Halictidae	*Halictus zonatus* (Friese)	Megachilidae	*Othinosmia nitidula* (Cockerell)

Appendix 4. Contd.

Halictidae	*Lasioglossum aethiopicum* (Cameron, 1905)	Megachilidae	*Pachyanthidium apicatum* (Smith)
Halictidae	*Lasioglossum bouyssoui* (Vachal)	Megachilidae	*Pachyanthidium benguelense* (Vachal, 1903)
Halictidae	*Lasioglossum candidicinctum* (Cockerell, 1945)	Megachilidae	*Pachyanthidium bicolor* (Lepeletier, 1841)
Halictidae	*Lasioglossum choronotum* (Cockerell)	Megachilidae	*Pachyanthidium bouyssoui* (Vachal, 1903)
Halictidae	*Lasioglossum cinctulum* (Cockerell)	Megachilidae	*Pachyanthidium cordatum* (Smith, 1854)
Halictidae	*Lasioglossum claripenne* (Cockerell)	Megachilidae	*Pachyanthidium micheneri* (Pasteels)
Halictidae	*Lasioglossum duponti* (Vachal, 1903)	Megachilidae	*Pachyanthidium obscurum* (Pasteels)
Halictidae	*Lasioglossum entebbianum* (Cockerell, 1945)	Megachilidae	*Pachyanthidium paulinieri* (Guérin–Méneville)
Halictidae	*Lasioglossum flavolineatum* (Cockerell)	Megachilidae	*Pachyanthidium rufescens* (Friese, 1915)
Halictidae	*Lasioglossum geteinum (*Cockerell, 1945)	Megachilidae	*Pseudoanthidium lanificum* (Smith, 1879)
Halictidae	*Lasioglossum gossypiellum* (Cockerell)	Megachilidae	*Pseudoanthidium truncatum* (Smith, 1854)
Halictidae	*Lasioglossum griseocinctum* (Cockerell)	Megachilidae	*Pseudoanthidium tuberculiferum* (Brauns, 1905)
Halictidae	*Lasioglossum hancocki* (Cockerell)	Megachilidae	*Pseudoheriades moricei* (Friese, 1897)
Halictidae	*Lasioglossum macrurops* (Cockerell, 1937)	Megachilidae	*Pseudoheriades pellucidus* (Cockerell)
Halictidae	*Lasioglossum masaiense* (Cockerell)	Megachilidae	*Serapista denticulata* (Smith, 1854)
Halictidae	*Lasioglossum michaelseni* (Friese, 1916)	Megachilidae	*Serapista rufipes* (Friese, 1904)
Halictidae	*Lasioglossum moderatum* (Benoist, 1962)	Megachilidae	*Stenoheriades braunsi* (Cockerell, 1932)
Halictidae	*Lasioglossum modestum* (Benoist)	Megachilidae	*Stenoheriades mackieae* (Cockerell, 1936)
Halictidae	*Lasioglossum nairobicum* (Cockerell, 1945)	Megachilidae	*Stenoheriades truncaticeps* (Friese, 1922)
Halictidae	*Lasioglossum nairobiense* (Cockerell, 1945)	Melittidae	*Capicola braunsiana* (Friese, 1911)
Halictidae	*Lasioglossum namaense* (Friese, 1909)	Melittidae	*Capicola micheneri* (Michez, 2007)
Halictidae	*Lasioglossum natense* (Cockerell, 1935)	Melittidae	*Haplomelitta atra* (Michener, 1981)
Halictidae	*Lasioglossum nudatum* (Benoist, 1962)	Melittidae	*Meganomia andersoni* (Meade-Waldo, 1916)
Halictidae	*Lasioglossum nyasense* (Cockerell, 1945)	Melittidae	*Meganomia binghami* (Cockerell, 1909)
Halictidae	*Lasioglossum pachyacanthum* (Cockerell, 1937)	Melittidae	*Melitta albida* (Cockerell, 1935)
Halictidae	*Lasioglossum pellitosum* (Cockerell, 1934)	Melittidae	*Melitta arrogans* (Smith, 1879)
Halictidae	*Lasioglossum pernotescens* (Cockerell, 1934)	Melittidae	*Melitta danae* (Eardley, 2006)
Halictidae	*Lasioglossum plicatinum* (Cockerell)	Melittidae	*Melitta katherinae* (Eardley, 2006)
Halictidae	*Lasioglossum radiatulum* (Cockerell, 1937)	Melittidae	*Melitta schultzei* (Friese, 1909)
Halictidae	*Lasioglossum rubricaude* (Cameron, 1905)	Melittidae	*Melitta whiteheadi* (Eardley, 2006)
Halictidae	*Lasioglossum rubritarse* (Cockerell)	Melittidae	*Rediviva colorata* (Michener, 1981)
Halictidae	*Lasioglossum rufomarginatum* (Smith, 1853)	Melittidae	*Rediviva emdeorum* (Vogel & Michener, 1985)
Halictidae	*Lasioglossum semidiversum* (Cockerell, 1940)	Melittidae	*Redivivoides simulans* (Michener, 1981)

	Morpho-species and doubtful identification		
Family	**Morpho species**	**Family**	**Morpho species**
Andrenidae	*Andrena* sp.1	Halictidae	*Nomia* sp.2

Appendix 4. Contd.

Andrenidae	*Andrena* sp.2	Halictidae	*Nomia (Leuconomia)* sp.
Andrenidae	*Melitturga* sp.2	Halictidae	*Nomia*(*Acunomia*) sp.
Andrenidae	Melitturga sp.1	Halictidae	*Nomia* (*Crocisapidia*) sp.
Andrenidae	*Melitturgula* sp. 1	Halictidae	*Nomia* sp.1
Andrenidae	*Meliturgula* sp.2	Halictidae	*Nomioides* sp.
Apidae	*Afromelecta* sp.	Halictidae	*Patellapis sp.3*
Apidae	*Allodape* sp.1	Halictidae	*Patellapis (Archihalictus)* sp.
Apidae	*Allodape* sp.2	Halictidae	*Patellapis (Chaetalictus)* sp.
Apidae	*Allodapula* sp.1	Halictidae	*Patellapis (Lomatalictus)* sp.
Apidae	*Amegilla* sp.1	Halictidae	*Patellapis* (*Zonalictus*) sp.1
Apidae	*Ammobates* sp.	Halictidae	*Patellapis* (*Zonalictus*) sp.2
Apidae	*Anthophora* sp.1	Halictidae	*Patellapis* sp.1
Apidae	*Anthophora* sp.2	Halictidae	*Patellapis* sp.2
Apidae	*Braunsapis* sp.	Halictidae	*Patellapis* sp.4
Apidae	*Ceratina* (*Ctenoceratina*) sp.1?	Halictidae	*Pseudapis* sp.1
Apidae	*Ceratina* (*Ctenoceratina*) sp.2?	Halictidae	*Pseudapis* sp.2
Apidae	*Ceratina* (*Neoceratina*) sp.?	Halictidae	*Sphecodes* sp.
Apidae	*Ceratina* (*Pithitis*) sp.?	Halictidae	*Thrinchostoma* sp.
Apidae	*Ceratina* sp.1	Halictidae	*Halictus* sp.1
Apidae	*Ceratina* sp.2	Halictidae	*Halictus* sp.2
Apidae	*Ceratina* sp.3	Megachilidae	*Afranthidium* sp.
Apidae	*Cleptotrigona* sp.	Megachilidae	*Afroheriades* sp.1
Apidae	*Compsomelissa* sp.1	Megachilidae	*Anthidiellum* sp. 1.
Apidae	*Ctenoplectra* sp.2	Megachilidae	*Anthidiellum* sp.2.
Apidae	*Ctenoplectra* sp.1	Megachilidae	*Anthidium* (*Severanthidium*) sp.1
Apidae	*Ctenoplectrina* sp.	Megachilidae	*Anthidium* sp.
Apidae	*Dactylurina* sp.	Megachilidae	*Dianthidium* sp.1
Apidae	*Epeolus* sp.	Megachilidae	*Euasapis* sp
Apidae	*Liotrigona* sp.	Megachilidae	*Fideli*a sp
Apidae	*Melecta* sp.	Megachilidae	*Heriades* sp.1
Apidae	*Nomada* sp.	Megachilidae	*Heriades* (*Amboheriades*) sp.?
Apidae	*Pachymelus* sp.1	Megachilidae	*Heriades* (*Pachyheriades*) sp. ?
Apidae	*Pachymelus* sp.2	Megachilidae	*Heriades* sp.2
Apidae	*Pachymelus* sp.2	Megachilidae	*Hoplitis* sp.1
Apidae	*Pasites* sp.2	Megachilidae	*Hoplitis* sp.2
Apidae	*Pasites* sp.1	Megachilidae	*Lithurge* sp
Apidae	*Sphecodopsis* sp.	Megachilidae	*Lithurgus* sp

Appendix 4. Contd.

Apidae	*Tetralonia* sp.1	Megachilidae	*Megachile* (*Amegachile*) sp.
Apidae	*Tetralonia* sp.2	Megachilidae	*Megachile (Creightonella*) sp.1
Apidae	*Tetralonia* (*Eucara*) sp.1	Megachilidae	*Megachile (Creightonella*) sp.2
Apidae	*Tetralonia* (*Eucara*) sp.2	Megachilidae	*Megachile (Creightonella*) sp.3
Apidae	*Tetralonia* sp.3	Megachilidae	*Megachile* (*Eutricharaea*) sp.1
Apidae	*Tetraloniella* sp.4	Megachilidae	*Megachile* (*Eutricharaea*) sp.2
Apidae	*Tetraloniella* sp.1	Megachilidae	*Megachile (Paracella*) sp.
Apidae	*Tetraloniella* sp.2	Megachilidae	*Megachile* (*Xeromegachile*) sp.?
Apidae	*Tetraloniella* sp.3	Megachilidae	*Megachile* sp.1
Colletidae	*Colletes* sp.1	Megachilidae	*Megachile* sp.2
Colletidae	*Colletes* sp.2	Megachilidae	*Noteriades* sp.
Colletidae	*Hylaeus* sp.1	Megachilidae	*Osmia* sp. 1 ?
Colletidae	*Hylaeus* sp.2	Megachilidae	*Osmia* sp.2 ?
Colletidae	*Scrapter* sp.	Megachilidae	*Pachyanthidium* sp.
Colletidae	*Scrapter* sp.1	Megachilidae	*Pseudoanthidium* sp.
Colletidae	*Scrapter* sp.2	Megachilidae	*Pseudoheriades* sp.
Halictidae	*Cellariella* sp.1	Megachilidae	*Serapista* sp.1
Halictidae	*Cellariella* sp.2	Megachilidae	*Serapista* sp.2
Halictidae	*Ceylalictus* sp	Megachilidae	*Stenoheriades* sp.
Halictidae	*Lasioglossum* sp.1	Melittidae	*Capicola sp*
Halictidae	*Lasioglossum* sp.2	Melittidae	*Capicola* sp
Halictidae	*Lasioglossum* sp.3	Melittidae	*Haplomelitta* sp.
Halictidae	*Lipotriches* sp.1	Melittidae	*Meganomia* sp.
Halictidae	*Lipotriches* (*Afronomia*) sp?	Melittidae	*Melitta* sp. 2
Halictidae	*Lipotriches* (*Macronomia)* sp.?	Melittidae	*Melitta* sp.1
Halictidae	*Lipotriches* (*Trinomia*) sp.?	Melittidae	*Rediviva* sp.1
Halictidae	*Lipotriches* sp.2	Melittidae	*Rediviva* sp.2
		Melittidae	*Redivivoides* sp.