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Bee Pollinators and Economic Importance of Pollination in Crop Production: Case of Kakamega, Western Kenya

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To Gacheri and Mwende

ABSTRACT

Bees are the main animal pollinators of crops worldwide. In Kakamega, Western Kenya, farmers do not manage them for pollination but rely on feral pollinators from the nearby habitats. The ability of these habitats to continuously support bees depends on how they are managed by the adjacent communities. Therefore, the overall aim of this study was to elucidate strategies that can be used to improve bee pollination in the Kakamega farmland. The following objectives were defined: i) determine whether the presence of Kakamega forest affects bee pollinator diversity and foraging activity density in crops in the farmland, ii) establish the contribution of bee pollination to crop productivity, iii) assess the knowledge of farmers about bees and pollination, and iv) quantify the economic benefit that farmers derive from pollination of their crops by bees. The data were collected: i) through observation of bees along a transect from fields near the forest to fields 8 km away, ii) in experimental plots with crops with and without bee-pollination, iii) through questionnaire administration to 352 farmers, and iv) through secondary data, mainly sourced from the Ministry of Agriculture.

The number of bee species recorded in the fields near and far from the forest was not statistically different, implying that bee diversity in the farmland does not necessarily depend on the forest. However, the activity density of some bee populations (e.g., *Xylocopa calens)* was significantly higher in fields near the forest, indicating that the forest might be an important element in providing sufficient pollination services in the system, while the presence of a sufficient number of bees for pollination will depend on how the farmland landscape is managed. The increase in crop yield due to bee pollination, tested on nine crops (beans, cowpeas, green grams, bambara nuts, tomatoes, capsicum, passion fruit, sunflower and squash) ranged from 25% (tomatoes) to more than 99% (squash). Thus, although some crops can produce without bee pollination, presence of bees is important to increase yields, and hence, food security and income. Similarly, bee pollination is essential for reproduction in other crops. There was a significant increase in the quality of seeds (e.g., 21%; sunflower oil) and fruit sizes (e.g., capsicum by 29%, leading to a higher market price). The contribution of bee pollination to the farmers' income in Kakamega in 2005 was about 50% of the annual value of the selected crops (except squash). This was an almost 40% net benefit, suggesting that bee pollination economically benefits crop producers. More than 98% of the farmers knew different bee species but only about 50% knew of the function of bee pollination in crop production. However, after informing them of the role of pollination, more than 98% were willing to pay an estimated US$ 90 per household annually for pollination of their crops by bees. Both the knowledge of pollination and willingness to pay amount correlated significantly with the education of the farmers. This suggests that education of farmers on issues of bees and pollination can have an impact on bee conservation in the Kakamega farmland.

Therefore, farmers and other stakeholders should be trained on the role of bee pollination and its contribution to their welfare and on the use of cost-effective strategies for bee conservation, taking into consideration the locally available resources. For example, landscape management strategies are possible, e.g., proper utilization of hedgerows, which are unique in the farmland and connects it with the forest. Other methods such as use of trap nests for cavity nesting bees and integrated farm management systems, e.g., pest management, should also be considered. Research should be done to provide guidance on how best these strategies can be adopted for bee conservation in the region.

Bienenbestäuber und die wirtschaftliche Bedeutung der Bestäubung in der landwirtschaftlichen Produktion: Beispiel Kakamega, West-Kenia

KURZFASSUNG

Bienen sind die wichtigsten tierischen Bestäuber von Nutzpflanzen weltweit. In Kakamega, West-Kenia, betreiben die Bauern keine Bienenhaltung, sondern verlassen sich ausschließlich auf wilde Bestäuber aus den nahe liegenden Habitaten. Die Fähigkeit dieser Habitate, dauerhaft als Lebensraum für die Bienen zu dienen, hängt davon ab, wie diese durch die angrenzenden lokalen Dorfgemeinschaften bewirtschaftet werden. Das Gesamtziel dieser Studie war daher, Strategien zur Verbesserung der Bienenbestäubung im Farmland in Kakamega herauszuarbeiten. Die Ziele im einzelnen waren: i) herauszufinden, ob die Existenz des Kakamega-Waldes die Diversität der Bienenbestäuber sowie die Aktivitätsdichte der futtersuchenden Bienen in den Nutzpflanzen beeinflusst, ii) den Beitrag der Bienenbestäubung zur Produktivität der Nutzpflanzen zu bestimmen, iii) die Kenntnisse der Bauer über Bienen und Bestäubung zu ermitteln, und iv) den wirtschaftlichen Nutzen für die Bauern durch die Bestäubung ihrer Nutzpflanzen durch die Bienen zu quantifizieren. Die Daten wurden erhoben durch: i) Beobachtung der Bienen entlang eines Transekts von Feldern nahe dem Wald bis zu Feldern in 8 km Entfernung, ii) in Versuchsflächen mit Nutzpflanzen mit und ohne Bienenbestäubung, iii) durch Befragungen (Fragebogen) von 352 Bauern, und iv) durch Sekundärdaten, hauptsächlich vom Landwirtschaftsministerium.

Die Anzahl der Bienenarten in den Feldern in der Nähe und weiter entfernt vom Wald unterschied sich nicht signifikant. Dies deutet darauf hin, dass die Bienendiversität in den Feldern nicht notwendigerweise von der Nähe des Waldes abhängt. Jedoch war die Aktivitätsdichte einiger Bienenvölker (z.B. *Xylocopa calens)* signifikant höher in Feldern nahe am Wald, was darauf hindeutet, dass der Wald ein wichtiges Element in der Bereitstellung von Bestäubungsdiensten durch diese Bienenarten darstellen könnte. Der Mehrertrag der Pflanzen durch Bienenbestäubung wurde an neun Anbaupflanzen (Bohne, Kuhbohne, Kichererbse, Bambaranuss, Tomate, Paprika, Passionsfrucht, Sonnenblume und Kürbis) gemessen und lag zwischen 25% (Tomaten) und mehr als 99% (Kürbis). Dies zeigt, dass, obwohl manche Pflanzen ohne Bienenbestäubung produzieren können, die Gegenwart von Bienen den Ertrag und damit Nahrungsmittelsicherheit und Gewinn erhöhen kann. Die Qualität (z.B. 21%; Sonnenblumenöl) und auch die Größe der Früchte (z.B. 29% bei Paprika, wodurch höhere Preise erzielt werden können) waren signifikant erhöht. Der Beitrag der Bienenbestäubung zum Einkommen der Bauern in Kakamega betrug in 2005 ca. 50% des jährlichen Wertes der ausgewählten Anbaupflanzen (außer Kürbis). Dies war ein fast 40%iger Nettogewinn, und zeigt, dass Bienenbestäubung einen wirtschaftlichen Vorteil für die Bauern darstellt. Mehr als 98% der Bauern kannte verschiedene Bienenarten, aber nur ungefähr 50% wussten von der Funktion der Bienenbestäubung in der landwirtschaftlichen Produktion. Nachdem sie allerdings über die Rolle der Bestäubung informiert wurden, waren mehr als 98% bereit, für die Bestäubung ihrer Pflanzen ca. US$ 90 jährlich pro Haushalt zu bezahlen. Sowohl die Kenntnisse über die Bestäubung als auch die Höhe der Summe, die sie bereit waren zu bezahlen, korrelierte signifikant mit der Bildung der Bauern. Dies deutet darauf hin, dass eine entsprechende Ausbildung zum Schutz der Bienen im Farmland in Kakamega beitragen würde.

Daher sollten die Bauern und andere Beteiligte eine Ausbildung hinsichtlich der Rolle der Bienenbestäubung und deren Beitrag zu ihrem Wohlergehen sowie über kosteneffektive Bienenschutzstrategien erhalten, wobei die lokalen Gegebenheiten berücksichtigt werden sollten. Strategien zur Bewirtschaftung der Landschaft wären u.a. möglich durch die richtige Nutzung der dort einzigartigen Hecken, die die Felder mit dem Wald verbinden. Andere Maßnahmen wie die Nutzung von Fallennestern für höhlennistende Bienen und integrierte Farmbewirtschaftung, z.B. in der Schädlingsbekämpfung, sollten ebenfalls in Erwägung gezogen werden. Weitere Forschung sollte aufzeigen, wie diese Strategien für den Bienenschutz in dieser Region umgesetzt werden können.

Nyuki chavushi na umuhimu wa kiuchumi wa ushavushi kwa uzalishaji wa mazao: mfano wa Kakamega, magharibi ya Kenya

MUHTASARI

Nyuki ni mdudu maarufu katika uchavushi wa mimea duniani kote. Wakulima wa Kakamega, magharibi ya Kenya, hawajaweza kuwadhibiti nyuki kwa ajili ya uchavushi wa mimea, bali hutegemea uchavushi wa nyuki pori kutoka katika makazi asilia yalio karibu na mashamba yao. Uwezo wa hayo makazi asilia kuendelea kumudu nyuki unategemea jinsi unavyothibitiwa na jamii inayoyazunguka. Kwa hiyo, lengo kuu la utafiti huu lilikua kubaini mikakati itakaotumika kuboresha uchavushi wa nyuki katika eneo la mashamba ya Kakamega. Madhumuni mahsusi ya utafiti yalikuwa kama yafuatayo: i) kuangalia kama uwepo wa msitu wa Kakamega unaathiri aina mbalimbali za nyuki chavushi na uwingi wa kazi zao katika mazao ya mashamba, ii) kuangalia mchango wa uchavushi wa nyuki katika uzalishaji wa mazao, iii) kutathimini uelewa wa wakulima juu ya nyuki na uchavushi, na iv) kupima faida za kiuchumi ambazo wakulima wanapata kutokana na uchavushi wa nyuki kwenye mazao yao. Takwimu zilizotumika kuyafikia madhumuni ya utafiti zilikusanywa kama ifuatavyo: i) kufanya uchunguzi wa nyuki mashambani yaliyo kandokando ya msitu hadi mashamba yaliyo umbali wa takribani kilometa nane kutoka kwenye msitu, ii) kufanya uchunguzi kwenye vishamba vya majaribio vyenye mazao yaliyochavushwa na yasiyochavushwa na nyuki, iii) kukusanya takwimu kwa kutumia dodoso kwa wakulima wapatao 352, na iv) kukusanya takwimu kwa njia wakilishi hasa kutoka wizara ya kilimo.

Idadi ya nyuki mbalimbali waliorikodiwa kutoka katika mashamba ya karibu na pia mbali na msitu haikuwa na utofauti adhimu, ikimaanisha kuwa uwingi wa nyuki katika mashamba hautegemei uwepo wa msitu. Lakini uwingi wa kazi zao kwa baadhi ya nyuki (mfano, *Xylocopa calens*) ulikuwa katika mashamba yaliyo karibu na msitu, ikimaanisha kuwa msitu ni muhimu katika uchavushi mahili, wakati kuwepo kwa nyuki tofauti wanaotosheleza uchavushi kutategemea jinsi mazingira ya mashamba yanavyodhibitiwa. Ongezeko la uzalishaji wa mazao kutokana na uchavushi wa nyuki uliojaribiwa kwa mazao tisa (maharage, njegere, choroko kijani, njugu mawe, nyanya, pilipili tamu, karakara, alizeti na njugu siagi) ulikuwa kuanzia asilimia 25 (nyanya) hadi zaidi ya asilimia 99 (njugu siagi). Japokuwa baadhi ya mimea ya mazao inaweza kuzaa pasipokutegemea nyuki, uwepo wa nyuki ni muhimu katika ongezeko la mazao linalopelekea uhakika wa chakula na ongezeko la kipato. Vivyo hivyo uchavushi wa nyuki ni muhimu kwa uzao wa mazao mengine. Kulikuwa na ongezeko adhimu katika ubora wa mbegu, (mfano asilimia 21 kwa mafuta ya alizeti) na ukubwa wa matunda, (mfano asilimia 29 kwa pilipili tamu na kusababisha ongezeko la bei katika soko). Mchango wa uchavushi wa nyuki kwa pato la wakulima katika mwaka 2005 ulikuwa ni asilimia 50 ya dhamani ya mazao yaliyochaguliwa kwa mwaka (isipokuwa njugu siagi). Hii ilikuwa ni faida kwa kadirio la asilimia 40 ikidhihilisha kuwa uchavushi wa nyuki unamnufaisha mkulima kiuchumi. Zaidi ya asilimia 98 ya wakuliwa walifahamu aina mbalimbali za nyuki lakini ni asilimia 50 tu waliofahamu kazi ya uchavushi wa nyuki katika uzalishaji wa mazao. Baada ya kuwaelimisha juu ya uchavushi, zaidi ya asilimia 98 ya wakulima walikuwa tayari kugharamia makadirio ya dola za kimarekani 90 kila kaya kwa mwaka kwa ajili ya uchavushi wa nyuki kwa mazao yao. Uelewa wa uchavushi na ridhaa ya kugharamia vilitokana kwa kiasi kikubwa na elimu waliyonayo wakulima. Hii inamaanisha kuwa elimu kwa wakulima juu ya nyuki na uchavushi inaweza kuwa na manufaa katika uhifadhi wa nyuki katika mashamba ya Kakamega.

Kwa hiyo wakulima na washikadau wengine watatakiwa kufundishwa juu ya jukumu la uchavushi wa nyuki na mchango wake kwenye maslahi yao, na katika uandaaji wa mikakati nafuu kwa utunzaji wa nyuki inayotumia rasilimali zilizo ndani ya jamii wanamoishi. Kwa mfano, mikakati ya udhibiti wa mazingira inayowezekana ni kama vile matumizi mazuri ya safu za miti ambazo ni pekee kwenye mashamba ikiunganishwa na misitu. Njia nyingine ni matumizi ya viota mitego kuwaotesha nyuki na uthibiti wa mashamba kwa kutumia njia mbalimbali kama vile uthibiti wa visumbufu. Utafiti utatakiwa kufanyika ili kutoa mwongozo juu ya namna mikakati hii inavyoweza kuchukuliwa kwa ajili ya uhifadhi wa nyuki kwenye eneo husika.

TABLE OF CONTENTS

ABBREVIATIONS, ACRONYMS AND DEFINITIONS

ANOVA	Analysis of variance
API	Africa pollinator initiative
BioDiversity Pro	BioDiversity Professional Beta software, written by Neil McAleece © 1997
BIOTA	Biodiversity monitoring transect analysis in Africa
CBD	Convention on Biological Diversity of United Nations
CM	Choice modeling
CV	Contingent valuation
FAO	Food and Agriculture Organization of the United Nations
FP	Factor of production
GEO-4	Global environment outlook project 4 of the United Nations
GM	Genetically modified
GPS	Geographic positioning system
KIFCON	Kenya indigenous forest conservation program
KSh.	Kenya shillings
LIMDEP-NLOGIT 3.0.10	Econometric software written by W.H. Green. October 31 2003
MA	Milleniun Ecosystem Assessment
MOA	Ministry of Agriculture
MOLD	Ministry of Livestock Development
NOAA-CSC	National Oceanic and Atmospheric Administration- Coastal Services Center of USA
NS	Not significant
OECD	Organization of economic cooperation and development
P	Probability level of significance
RP	Revealed preferences
SD	Standard deviation from mean
SE	Standard error of difference of means
SP	Stated preferences
SPSS	Statistical software written by SPSS Inc., 1989-2005. released on September 5 2005
WTP	Willingness to pay
WTP	Willingness to accept compensation

1 GENERAL INTRODUCTION

In this chapter, I briefly review the general information concerning crop pollination and bee pollinators. I will also mention some factors that affect the pollination process, especially through their influence on bees. The problem statement and justification of the study will be discussed before presentation of the objectives of this study, which will be followed by the thesis philosophy and thesis structure.

1.1 Pollination

Pollination is the transfer of pollen grains[1] from anthers (pollen bearing part of a stamen, the male floral organ) to the stigma (receptive surface of the pistil, the female organ of a flower). Once the pollen gets into contact with the stigma, pollen tube germination takes place, which precedes fertilization of ovules. Pollination is, therefore, critical as a precursor to sexual reproduction in plants. Many flowering plants cannot set seeds or fruits without fertilization.[2] Similarly, fertilization cannot occur before the pollen comes into contact with stigma. Although the definition seems simple, the process to a successful completion of pollination can be complex. Many factors such as the flower physiology and morphology, pollinator characteristics, as well as effects of weather, influence the success of pollination. For example, Morton (1987) reported that if rain occurs 1.5 hours after pollination of yellow passion fruits (*Passiflora edulis* Sims), there will be no fruit set.

Plants have different requirements for effective pollination to be achieved. The extent to which a plant is dependent on insects for pollen transfer largely depends on the structure of the flowers, their degree of self-fertility and their arrangement on the plant[3] (Free 1993; Williams 1994, 1996; Richards 2001). The degree of self-fertility and self-pollination is a very important aspect in crop pollination. Plants that are dioecious (male and female organs occur in different plants), monoecious (male and female organs occur

[1] The pollen grains contain three kinds of cells, one of which germinates once the pollen comes into contact with stigma to form the pollen tube that transports male gametes (sperm cells) to the egg cell in the embryo sac during sexual reproduction. One of the 2 remaining sperm cells fertilizes the ovule to form zygote and embryo while the other fuses with the central cell to produce endosperm (see Friedman 1995; Lord and Russel 2002).

[2] Two main processes precede ovule fertilization: successful contact of pollen and stigma, and subsequent pollen tube germination. The first part requires an agent to carry the pollen, and forms the base of this study.

[3] This is in terms of the placement of the pollen source flower and pollen receiver flower in a plant.

on same plant but on different flowers), dichogamous (male and female organs mature at different times) or heterostylous (stamen and style have different lengths, and require pollen transfer) require insects to effect pollination. In addition, some hermaphrodite flowers (with male and female organs maturing at the same time) are self-infertile and hence they also require insect pollination. Other plants are self-fertile and can self-pollinate, but insects greatly improve the pollination process, and sometimes pollinators benefit the plant through cross-pollination. For example, Ibarra-Perez et al. (1999) reported beans (*Phaseolus vulgaris* L.) as highly self-fertile but noticed that they benefited from flower tripping[4]. There are many other crops as well that were previously considered independent of insect pollination for maximum yields but which now show increased yields when bees are added in their production process. For example, Roubik (2002) reported a more than 50% yield increase in coffee (*Coffea arabica* L.) in Panama as a result of pollination by naturalized non-native honeybees.

Many staple crops, e.g., maize or wheat, are wind pollinated. Although bees visit these crops for pollen, they can produce without bee pollination because in most cases wind will provide sufficient pollination. But the presence of bees has been shown to significantly increase seed set in combination with wind effects (Soderstrom and Calderon 1971; Adams et al. 1981). This occurs mainly in areas where wind velocity is too low to carry the pollen.

Animal pollination is effected by many different species ranging from vertebrates (e.g., bats) to invertebrates such as insects. Insects provide more than 85% of the animal pollination in crops, of which bees are the main pollinators worldwide. Humans have relied on bees since long to provide pollination services to the crops (Kevan and Phillip 2001). Bees have many traits that make them good pollinators, e.g., their numerous body hairs, their foraging behavior and the fact that they collect food for themselves and their young. This last trait is very important, as other insects just feed on nectar and pollen, but do not collect them, hence they may not be reliable although they supplement bees in pollination (Free 1993).

[4] Flower tripping occurs when the staminal column of a flower is released under the weight of a visiting insect as it alights on the wing petal of a flower and forages on the intra-staminal nectary at the base of ovary (see Roubik 1995; Ibara-Perez et al. 1999). This enables forced self-pollination and facilitates possibility of cross-pollination.

Apart from the importance of pollination in fruit or seed set, the process enhances higher yields of better quality (McGregor 1976; Free 1993). Some crops benefit also in terms of uniform ripening, which reduces yield losses in the field. Plant vigor has also been shown to be enhanced by cross-pollination, e.g., in broad beans (*Vicia faba* L.), which requires flower tripping to produce viable seeds (Stoddard and Bond 1987).

1.2 Natural history of bees

The social behavior of bees (Hymenoptera: Apiformes) is highly varied ranging from solitary to highly eusocial forms (Michener 2000). A solitary bee makes her own nest and provides food to her offspring with no help from other bees, and she usually dies before maturation of her offspring. On the other hand, highly eusocial bees have division of labor (e.g., egg layers, foragers) among cooperating adult females of two generations (mothers and daughters). The queen cannot survive on their own because she depends on workers for food, while the workers cannot survive on their own as they are not mated and hence cannot reproduce. Between the solitary and eusocial bee life, there are different social forms. For example, subsocial life where the solitary bee feeds and cares for the emerging young ones, and the communal form where bee colonies lack division of labor and all members behave in a similar way and are united by one nest (but each bee managing its own cells). While it is easy to recognize highly eusocial bees, other social forms are quite variable and bees may pass through many ontogenic stages of sociality (see O'Toole and Raw (1991) and Michener (2000) for more information on bee social life). Therefore, in this study, eusocial bees will refer to *Apis mellifera* (honey bees) and *Meliponula* spp. (stingless bees) while solitary bees will refer to the rest.

Apis mellifera L. is the most widely known eusocial bee, having been reared by man for many ages mainly for honey production. The stingless bees (such as *Meliponula* species) are also widely distributed in the pan tropical world. Their role as pollinators and honey producers is gaining popularity and there is growing market in their utilization for crop pollination (Heard 1999; Macharia et al. 2007).

Bees comprise seven main families (Michener 2000) of which only a few are currently utilized for crop pollination purposes. Except *A. mellifera*, other bees, e.g., *Bombus* spp., *Megachile* spp., and *Osmia* spp. are reared for pollination of highly priced crops such as greenhouse tomato or alfalfa seed crops. Rearing of bees other than *A. mellifera* is practiced in several countries where the need for better pollination of crops is highly regarded. In other countries, inputs of crop production other than pollination, e.g., fertilizer or pesticides are given priority in policy formulation and have masked the importance of pollination in crop productivity. *Apis mellifera* rearing in these countries is more for honey and wax production and less for provision of pollination (e.g., as reported by Gichora 2003, working in Kenya).

The main food resource of bees is nectar and pollen, which they get from flowers of different plant species. In some instances, bees may forage for floral oil in specific plants, e.g., *Lysimachia* spp. (Loosestrife) (Vogel 1986). Therefore, both plants and pollinators could have co-evolved, such that flowers of different plants would require specific bee pollinator (s) for effective pollination to occur (see also Michener 2000, p. 13-18). However, agricultural crops have been manipulated by breeders over many decades, with resulting negative impacts on the role of flowers as a possible advertiser/attractant to pollinators. Many bees visiting crop flowers have to adjust (find ways) to gain assess to pollen or nectar. Some bees perforate holes on the flower side to extract nectar from the nectaries. This denies the flower all possibilities of being pollinated. Other bees glean on the fallen pollen after a larger bee has visited the given flower. These are mainly small bees that cannot access or forcefully open such flowers, as observed by Gikungu (2006).

Apart from food, bees require plants for other purposes such as for nest material, hiding, mating or just as resting sites. Undisturbed habitats provide the best home for different bees, as here there are enough dead logs, leaves, etc. for the bees to construct their nests. There are also holes left by wood-boring beetles, tree cavities, pithy hollow plant stems, abandoned rodent burrows, soils of suitable texture, depth and slope, vegetation cover and moisture etc. suitable for use as nests (Cane 2001). Bees also require mud, resins, pebbles or plant hairs for nest construction (O'Toole and Raw 1991; Rust 1993), which can only be provided optimally in undisturbed areas. Lack of safe sites causes bees to seek other areas, e.g., construction of nests on buildings or furniture, which is perceived as damage to property. This can lead to decimation of bees as long as people do not recognize their importance, do not know how to handle them, and government policy does not address the need for their conservation.

1.3 Bee pollination of agricultural crops

For the animal-pollinated agricultural crops, bees are the most important pollinators worldwide especially because of their foraging behavior and floral constancy (ability to visit flowers of only one plant species on every foraging bout). However, only about 15% of the world's crops are pollinated by a few managed bee species, e.g., *A. mellifera* and *Bombus* spp., while the rest are pollinated by un-managed solitary bees and other wildlife (Ingram et al. 1996; Almanza 2007). The crucial role of bees as providers of pollination services in developing countries cannot be ignored, although this service is mainly feral[5] there. It is only in plantations where you will get farmers having *A. mellifera* colonies for pollination purposes. This is done even without determining whether this bee species is the most effective pollinator for those crops (see also Corbet et al. 1991; Goulson 2003). Management of bees for commercial pollination purposes only began in the 1940s following studies that showed bees are important in crop production through their pollinating activities (see Olmstead and Wooten 1987). Therefore, use of managed wild bees has only gained importance lately, and currently there are several bee species that can be rented for crop pollination purposes in most developed countries, e.g., *Bombus* spp. for greenhouse tomato (Heemert et al. 1990).

In many agriculture systems, pollinator force is important for successful pollination of the crops (Banaszak 1983). This is usually determined by the characteristics of an effective pollinator, e.g., abundance (minimum number of individuals of the said pollinator required for pollination to be effective). Other factors such as pollen load, frequency of visitation and flower constancy are also very important for adequate pollination. Pollinator diversity is also important in pollination. Bees complement each other in pollination. A more diverse bee community provides better pollination service especially in areas where mixed cropping is done, as different pollinators target different flowers. Diversity can help to reduce the risk that may arise due to lack of a pollinator during the critical period of crop flowering. For example, *A. mellifera* are known to abandon flower patches for more suitable ones and in such a case, having other bee species can help counteract the lost honeybee function, although this also depends on the crop requirements. Competition arises where the floral

[5] Feral pollination (here and henceforth) refers to pollination by unmanaged bees that visit crop flowers from nearby natural habitats and farmers do not pay for the pollination service in any way.

resources are limited while at the same time there are many individuals of different foraging bee species. This is rare in most agricultural systems.

1.4 Effects of human activities on bees and pollination

Human activities that result in habitat modification usually affect the population of bee species and their abundance (see Richards 2001; Richards and Kevan 2002). This can be through modification of food sources, nesting, resting or mating sites. In agriculture, habitat modification can be in form of establishment of monocultures, overgrazing, land clearing or even irrigation. Some crop management approaches, e.g., pesticide sprays or smoking, kill or repel foraging bees especially when applied during the flowering period, which is when bee activities are at the peak. Other practices such as zero tillage have minimal negative effects compared to mechanical farming, because they do not disturb soil-nesting bees.

Any activity that decreases population sizes of bees will usually result in inadequate pollination, unless the dominant bee is an effective pollinator and its population size is sufficient. Even if so, many other crops will suffer and may not produce optimally, as the dominant bee may not be a pollinator of these crops. Farmer knowledge of bees and pollination has been shown in many parts of the world to improve sustainable use of pollinating agents (Olmstead and Wooten 1987). For example, it is possible that farmers can conserve bees if they expect income gains in doing so.

There are of course natural impacts that can enhance or speed up decimation of bees. These are mainly in form of natural calamities, e.g., flooding, drought, fire, pests and diseases. These factors reduce bee populations through the negative effects on bee forage, nests and on individuals, or a mixture of these. Another emerging concern regards the effects of genetically modified plants. There is to date not enough evidence to show effects of some traits, e.g., insecticide resistance particularly if expressed in plant nectar and pollen, which are the bee's main food. Therefore, it is conceivable that humans can halt or manage the impacts of such calamities by providing bees with alternative means of survival and protecting them, for example, against pests and diseases.

1.5 Economic value of pollination services

Pollination is an ecosystem service that economically has both ecological and agricultural values. Ecological values are portrayed in the regulatory functions provided by an ecosystem, e.g., supporting the reproduction success of different plants. Plants support many life forms that benefit human beings through their use and non-use values. However, very little has been done to value such ecological role of pollination both regionally and globally. Costanza et al. (1997) attempted to provide a global value. While they estimated the value of pollination at US$ 120 billion annually for all ecosystem pollination services, Richards (1993) stated a value of US$ 200 billion for the role of pollination in global agriculture alone. Such differences in the estimation of global value of pollination point to inconsistencies in the methodologies used to evaluate the service. In agriculture, pollination is an important input of crop production, comparable to any other input such as fertilizer, labor or pesticides. Similar to the global values, the few studies that have tried to measure pollination contribution to commodity yield at national levels also have produced inconsistent values. In the USA alone, the value of pollination has been reported to range from US$ 4.5 billion in the 1960s to US$ 18.9 billion in the late 1980s (O'Grady 1987; Robinson et al. 1989; Morse and Calderone 2001). In the UK, Carreck and William (1998) valued honeybee pollination at US$ 321 million annually while in Australia, values of US$ 0.5 billion to US$ 1.4 billion have been reported (Gordon and Davis 2003). Although the monetary amounts are different, they all measured the role of pollination by honeybees, mainly because this bee species has been used widely in the provision of commercial pollination services and there is a ready rental market in those countries.

Although pollination services can both be managed and purchased from a market, or, be feral and provided 'free' by wild bees, the valuations have only concentrated on the managed service. Rented bees may sometimes not provide optimal pollination compared to wild bees, and in case the wild population is large enough, the crop may benefit more from wild bees than from managed bees. The farmer who rents bees in the market only pays for the managed pollination. All previous studies measured the market value of pollination, which expresses only the direct use value of pollination. At the same time, pollination has indirect-use values, e.g., in genetic improvement or in enhancing the survival of plant species revered by certain communities. Therefore, the market value is just a component of the total economic value of pollination. However, it can be used to trigger dialogue among stakeholders and help in formulating policies that can help harness the benefits of the pollination service. Understanding the economic value of pollination creates an incentive for implementing policies required to conserve bees. Results of past valuations have shown success in countries such as USA (Levin 1983), Australia (Gill 1991) and many other countries.

1.6 Problem statement

Crop pollination studies are rare compared to those of non-crop plants, and this is especially true for Africa compared to developed countries. In Kenya, for example, only a few studies have been done on crop pollination requirements of a very small number of crops. One of the latest is Njoroge et al. (2004) on pollination of water melon (*Citrullus lanatus* Thunb.) in semi-arid areas of eastern Kenya. Therefore, there is a need to improve the knowledge about pollination requirements of crops and not rely on information from studies done elsewhere in the world, as they may not be applicable in the Kenyan situation. Intensive studies on biotic pollination would help in policy formulation and decision making concerning management of pollination for agricultural purposes, which is lacking. Although pollination improves crop yield, there is no study in Kenya that links its role to the economic benefits gained by farmers. This study aims to fill this knowledge gap and to create a tool to be used in discussion by all stakeholders, on issues such as those pertaining policies needed to guide usage of pollination services in a sustainable manner.

1.7 Study site

This study was conducted in the Kakamega district, which is situated in the western region of Kenya in East Africa (Figure 1.1). The study was located in the farmland within a 10- km zone from the forest edge. The forest occupies an estimated area of 240 km^2 and is in the upper catchment area of Lake Victoria, about 50 km north of the town Kisumu. The area has rich agricultural soils and receives plenty of rain (more than 1500 mm per annum), which is well distributed throughout the year. There are two rainfall peaks in a year, April-May (long rain) and September-November (short rains). The mean monthly temperatures range from 11 °C to 29 °C, with an average temperature of

22 °C. These attributes makes it suitable for farming, and the region is classified as one of the high potential areas in Kenya for agricultural production (Jaetzold and Schmidt 1982). The agriculture matrix in the area consists of small land units ranging from 0.2 ha to 0.7 ha per household (Greiner 1991; MOA 2006), which continue to be subdivided to smaller units. The farmland is highly populated with a range of 433 to 713 inhabitants per km^2 (Greiner 1991; BIOTA 2004). This makes it one of the most highly populated rural areas in the world. Most households are small-scale farmers of crops and livestock. The farming system in the farmland on the north and south sides of the forest is relatively diverse, with sugarcane and tea as the main cash crops, respectively. Apart from these crops, farmers rely mainly on staple crops, vegetables, and fruit crops, for their daily dietary requirements. Most of these crops require biotic pollination and are strongly affected by any decline in the pollination service. The farmers allocate sufficient portions of their land for these crops, which they grow all year round.

One of the unique features of the farmland is the presence of the Kakamega forest, which is exceptional in that it has a mixture of Guineo-Congolian and Afro-montane species. It is also the only remaining patch in Kenya of the once Guineo-Congolian rainforest that used to span from West Africa through central to East Africa. It is the most species-richest forest in Kenya and habitat for a large number of rare animal and plant species, some of which are endemic (KIFCON 1994). The forest is also reported to be sensitive to human influence. Indeed, most of the past reports show that the area has been decimated by about 52% since 1933 when it was placed under government protection (BIOTA 2004). The forest is one of the main sources of pollination services to the crops, but due to continued disturbance and intensive farming, pollination service provision is threatened (BIOTA 2004). If no measures are taken to conserve pollinators, there is a likelihood of considerable reduction of the commodities produced from pollinator-dependent crops. Households in the immediate proximity of the forest create a buffer zone between the forest and the more distant population. In essence, these households benefit (e.g., pollination) from the forest, but they also experience damage to their crops by animals that come from the forest. Therefore, this populace has an impact on the conservation of the forest. This study was done within BIOTA project, which is an interdisciplinary project involved in the issues of the influence of fragmentation and disturbance on the biodiversity of the East Africa highlands rainforest (BIOTA 2004).

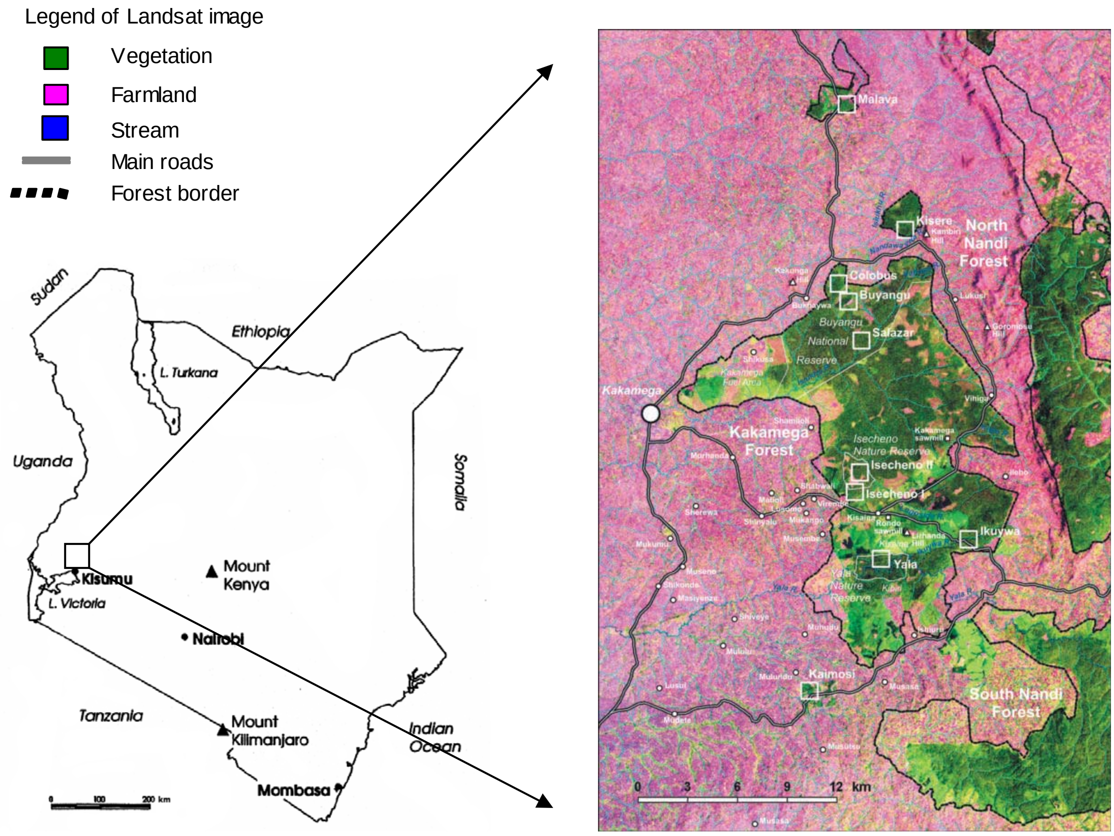

Figure 1.1: Map of Kenya showing location of Kakamega forest. Landsat ETM+ (7) satellite image (5 February 2001, spectral bands 5/4/3, contrast enhanced) of Kakamega forest, its peripheral fragments and the adjacent Nandi forests. White frames mark 10 BIOTA study sites (Source: USGS; access and preparation: BIOTA-E02, G. Schaab, Karlsruhe, Germany)

1.8 Justification of the study

Food security is of first priority in many developing countries, Kenya included. Most of the efforts to address this issue have been directed to almost all inputs of production for improving crop yields other than pollination. However, there is no tangible evidence of optimal crop achievements reported by farmers even when such research has provided guidelines. There is need to better understand the reasons for non-optimal crop production. There is evidence that if pollination is not sufficient yields can be low. Bees are the main agents of pollination for most agricultural crops. Because there is no reported managed pollination service in Kenya, farmers mainly rely on feral pollination.

A recent study done at Kakamega (Gikungu 2006) found a high diversity of bee species in the forest and its surroundings visiting flowers of non-crop plants. It is, however, not known how many of these species are pollinating crops in the farmland and whether crops are pollinated sufficiently. Nevertheless, it is possible to manage agricultural landscapes in such a way that habitats for bees and other pollinators are provided. This would compliment the role of the forest. However, such initiatives require participation of many stakeholders, e.g., the government, civil society and farmers. Therefore, this study aims at providing information that may be useful in formulating strategies to improve utilization of pollination for crop production in Kakamega farmland and that can also be applicable in other areas with similar characteristics.

1.9 Objectives

The goal of this study was to elucidate strategies that can be used to improve bee populations in Kakamega farmland for crop pollination purposes. The main objective was to determine bee pollinators of crops and the economic importance of their pollination in Kakamega. To attain this, several specific objectives were formulated:

1. To determine the influence of the forest on the activity density[6] of bees visiting crop flowers in the farmland.
2. To assess the contribution of bee pollination to the yield of specific crops grown in the farmland.
3. To appraise knowledge of farmers about bee pollinators, their natural history and crop pollination.
4. To measure the economic benefit that farmers derive from pollination of their crops by bees.

1.10 Research questions

To meet the above specific objectives, the following questions were formulated to guide the research:

1. Does the activity density of different bees visiting crop flowers change as the distance from the forest edge to the farmland increases?

[6] Activity density, as used in this thesis means the visitation rate of the bees to the flowers. It may be used interchangeably with frequency. Abundance is closely related to the term and will refer to numbers of individuals in a single species, while diversity refers to number of bee species.

2. Do crops grown in Kakamega district require specific bee pollinators?
3. How much do the crops depend on bee pollination?
4. Are the Kakamega people familiar with bees and pollination, and what factors influence their knowledge?
5. What is the worth of bee pollination to crop production?
6. What would be required to enable management of pollination in Kakamega?

1.11 Thesis philosophy

I have already indicated that bees are the main pollinators in agriculture. Therefore, I wish to determine which bees visit crop flowers in the farmland, and among these bees, which are the pollinators of each specific crop. I wish to know whether farmers are familiar with these bees and whether they understand the function of pollination in crop production. These initial findings are important in the furtherance of this study. First, I will be able to determine the economic benefit derived by farmers from feral bee pollination of specific crops, and second, I will be able to measure the value that farmers attach to pollination of their crops by bees. Finally, I will be able to define strategies required for bee conservation in Kakamega.

1.12 Thesis structure

The thesis is comprised of 5 main data-oriented chapters. Chapter 2 discusses the influence of the forest on the diversity and activity density of bees that visit crop flowers in the farmland, while Chapter 3 provides information on the pollination requirements of different crops grown in the farmland. Chapter 4 is about the knowledge of Kakamega farmers on issues of bee crop pollinators and pollination. Chapters 6 and 7 provide case studies on the measurement of the economic value of pollination in agriculture, each using a different approach. Before these two chapters, I have provided a general understanding of the techniques that are available for use in measuring the value of ecosystem services such as pollination (Chapter 5). Finally, Chapter 8 provides a general summary of the findings and lesson learned from them. This chapter will discuss the way forward to achieve sufficient pollination of crops by bees in Kakamega farmland.

2 BEE SPECIES OF KAKAMEGA FARMLAND: THE CROP FLOWER VISITORS

The majority of insect pollination is effected by bees, both in agricultural and non-agricultural ecosystems. In agriculture, several bee species are currently managed to pollinate specific crops of commercial importance. Where such activities do not exist, crops rely on pollination by solitary bees (also referred as wild bees in many literature materials) as well as honeybees that are kept mainly for the honey industry. Apart from their role in pollination, bees have also been used as an indicator of habitat quality especially in areas where monitoring of their population is continuous (Tscharntke et al. 1998; Dauber et al. 2003). This is more important in agricultural areas where pollination is feral and nearby agro-ecosystems supports the bees. The quality of that ecosystem determines the population size of different bee species, which in turn influences optimization of crop pollination. Anthropogenic activities are the main factors affecting the health of an ecosystem in the farmland. These activities usually affect (positively or negatively) both the bee population and their activity density on crop flowers. Actions such as bush clearing and over-stocking can decimate bee populations through reduction of sites for mating, nesting, sleeping, resting or hiding in the farmland. Some agronomic activities, e.g., pesticide use or smoking to repel insect pests, also disrupt bee pollen or nectar collection especially when done during the flowering period. This disruption reduces the effectiveness of pollination services. However, when these anthropogenic activities are undertaken while considering bee needs, they can enhance survival and growth of bee population sizes. This would result in adequate pollination of the crops and improved crop yield.

Kakamega forest is known for its richness of both flora and fauna. More than 234 bee species visiting flowers in the forest and the adjacent farmland have already been recorded (Gikungu 2006). It is, however, not clear which bees are important in agriculture, especially in the pollination of crops. The forest can play a major role as a reservoir of bees that pollinate crops. It can also provide floral sources when crops are not flowering, ensuring year-round bee food. It is not known how far these roles can support bees that forage in the farmland. This means that the farmland itself also needs to supplement or even complement the forest’s role in the provision of bee habitats. In some parts of the world, even where bees are managed for pollination, government policies have been implemented to manage farmland landscapes so that they can provide suitable habitats for bees (Matheson 1994). In addition to ensuring that crops are adequately pollinated, such measures would also enable pollination of non-agricultural plants, which are known to support many life and non-life systems, e.g., herbs that are important in soil erosion control (Barclay and Moffett 1984).

The study discussed in this chapter was done to assess abundance and diversity of bees visiting flowers of crops grown in Kakamega farmland and to determine whether the presence of the forest has effects on the foraging activity of those bees in the farmland. The agricultural activities in Kakamega are diverse. In the north of the forest the soils are mainly alfisols (sandy loam), while the soils in the south are ferrosols (red soils), which has resulted in different agricultural activities in the two areas. Sugarcane is the main cash-crop in the north and tea in the south. However, in both areas, all other kinds of crops are planted on which the people rely for their daily needs. It was therefore important to find out whether bees are influenced by the different farming systems.

2.1 Materials and methods

2.1.1 Experimental crop

Dry common bean (*Phaseolus vulgaris* L.) was the focal crop used in this study. It was selected because it is the most common crop planted by all farmers. The bush type cultivar was used because it is widely grown in the farmland. The bean fields were managed by their owners.

2.1.2 Study sites and design

In the north and south of the Kakamega forest, 14 field sites were randomly selected, making a total of 28 study sites (see Appendix 10.1a). Farmers were requested to allow data collection in their bean fields from the onset of flowering period. The sites were selected at 0.00, 0.10, 0.20, 0.50, 0.80, 1.00, 1.50, 2.00, 3.00, 4.00, 5.00, 6.00, 7.00 and 8.00 km from the forest edge into the farmland. The edge of the forest was defined as the border of the protected secondary forest with the farmland. The zero (0) distance was the field which was just bordering the forest. Site selection was done with the help of geographic positioning system (GPS) coordinates analysis. The sites had more than 0.1 ha under bean crop production. Sampling was done after 50% of the beans in each field had started to flower (all fields had a crop of the same age). Observations at each sites was done to document the number of bees visiting the bean flowers.

2.1.3 Sampling

Bees were observed visiting flowers of beans at each site for 25 minutes, the observer usually moving in a zigzag path. Observation was confined to a 2 m strip on the left and right side of the walk. A total of 35.0 hours and 58.3 hours of bee observations were done in 2005 and 2006, respectively, summing up to 93.3 hours in the two years. Three samplings were done at each site in 2005 and five samplings in 2006 (in total 224 samples[7] cumulative for the two years). This is same as saying it took a total 200 minutes of observation time at each site over the two years. During observation sessions, bees were differentiated by color and size, and if a new species was noticed, an effort was made to capture it for further identification. Some bee species were identified to the generic level only. To minimize the gap between the least common and most common species, bees that were easier to identify in flight and those not on crop flowers were not recorded (see Heithaus 1979). A tally counter was used to record *A. mellifera* individuals, while solitary bees were counted manually. Sampling was done between 08:00 h and 14:00 h on sunny and slightly cloudy days with low wind velocity. No sampling was done when it was drizzling or raining. Sampling was done alternating between north and south of the forest at 4-day intervals from 25 May 2005 (first season) and 18 April 2006 (second season).

Data were analyzed with the aid of SPSS version 14 and BioDiversity Pro statistical software. They were subjected to logarithmic transformation whenever they were found to be skewed. Multiple analysis of variance was carried out to compare interaction of independent factors and their effects on individual numbers of bee species. Simple linear regression and correlation analyses were done. Mean, standard error of means (SE) and probability of significance (P) are provided.

[7] A sample as used in this chapter is the single observation period lasting 25 minutes in a site. A single sample therefore comprises the number of all individuals of bees observed visiting bean flowers in a site in 25 minutes.

2.2 Results

Individuals of about 20 bee species belonging to five genera were observed visiting bean flowers in the Kakamega farmland. The number of these individuals differed in the frequency of visitation (Table 2.1). The most common bees were *Apis mellifera*, *Xylocopa calens* and *Xylocopa incostans*. The activity density of *A. mellifera* individuals was higher than that of all other bees. This is reflected in the few samples (17%) in which *A. mellifera* individuals were not recorded compared to the high number of samples in which individuals of different solitary bee species were absent. *Xylocopa calens* had the highest activity density among the solitary bees, which was much lower than for *A. mellifera*. In 42% of the 224 samples taken, no *X. calens* individuals were observed. Another relatively frequent solitary bee on bean flowers was *X. incostans*, which was observed in only 43.3% of the 224 samples. Therefore, among the solitary bees, only *X. calens* and *X. incostans* were common during the sampling period. Individuals of other species were not regular and their numbers was low. For example, only 24.1% of the total observation time taken (93.3 h) in 2 years were these individuals observed. No bee individual was observed in 2 h of the cumulative period of 93.3 h in two years. This is similar to saying that out of the 224 samples taken, almost five samples (2.2% of the total samples) recorded no bee visiting bean flowers within the 25 minutes of observation. This is an indication that only a small number of bees visit crop flowers.

Table 2.1: Percent number of samples out of a total 224 samples in which bees were observed visiting bean flowers in Kakamega farmland, Western Kenya in 2005 and 2006

Species	% no. samples in which an individual was observed
Apis mellifera	82.6
Xylocopa calens	57.6
Xylocopa incostans	43.3
Xylocopa flavorufa	24.1
Xylocopa spp.[a]	19.2
Xylocopa nigrita	17.9
Megachile spp.[a]	9.8
Amegilla spp.[b]	7.6
Ceratina spp.[b]	1.3
Solitary bees	83
All bees	97.8

"Solitary bees" are all bees except A. mellifera; "All bees" include solitary bees plus A. mellifera; [a] 5 species; [b] at least 2 species

The samples collected adequately represent the number of bee species visiting bean flowers in the farmers' fields, as shown by the asymptotic nature of the species accumulation curve (Figure 2.1). This means it was highly likely that more than 8 observations (which was the sampling number for the two years at each site) would have yielded similar results, and it was unlikely to observe a different bee species visiting bean flowers other than those reported here. However, the number of bee species might have been higher if other crops had been considered, as there are bees that only visit flowers of specific crops.

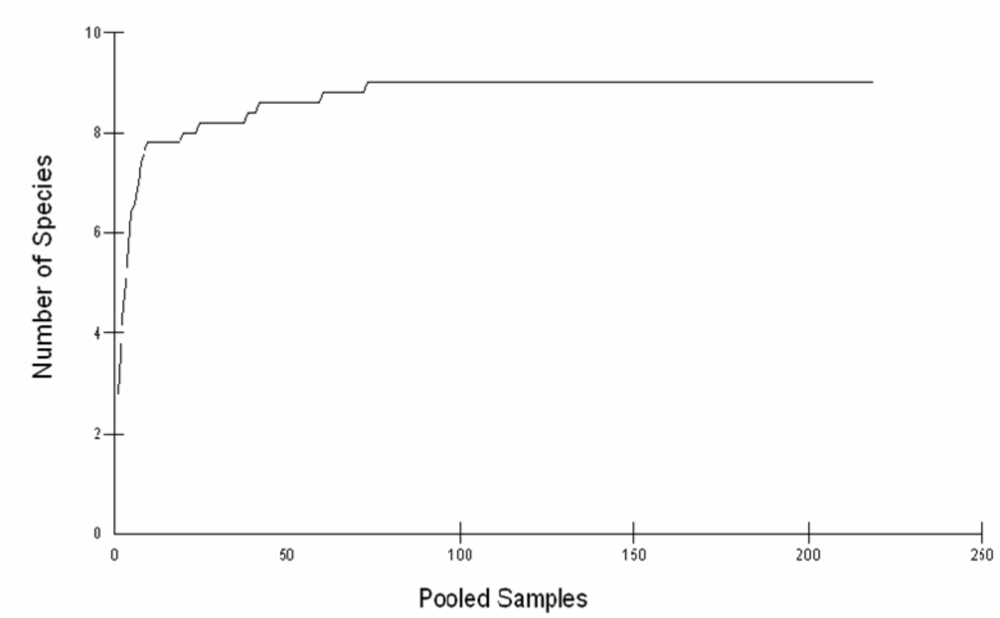

Figure 2.1: Accumulation curve of bee species observed visiting crop flowers in Kakamega farmland, Western Kenya in 2005 and 2006

The number of samplings and the beginning of the observations had no significant effects on the number of bee individuals observed visiting bean flowers (P > 0.05). There was no observable relationship between the number of bee species observed at different sites and the distance of the site from the forest edge, neither north nor south of the forest. However, the intercept of the species observed north and south of the forest was significantly different (P < 0.05), implying that the number of species was higher in the south than in north (Figure 2.2). Individuals of some bee species were influenced by the ecological differences north and south of the forest, e.g., the number of *A. mellifera* individuals was significantly (P<0.10) higher in the north than in the south. In contrast, the number of solitary bees was significantly higer (P < 0.05) in the south than in the north (Table 2.2).

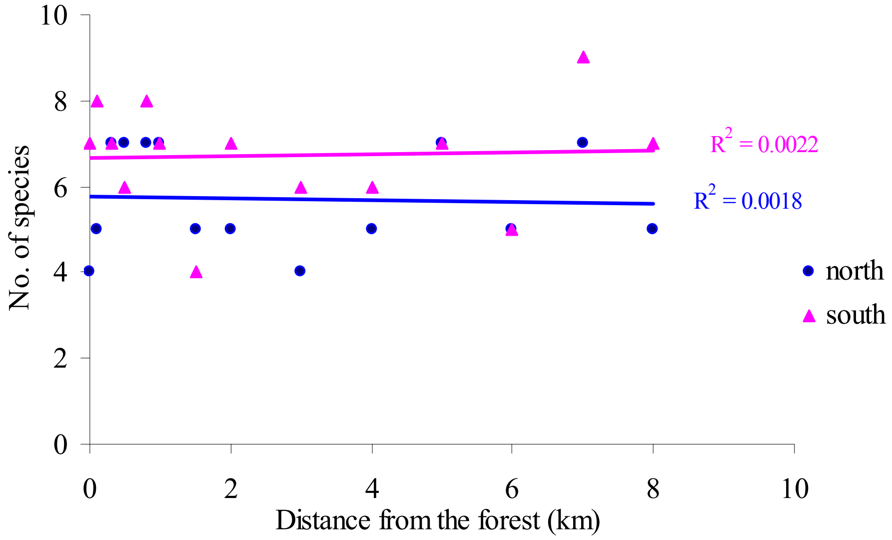

Figure 2.2: Number of bee species distributed in a transect of 8 km from the forest edge into the Kakamega farmland, Western Kenya in 2005 and 2006

Table 2.2: Number of different bee species individuals observed visiting bean flowers north and south of Kakamega forest, Western Kenya, 2005 and 2006

	A. mellifera	*X. calens*	*X. incostans*	Other solitary bees	All solitary bees	All bees
North	1922	118	77	108	303	2225
South	1635	196	89	157	442	2077
P	*	*	NS	NS	**	NS

*ANOVA test; *,** significant at 90% and 95% level; NS not significant; Time of observation was 46.65 h in north and similar time in south*

Distance from the forest edge had significant effects on the activity density of individuals of some bee species visiting bean flowers in the farmland. The number of *A. mellifera* individuals increased as the distance from the forest edge into the farmland increased ($P < 0.05$). This was recorded both north and south of the forest. On the other hand, individuals of *X. calens* decreased as the distance from the forest edge into the farmland increased. This was mainly in the south ($P < 0.05$), as no such influence was observed for the sites in the north ($P > 0.05$) (Figure 2.3). There was also a tendency of *X. incostans* individuals to increase as the distance from the forest edge increased ($P<0.05$), but there was no difference between north and south ($P > 0.05$).

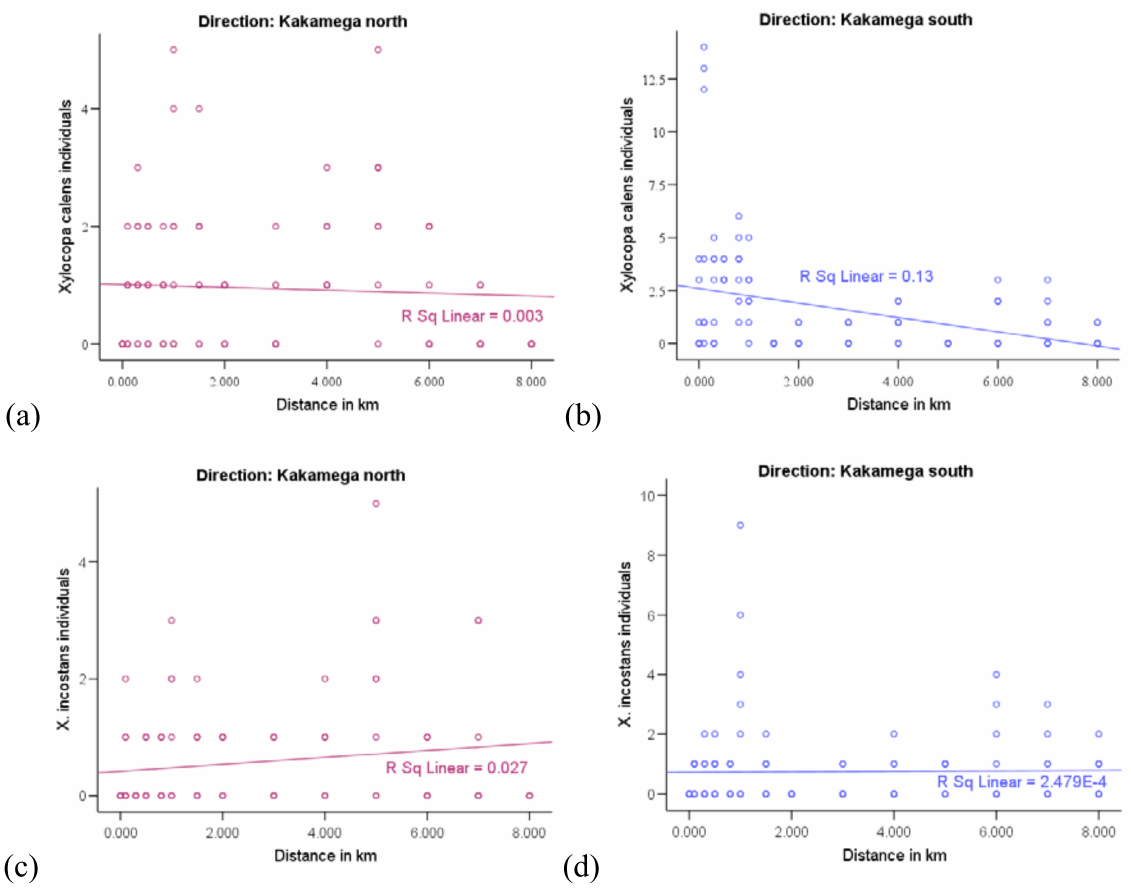

Figure 2.3: Number of *X. calens* (a, b) and *X. incostans* (c, d) individuals observed visiting bean flowers in transect of 8 km from Kakamega forest edge (north and south) into the farmland, 2005 and 2006

2.3 Discussion

2.3.1 Study limitation

Observations were made on bean flowers only. Therefore, specific bee pollinators of other crops, e.g., fruits, nuts, or some vegetables, may not have been observed. Flowers of beans are not so easily accessible, and large-bodied bees have an advantage over small ones. This could be the reason for the absence of small bees in the results of this study. It was not possible to use other crops, because these are not common in the farmland, and hence it would not have been possible to create a transect stretching several kilometers into the farmland; the use of beans was thus a compromise. More samplings were impossible, as the bean crop could not sustain more flowers. Most bees that visit bean flowers have a wide range of floral food sources. Therefore, the observed bees may be the main pollinators of different crops grown in the farmland. This will be confirmed in the next chapter (Chapter 3) where results of observations of bee pollination on several crops were considered. More than one transect in each direction would have added impetus to the observed activity density of bees. This was not possible for time and manpower reasons.

2.3.2 Bees that visit bean flowers in Kakamega farmland

Individuals belonging to about 20 bee species observed visiting bean flowers in the Kakamega farmland had low activity density. This was portrayed by the few number of bees observed at each site, and sometimes no bee was recorded during the observation time. Low activity density could imply that pollination of the crops grown in the farmland is not sufficient. However, the bee diversity is comparable to the 17 bee species recorded by Gikungu (2006, p. 40) visiting flowers of non crop plants belonging to Fabaceae family. In addition, Gikungu (ibid.) found more than 200 species of bees in the forest and in the more open farmland. This observed high diversity may have been due to the sheer number of different plants considered in that study. However, the author actually expressed fears of low numbers of bee individuals and advocated conservation (p. 17-34). Some reasons for the low bee activity density observed in the present study could have been due to the presence of better bee forage elsewhere. Such sources can deny a crop the much needed pollinator, but if the population is high, the ‘spill-over’ effect could prevent a deficiency of pollinators on crops.

The observed tendency of some bee populations to decrease from the forest edge towards the farmland may be due to the fact that the forest acts as the main habitat for those bees. This could be especially through provision of good sites for bee nests, resting, hiding and mating, as well as forage in times when crops are not flowering. This affirms the role of the forest as a main habitat of such a species. It is acknowledged that the distance a bee will fly from the nests depends on the expected gain from floral rewards, i.e., they consider their energy dispensation while sourcing their food. Bees will only fly a certain distance if the net gain (food) is higher than the cost (energy used) (Corbet et al. 1991; Klein et al. 2003; Ricketts 2004; Chacoff and Aizen 2006). The interconnectivity of the Kakamega farmland with the forest through the live fencing rows seems not to provide *X. calens* individuals with a good habitat. This may be due to the fact that many farmers use the trees and shrubs on the fence for fodder, fuel wood and timber, causing disturbance and making the fence corridor uninhabitable by the bees. On the other hand, *X. incostans* had the tendency to increase towards the farmland. This could imply their preference to nest in the farmland. Their large body size may also contribute to long-distance flights although the energy balance is a critical consideration. Individuals of many other bee species had quite a low activity density. It can, therefore, be argued that at the time of the study, the agricultural matrix was not sufficiently providing these bees with the temporal and spatial needs they require for their living. This includes diversity of flora throughout the year and minimal disturbance to accommodate bee sites for nesting, mating, hiding or just resting.

Increase of *A. mellifera* as distance increased may be due to the fact that more hives were located in the farmland than in the forest. Beekeeping is widely practiced in Kakamega, with *A. mellifera* being the common bee kept. There were more honey bee hives in the north than in the south (MOLD 2006), and this was reflected by the observed higher number of *A. mellifera* visiting beans in the north. However, the presence of many sugarcane factories (juggary) in the north denies crops more honey bee visits as they are attracted to the sugary substances in the factory. Low *A. mellifera* presence may also be explained by the foraging behavior of *A. mellifera* that make them visit only flower patches which provide maximum net gain (Corbet and Osborne 2002). If the beans were not providing such gain compared to other shrubs or trees in the farmland or forest at same period, it could explain the low number of the bees observed visiting bean flowers during the sampling period. This is also one of the disadvantages of relying on *A. mellifera* as the main crop pollinator. Therefore, enhancement of more individuals of solitary bee species is inevitable for improvement of pollination services in the research area.

Lack of dominant bee species indicates that bees complement each other in pollination of crops (see also Klein et al. 2003). The findings that in only 2% of the total observation time no bees were to be seen shows that there was always an individual in each site at any particular moment, although this small number may not be of benefit to the crop. It is not surprising to find out that solitary bees were more prevalent on bean flowers in the south than in the north of Kakamega forest. The south is more highly populated, and the farming system does not allow growth of large hedges as witnessed in the north. Therefore, bees in the north may have a wider choice of flowers compared to the south. The findings, therefore, suggest that bees in the north may be going to pollen and nectar sources other than beans.

A study is required to determine possible causes of the differences observed in bee occurrence especially *A. mellifera* versus the solitary bees. Lack of earlier studies in the farmland on bees visiting crop flowers make it impossible to determine whether the bee population is on the decline. The population of solitary bees observed was low and may not be reliable for pollination even though many species have been reported to be good pollinators of a wide range of crops elsewhere (e.g., Westerkamp and Gottsberger 2000). The number of individuals of *A. mellifera* was higher than those of other bee species, although this species does not pollinate beans better than other bees (see Chapter 3). The number is especially of importance in improving the pollinator force of the effective pollinator.

Interpretation of the species accumulation curve would imply that it would have been unlikely to find new bee species visiting flowers of beans in the research area even with more sampling or time for observations. This could also be explained by the fact that the observed species comprise the main bean flower visitors, and that they also visit other crops grown in the farmland. Visitation, however, does not imply pollination, and hence the need to determine the bees that effect pollination on each different crop grown in the farmland. However, visitation is an initial step towards successful pollination, as bees do so unknowingly as they take their food.

2.4 Conclusion

Individuals of about 20 bee species were observed visiting bean flowers in the two-year period. The number of bee species was not different on the fields near or far from the forest towards the farmland. However, species numbers were higher in the south than in the north of the forest. The activity density of individuals belonging to different bee species was dissimilar. Among the solitary bees, only *X. calens* and *X. incostans* were numerous. The individuals of *X. calens* reduced as the distance from the forest into the farmland increased in the south, but there was no significant difference in the north. *Apis mellifera* individuals were the most numerous among all bee species, and there were more in the north than in the south, while there were more solitary bees in the south than in the north. Generally, the number of bee individuals was low, and in some observations no bee was recorded at all. Therefore, efforts should be geared towards improvement of population sizes of different bee species for pollination of crops grown in the farmland. There is also a need to establish whether there is a possible competition between different bee species and whether these have complimentary roles, and to determine the effect of such behavior on crop pollination. It is suggested that long-term bee monitoring be established as an indicator of ecosystem health in the study area. In the next chapter, studies on the bee pollinators of some selected crops grown in the farmland are provided, together with data on the contribution to the harvestable yield by these bees through pollination.

3 BEES IN KAKAMEGA FARMLAND: CROP POLLINATORS AND POLLINATION

Neither insect pollination in agriculture is well understood, nor the actual use of pollinating insects as agricultural tools for improving production of crops (McGregor 1973). Although tremendous steps have been taken to improve the knowledge, there is still quite a lot that needs to be done (Klein et al. 2007). The knowledge gap is quite large between the scientists and the general public. However, there is an indication that crop growers, especially the commercially oriented, are embracing the findings from research.

It is generally believed that among animal pollinators of crops, bees provide the largest share of pollination and are the most relied-on pollinators in agriculture (McGregor 1976). It is no wonder most crop pollination studies have continued to concentrate on bee pollination. A reason for the growing global interest in bee pollinators is due to the perceived decline of their populations. In high input agriculture, bees are sought from beekeepers for pollination of crops. This is in line with the supporting research findings in those regions that show the pollination needs and pollinators of a given crop. However, in low input farming, bees that pollinate crops come freely from nearby nature reserves, which support them by having habitats for their nests and forage. In such farming systems, it is difficult to predict whether crops are receiving adequate pollination as bees are not managed in any way. It is also not easy to know the effective pollinator, as there are many different visitors to the same crop flowers. These limits suggest lack of scientific evidence for those regions. The role of pollination there has been masked by biased research interests in other factors of production such as soil fertility, pests, and water (Free 1999). Indeed, it is appreciated that the positive effects of pollination on crop yield can easily be reduced or hidden when other factors affecting crop yield, e.g., nutrients, micro-climates, water, pests or disease status are sub-optimal (Klein et al. 2007).

The varying pollination requirements of the flowering crops and their varieties make research needs more complex. For example, self-pollination is spontaneous in a flower. The flower structures are arranged such that it is easy for the pollen to touch stigma without need of an external agent. Physiologically, the male and female parts also mature at the same time. Although self-pollinated flowers may not require an external agent, sometimes the presence of agents such as bees enhances self-pollination, or enables cross-pollination that may be vital to the offspring performance. As an example, broad bean (*Vicia faba*) seedlings resulting from bee-pollinated flowers do not require bee visits to set good seeds, but those from unvisited (self-pollinated) flowers do not set seed (Stoddard and Bond 1987). Hybridization (cross-pollination) in such cases reduces inbreeding depression (Dryner 1956, 59; Bond and Fyte 1962). Other than self-pollination, which requires bees to enhance yield, there are other forms that require bees entirely for pollen transfer. These are geitonogamy and cross-pollination. Geitonogamy is the transfer of pollen from anthers to stigma of different flowers but in the same plant. It is also referred to as neighbor pollination. In 'true' cross-pollination, pollen source and pollen receiver flowers occur in different plants but of same species.

Most of the crop pollination studies have been done in developed countries. The information generated from such studies cannot be simply transferred to developing countries, e.g., Kenya, due to differences in ecologies. Pollinators in these countries may also be different. For example, while the bumble bee (*Bombus* spp.) is reported as the main pollinator of tomatoes in UK and US, there is need to determine the pollinators of this crop in Kenya where the bee does not occur. Several bees were observed in the farmland visiting flowers of beans (see Chapter 2). It is not known whether these bees also visit flowers of other crops grown there and who are the actual pollinators of the different crops grown in the farmland. One of the main features of the Kakamega people is their reliance on crops (staple, vegetables, fruits, nuts) for their daily needs. These crops require bee pollination to some extent, ranging from 0% to 100% reliance on bee pollination. For example, a crop such as maize is wind pollinated and may not require bees to vector its pollen. On the other hand, cucurbits require bee pollen vectors to ensure pollen is transferred from male flowers to female flowers in order to set fruits.

The results in this chapter are based on a study that was done to determine the possible bee pollinators of crops grown in the Kakamega farmland, and to measure the contribution of bee pollination to the harvestable yield of those crops. The findings would be useful in encouraging the Kakamega people and other stakeholders to invest in the management of crop pollination as one of the measures to curb food insecurity. The results of this study will be required to determine the effects of changes in bee pollination services on the net benefit gained by farmers who grow those crops (Chapter 6).

3.1 Materials and methods

Nine crops were selected and assessed for their dependence on bee pollination to reproduce, in Kakamega, Western Kenya. A large field was rented in the farmland and ploughed to fine tilth by use of a disc harrow plough. Plots of 15 m x 15 m were manually demarcated for sowing the different crops. Seeds of each crop were hand sown on a single plot at different times in 2005. This was done to avoid concurrence of flowering and to enable observations of pollinators for each crop. The crops included beans (*Phaseolus vulgaris* L.), cowpea (*Vigna unguiculata* Walp) and sunflower (*Helianthus annuus* L.), which were planted in the first season from the third week of March 2005. Other crops were planted in the second season (from first week of August 2005) and included tomato (*Lycopersicon esculentum* Mill), the purple passion fruit (*Passiflora edulis* Sims), squash (*Cucurbita pepo* L.), bambara nuts (*Voandzeia subterranean* (L.) Thouars), green grams (*Vigna radiata* (L.) Wilczek) and capsicum (*Capsicum annum* L.). These crops are all grown by the local farmers although under different acreage.

At the onset of flowering, bees were observed visiting flowers and their behavior noted to determine their potentiality to pollinate the crop. This was done differently for each crop. Bees were observed whether they were able to trip legume flowers or whether they could buzz pollinate[8] solanaceous crops. For passion fruits, bees were watched to see whether they could touch both anthers and stigma of a flower, as the gap between the two parts is usually large and not all bee visitors can bridge this gap to effect pollination. For sunflowers, observations were made to determine whether bees visited flowers in the female phase as they collected pollen, or nectar in the flowers that were in the male phase. The sunflower used was not male sterile, hence pollen of flowers in the same head could fertilize. Squash has separate male and female flowers although they occur in the same plant. Ability of a visitor to pollinate was done by observing whether when the visitor moved to the male flowers, it touched the anthers,

[8] Buzz pollination is when a bee shakes the porricidal anthers of solanaceous flowers as they collect pollen. This enables the pollen to be released, hence effecting pollination (see Buchmann 1983).

and while visiting the female ones whether it touched the stigma. The crop has massive pollen and once a bee visitor touches the anther, a lot of pollen becomes attached to its body hairs.

Some flowers (as many as possible to take care of abortion/drop-outs resulting from, e.g., hailstorm, strong wind, etc.) of each crop were bagged (with perforated insect netting) to prevent bee visits. This was done at the budding stage and the bag was removed shortly after fruit formation. Yield from bagged flowers was compared to yield from flowers left open (un-bagged) for natural bee visitation. There was no artificial introduction of bees, but passion fruit flowers were hand pollinated due to low number of bee pollinators present at the time of flowering, otherwise it would not have been possible to compare bagged with un-bagged flowers. Each crop was harvested after reaching physiological maturity, and yield (quantity) parameters were measured (seed number, seed weight, fruit weight). Quality measurements of the harvested products were also done for some crops. The size of the fruits of tomatoes, capsicum, passion fruit and squash were measured (polar and equatorial diameters), while seeds of cowpea and beans were analyzed for protein content using the Kjeldehl method of nitrogen determination (Pearson 1973). This method measures the percent nitrogen content of the sample and then multiplies it by a factor of 6.25 to get the percent protein content. Sunflower seeds were analyzed for oil content using the soxhlet extraction procedure (Pearson 1973). Solvent petroleum ether was used for the extraction. Percent oil content was calculated. The two procedures are commonly used for such analyses and results are comparable for samples of different weight.

3.1.1 Dependence of crops on bee pollination

The dependence of a crop on bee pollination (i.e., the contribution of bee pollination to the crop yield in quantity and quality) was measured for each crop. This was done by comparing the yield from bee pollinated flowers (un-bagged flowers) with those which had been denied bee visits (bagged flowers). This can be expressed formally as:

$$pdr = \frac{Y_{ub} - Y_b}{Y_{ub}} + qcv \qquad (3.1)$$

where pdr is the pollination dependence ratio of a crop; Y_{ub} is the yield (kg) from un-bagged flowers (with unlimited access by bees or from hand-pollinated flowers, whichever is higher); Y_b is the yield (kg) from bagged flowers (not accessed by bees); qcv is a quality coefficient value that represents the value addition due to a better quality after bee pollination.

The qcv equals 0.1 if there is quality enhancement or 0.0 if otherwise. The $\frac{Y_{ub} - Y_b}{Y_{ub}}$ is also known as pollination dependence amount, pda, which denotes the ratio of the amount of the harvestable product (kg) that is attributable to bee pollination. It is the pdr expression that has been used by previous studies such as Anonymous (2001), Carreck and Williams (1998) and Morse and Calderone (2001). The pdr value is a ratio that ranges from 0 to 1. The zero (0) value implies there is no (negligible) additional yield gain from bee pollinated flowers compared to the yield obtained from un-pollinated flowers, and hence bee pollination may not be required. The value one (1) means that without bee pollination the crop cannot reproduce. The solution in such a scenario is to incur cost of pollination by other means, e.g., employing people to carry out hand-pollination. The number of seeds are not included in the calculation of pdr, but only their weight and quality improvement, e.g., nutritional. Likewise, fruit size/juiciness is only included in the calculation through the qcv.

Data were analyzed by use of the SPSS statistical package version 14. One way analysis of variance (ANOVA) was done to compare means of the different treatments. Significance was tested at the 5% level. This was expressed in the probability (P) such that a value less than 0.05 was significant. Means were separated by use of standard error (SE).

3.2 Results

3.2.1 Bee pollinators

Individuals of more than 20 bee species were recorded visiting flowers of the selected crops (Table 3.1). It was not possible to make observations (records) of bees visiting flowers of capsicum, bambara nuts and green grams due to concurrence of their flowering with squash and tomato flowers. However, bees visiting flowers of the other crops were observed and noted for their pollination capability. Beans and cowpea flowers were pollinated by individuals belonging to several species of *Xylocopa*, *Megachile* and *Amegilla* bees. These bees are large, and their weight causes flower tripping. As they fly off, they leave some pollen scattered on the petals, which is gleaned by small bees, e.g., *Ceratina* spp. *Apis mellifera* steals nectar by accessing the nectary through the sides of the flower and therefore does not effect pollination[9]. Sunflowers were pollinated by *A. mellifera* and *Halictus* spp. Most of the *A. mellifera* visitors collected nectar on the male-phase flowers then moved to the female-phase flowers discarding the pollen on their body, thus effecting pollination. Tomato flowers were pollinated by *X. calens* and *Halictus* spp., which were able to buzz pollinate. *Apis mellifera* was observed robbing the tomato flowers of their pollen by tearing open the porricidal anthers and taking away the pollen. They did not buzz or agitate the anthers to release pollen. Passion fruit flowers were pollinated by the large bees belonging to *Xylocopa* species and *Megachile* species. These species are large enough to touch the stigma with their body hair while they collect nectar. *Apis mellifera, Ceratina* spp. and *Halictus* spp. are small sized and could easily collect nectar without touching stigma or anther. They also collected pollen without touching the stigma of the passion fruit flower. Squash was adequately pollinated by *A. mellifera. Meliponula* bees are quite small in size and do not pollinate the crop. They were observed collecting nectar, but with a great deal of effort. This is because the flowers of squash have numerous hairs, which prevent the small bees from moving easily. Also, most of the *Meliponula* bees drowned in the nectary.

In general, the observations revealed that squash and sunflower had the lowest number of effective pollinators. Any factor that reduces the number of *A. mellifera* in the farmland would impact on the productivity of these crops.

[9] A bee which is a thief collects nectar and/or pollen without effecting pollination. This may be due to the flower morphology that is not adapted to the bee's behavior. On the other hand, a robber bee causes tear or damage to the flower so that it can collect nectar/pollen. It also does not effect pollination.

Table 3.1: Behaviour of bee species visiting flowers of different crops at Kakamega farmland, Western Kenya, 2005

Bee species	Beans	Cowpeas	Sunflower	Tomato	Passion fruit	Squash
Apis mellifera	T	T	P	R	T	P
Xylocopa calens	P	P	-	P	P	-
Xylocopa incostans	P	P	-	-	P	-
Xylocopa flavorufa	P	P	-	-	-	-
Xylocopa [a] spp.	P	P	-	-	-	-
Xylocopa nigrita	P	P	-	-	-	-
Megachile [a] spp.	P	P	-	-	P	-
Amegilla [b] spp.	P	-	-	-	-	-
Ceratina [b] spp.	T	T	T	-	T	-
Halictus [b] spp.	-	-	P	P	T	-
Meliponula [b] spp.	-	-	T	-	T	T

- no bees observed; T pollen or nectar thief; R pollen robber; P pollinator; [a] 5 species; [b] at least 2 species

3.2.2 Dependence of crops on bee pollination

The bagged and un-bagged flowers were used to assess the effects of bee pollination on crop yield. The bagged flowers were assumed to have had spontaneous self-pollination (or non-bee pollination) while there was a strong possibility that the un-bagged flowers were visited by bees. The number of seeds per pod of the legumes (pulses) obtained from bagged and un-bagged flowers were found to be significantly different (Table 3.2). However, this difference was relatively lower for beans (25%) and green grams (27%) compared to the other legumes, while cowpeas showed the highest difference (43%). The results show that the mean number of seeds was lower than the maximum attainable in the un-bagged flowers, implying that bee pollination of the legumes in the study area was not sufficient.

Table 3.2: Mean number of seeds per pod of legume crops grown in Kakamega farmland in 2005 as influenced by bee pollination

	Beans	Cowpea	Green grams	Bambara nuts
Bagged flowers	4.86 (44)	7.75 (44)	8.36 (32)	1.10 (70)
Un-bagged flowers	6.48 (50)	13.51 (112)	11.50 (32)	1.68 (76)
Difference (%)	25.00	42.60	27.30	34.50
SE	0.227	0.319	0.37	0.05
P	0.000	0.000	0.000	0.000

Number in parentheses represents N value; maximum number of seeds attained by the un-bagged flowers was 7 (beans), 19 (cowpea), 15 (green grams), 2 (bambara nut)

Seeds per pod of the pulses obtained from un-bagged flowers were significantly heavier than those from bagged flowers (Table 3.3). Bambara nuts had the highest percent difference in weight (61%) that could be attributed to bee pollination. Generally, all the four pulse crops had 40% or more improvement in seed weight due to bee pollination. The difference in weight was higher than the difference in the seed numbers (Table 3.2). The only possible reason for this difference is the source of the pollen. Similarly, seeds of both beans and cowpeas from un-bagged flowers had higher protein content than those from bagged flowers. Cowpea seeds had higher percent protein content than beans, although the increment of protein due to bee pollination was higher for beans than for cowpeas.

Table 3.3: Mean seed weight (g) per pod and percent seed protein content of four legumes grown in Kakamega farmland, Western Kenya in 2005

	Beans		Cowpea		Green grams	Bambara nuts
	Weight (g)	Protein (%)	Weight (g)	Protein (%)	Weight (g)	Weight (g)
Bagged flowers	0.73 (40)	16.80	0.78 (40)	22.83	0.32 (32)	0.72 (59)
Un-bagged flowers	1.22 (45)	19.33	1.33 (95)	24.90	0.61 (32)	1.85 (71)
Difference (%)	40.00	13.00	41.00	8.00	43.00	61.00
SE	0.07	0.51	0.06	0.23	0.03	0.08
P	0.000	0.013	0.000	0.000	0.000	0.000

Number in parentheses represents N value

There was also a significant difference in the quantity and quality of fruits obtained from bagged and un-bagged flowers of tomatoes and capsicum (Table 3.4). Higher weight and seed number was recorded for fruits obtained from un-bagged flowers. Tomato fruits benefited from bee pollination by a 15% weight gain while capsicum fruits had a 56% weight gain due to pollination. The fruits were also larger in terms of polar and equatorial diameters, implying that they benefited in quality due to bee visits. Such increment in size of the fruits was catalyzed by the development of seeds.

Table 3.4: Yield parameters (mean) of tomatoes and capsicum fruits as influenced by bee pollination in Kakamega farmland, Western Kenya in 2005

		Fruit weight (g)	Polar diameter (cm)	Equatorial diameter (cm)	Developed seeds/fruit (No.)
Tomatoes	bagged flowers	36.44 (66)	4.47(66)	3.88 (66)	48.80 (66)
	un-bagged flowers	43.03 (152)	4.61(152)	4.16(152)	83.95(152)
	Difference (%)	15			
	SE	1.18	0.06	0.05	2.96
	P	0.000	0.000	0.000	0.000
Capsicum	bagged flowers	20.95 (31)	4.64 (31)	3.70 (31)	71.67 (31)
	un-bagged flowers	47.61 (62)	6.52 (62)	5.10 (62)	163.68 (62)
	Difference (%)	56.00			
	SE	2.89	0.22	0.15	10.83
	P	0.000	0.000	0.000	0.000

The number in parentheses represents N value

The purple passion fruit used in this study is known to be self-fertile but not self-pollinated. It was found to benefit from cross-pollination (Table 3.5). Fruits from hand pollination showed a significant difference in all measurements when compared with fruits obtained from bagged flowers except for polar diameter. Hand pollination usually provides sufficient pollination similar to having enough visits by the effective pollinator (*Xylocopa* spp.) for adequate pollen to be transferred to the flower stigma. Although the difference between the fruits obtained from bagged and hand-pollinated flowers was significant, bagged flowers were not expected to bear fruits. Some reasons that may have contributed to the pollen transfer within the same flower include effects of the netting material especially in combination with wind.

Table 3.5: Yield parameters (mean) of passion fruits obtained from bagged and hand-pollinated flowers at Kakamega farmland, Western Kenya in 2005

	Fruit weight (g)	Polar diameter (cm)	Equatorial diameter (cm)	Developed seeds/fruit (No.)
Bagged flowers	31.20 (36)	4.75 (36)	4.04 (36)	105.39 (36)
Hand-pollinated flowers	38.09 (43)	4.85 (43)	4.14 (43)	137.99 (43)
Difference (%)	18.00			
SE	0.66	0.03	0.03	2.11
P	0.000	0.143	0.075	0.000

Number in parentheses represents N value

Sunflower gained both in quantity and quality from cross-pollination (Table 3.6). Seeds obtained from bagged sunflower heads had significantly lower weight and oil content compared to those obtained from un-bagged heads. A difference in weight of 57% and 21% in oil content was noted in the seeds obtained from bagged and un-bagged flower heads. The number of developed seeds was also significantly different. Similarly, the number of undeveloped seeds was higher in the bagged flower heads, implying that bees enhance the yield of sunflower while collecting their food. Other than enhancing cross-pollination within the same head, bees can also bring pollen of different plants. The number of seeds obtained on the bagged heads could be the result of bagging effects, where wind helped to disseminate pollen that had fallen in the net, or just by rubbing and shaking the net on the flowers in a head.

Table 3.6: Yield parameters (mean) of seeds harvested from sunflower grown in Kakamega farmland, Western Kenya in 2005

	Seed weight (g)	Developed seeds (No.)	Developed seeds (%)	Oil content (%)
Bagged flower heads	6.17 (48)	93.04 (55)	18.33	35.36
Un-bagged flower heads	14.23 (33)	266.44 (36)	57.29	44.87
Difference (%)	57.00			21.20
SE	0.79	14.15		0.90
P	0.000	0.000		0.000

Number in parentheses represents N value; means are from ¼ of the sunflower head

All the fruits harvested from squash were due to bee pollination. The bagged flowers could not produce fruits, because there is no spontaneous self-pollination in this species (Figure 3.2). Both pistillate and staminate parts occur in different flowers, although in same plant. Therefore, this crop depends almost entirely on bee pollen vectors.

Figure 3.1: Fruits from bagged (small undeveloped fruit, top and tagged) and un-bagged flower of squash grown in Kakamega farmland, Western Kenya in 2005

The weight of squash fruits and their size depend on the number of developed seeds. The seeds usually trigger development of mesoderm, hence the more the seeds, the more ‘flesh’, and thus weight. In this study, the number of developed seeds was found to significantly correlate (positive) with the weight of the fruits (see Figure 3.3). Seed production follows successful pollen deposition in the stigma and subsequent pollen tube germination. Bees (*A. mellifera*) were responsible for the pollination, and the more pollen deposited, the higher the likelihood of fertilization of more ovules, resulting in an increased number of seeds. Thus, better pollinated flowers produced a higher fruit weight.

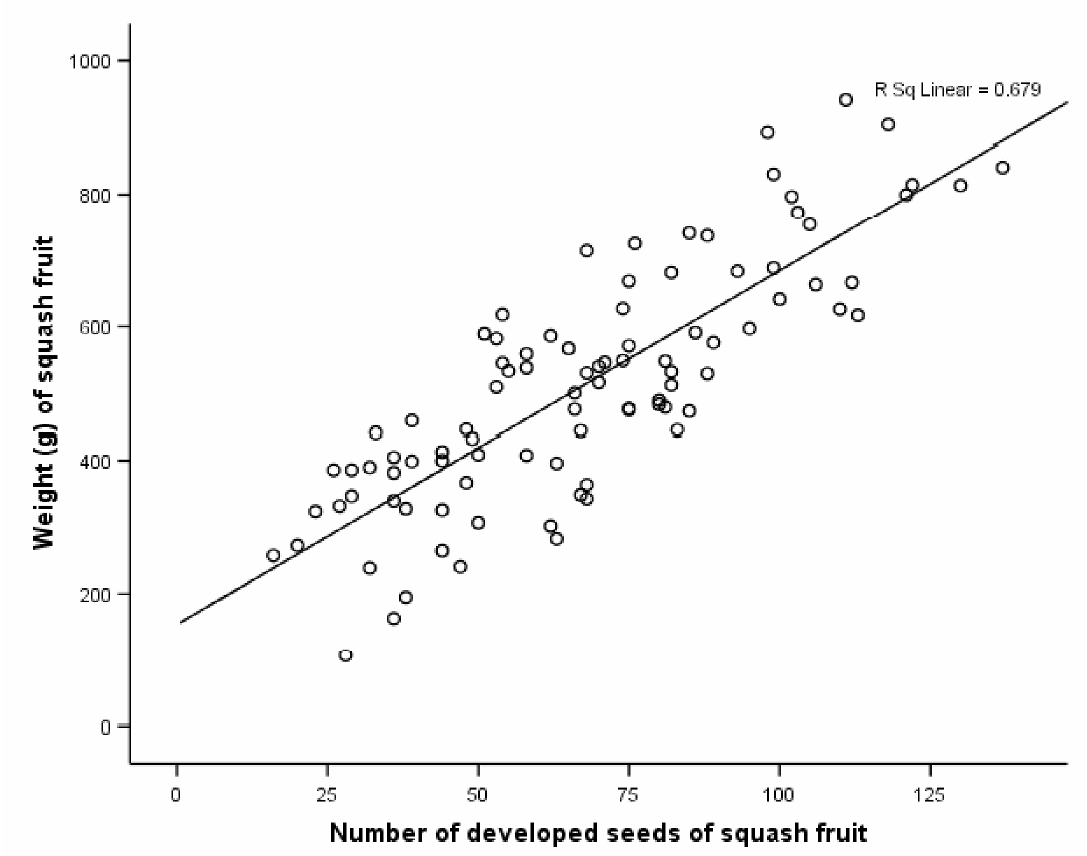

Figure 3.2: Relationship between the number of developed seeds and the fruit weight of squash grown in Kakamega farmland, Western Kenya in 2005

The dependence of the crops on bees for their reproduction varied (Table 3.7). Apart from squash, sunflower and capsicum had the highest pollination dependence ratio, while tomato had the lowest. The parameter given for passion fruits is not from bee but from hand pollination. Usually, hand pollination should provide the highest attainable yield as a result of cross-pollination, which can also be achieved if the number of effective bee pollinators is adequate. There was no yield comparison for squash, as no data were recorded from bagged flowers. It is assumed that without bees (*A. mellifera*), the crop can only produce with assistance from man or by chance if visited by nectar thieves. Therefore, the pollination dependence ratio due to bee pollination is close to 1.0. The ratio expresses the contribution of bees to the harvestable yield of the crop.

Table 3.7: Dependence of crops on bee pollination at Kakamega farmland, Western Kenya, 2005

Crop	*pda*	*qcv*	*pdr* [a]
Beans	0.40	0.1	0.50
Cowpea	0.41	0.1	0.51
Green gram [b]	0.43	-	0.43
Bambara nuts [b]	0.61	-	0.61
Tomatoes	0.15	0.1	0.25
Capsicum	0.56	0.1	0.66
Passion fruit	0.18	0.1	0.28
Sunflower	0.57	0.1	0.67
squash	Not calculated		*ca* 1.0

pda *pollination dependence amount;* qcv *quality coefficient value;* pdr *pollination dependence ratio;* [a] *see equation 3.1;* [b] *quality measurements were not done, and hence only* pda *explains the* pdr*; - not measured*

3.3 Discussion

3.3.1 Study limitation

The pollination experiments were done in one season to assess the contribution of bee pollination on crop yield. Long-term experimental studies may be required to assess the stability of pollination service for each crop as the pollinating insects are known to show high temporal variation (Cane and Payne 1993; Roubik 2001) as well as changes brought about by habitat changes (Cane et al. 2005; Tylianakis et al. 2005). It will be important also to determine the pollination biology and pollinator requirements for each crop, considering the many new crop varieties that are available and the contribution of pollination services by different pollinators. It was difficult to estimate dependence of passion fruit on bee pollination due to the absence of an efficient pollinator, while the bagged and hand pollination might have been affected by other factors (it was expected that bagged passion fruit flowers would produce no/or very few seeds). However, the experiments are useful and act as a pointer to the importance of bee pollination not only in the research area but in the country as a whole.

3.3.2 Crop pollinators and pollination

Among the different bees observed visiting flowers of different crops, only some were capable of effecting pollination. All the four legumes (beans, cowpea, green grams and bambara nut) were found to gain from pollination when yields between bagged and un-bagged flowers were compared. There are few studies world-wide on the dependence of these crops on bee pollination. The available literature indicates that beans can increase seed yield (weight) by 8% to 35% depending on the variety (Mackie and Smith 1935; Barrons 1939; Free 1966; Ibara-Perez et al. 1999). This is comparable to the 40% weight increase recorded by this study. This present study also noted an improved cowpea yield due to bee pollination similar to findings by Warnock and Hagedorn (1954). Generally, previous studies have noted that bee pollination does not result in a significant increase in pod numbers, but the number and weight of seeds in a pod do increase. The findings of this present study are relevant in Kenya and other developing countries where farmers grow beans mainly for seed consumption.

Previous studies do not relate seed protein content of beans and cowpeas to bee pollination (e.g., Bliss 1975; Langer and Hill 1991). This study therefore provides further information on the role of bee pollination in legume nutrition. In Kenya, beans, cowpeas and other legumes are the main protein source of most rural people, who can rarely afford animal protein. Increased protein content of these legumes could impact positively on the nutritional status and health of these people. Farmers should, therefore, be advised to manage bees for pollination of their legumes, which are grown by most of the farmers (MAO 2006). Not only legume crops but also commodities of other bee-pollinated plants are reported to have more nitrogen. Recently, Njoya (2005, unpublished data) reported Okra (*Abelmoschus esculentus* (L.) Moench) pods to have a higher nitrogen content when visited by bees.

The reliance of solanaceous crops (tomatoes and capsicum) on bee pollination has been reported by several studies done in other parts of the world (e.g., de Ruijter et al. 1991; Jarlan et al. 1997; Kwon and Saeed 2003). Tomato flowers require bees that can buzz pollinate. Honeybees are not buzz pollinators and are considered not effective in pollinating tomatoes. A few bees are reported to pollinate tomatoes elsewhere in the world such as halictid bee (*Augochloropsis ignita* Smith) and the bumble bee (*Bombus* spp.), which is currently managed for pollinating greenhouse tomatoes (see Banda and Pixton 1991; Kevan et al. 1991; van Ravestijn and van der Sande 1991; Almanza 2007 for more information on *Bombus* bee uses). The candidates *X. calens* and *Halictus* spp. as possible pollinators of tomatoes therefore seem to provide the local solution to tomato pollination. In terms of benefits gained, Hogendoorn et al. (2006) reported 11% increase in tomato fruit weight due to single *Amegilla* spp. buzzing in Australia, while unlimited flower visits increased fruit weight by 21%. Jarlan et al. (1997) likewise reported increased capsicum yields of up to 19.3% for flowers allowed unlimited visitation by bees. Later, a study by Kwon and Saeed (2003) showed 27.2% and 47.8% increase in fruit mass and seed number of capsicum, respectively, due to bumble bee pollination. Apart from increase in fruit weight, fruit sizes also increase when flowers were bee pollinated. Reduced pollination has been reported to result in malformation of fruits (McGregor 1976). The results of this study, therefore, are comparable to previous findings.

Flowers of passion fruit require large bees to effect pollination. Honeybees and other small-sized bees collect nectar and pollen without causing pollination. Although the purple passion fruit is self-fertile, it cannot self-pollinate and it requires *Xylocopa* species to effectively pollinate flowers as they collect pollen and nectar (Morton 1987; Knight and Sauls 1994). The activity density of *Xylocopa* bees was low, indicating that this crop was probably experiencing inadequate pollination in Kakamega. Unlike passion fruits, sunflower is pollinated by honey bees (e.g., Free 1993; DeGrandi-Hoffmann and Watkins, 2006; Greenleaf and Kremen 2006). The honeybee population in Kakamega was not limiting, but use of insecticides can affect its future pollination (Oronje 2006 unpublished data). In Kenya, this crop is mainly grown for seed oil (higher amounts were found in the seeds obtained from bee-pollinated heads). Squash, just like other cucurbits, benefits from bee visits. Honeybees are reportedly used in other parts of the world for commercial pollination of squash (e.g., Sanford 1995). Other bees reported to be better pollinators of squash (e.g., the *Peponapis* spp.) were not observed in Kakamega and it seems only honeybees effected pollination of this crop.

The findings that sunflower and squash are mainly pollinated by *A. mellifera* suggest that production of these crops could be considerably affected if *A. mellifera* population became limiting. Farmers willing to invest in large-scale production of these crops should consider managing *A. mellifera*. Although at the time of this study, there was no indication of a declining number of *A. mellifera* in the crop fields, this cannot be ruled out in future. This will especially be the case if only few farmers continue to engage in beekeeping (MOLD 2006), while at the same time their nesting sites are threatened. Although other crops seem to have a wide range of pollinators, they may not be reliable owing to their low population density. This is particularly so when one considers that these bees are not currently managed in the farmland.

3.3.3 Effects of bee pollination on market requirements of the commodity

The market requirements in Kakamega vary depending on the commodity. For example, the nutritional improvement of legumes does not play any role, as it is only observable traits that are considered in the market. Therefore, commodities with high protein will achieve same price as those with lower protein content. Similarly, oil content of sunflower seeds is not considered in its pricing. However, for fruits and vegetables, quality plays a major role. Polar and equatorial diameters therefore are very important for the price of tomatoes, capsicum, passion fruits and squash. The use of the quality of commodities as part of value addition may in future play a major role in the pricing of commodities as the awareness of nature increases.

3.4 Conclusions and recommendations

That the nine selected crops depended to a great extent on bee pollination for their yield is a key finding from this study. It is also shown that solitary bees play a major role in crop production in the Kakamega farmland, as they were the main pollinators of four out the six crops that bees were observed visiting. Honeybees were the main pollinators of two crops, which their production would be highly impacted if the honeybee population were to decline. About 57% and more than 99% of the yield increase in sunflower and squash, respectively, were due to honeybees. In addition, an increase of about 21% in sunflower seed oil was realized due to honeybee pollination. Among the legumes, the lowest difference in the number of seeds per pod in the bagged and un-bagged flowers was recorded in beans (25%); the highest number was observed in cowpeas (42%). However, both had a similar seed-weight difference (about 40%), but beans showed a greater difference in seed protein (13%). These yield improvements were due to solitary bee pollination. During the time of the research, the main pollinator of passion fruit flowers was limiting, but the results show that cross pollination improves fruit weight and size. Although field tomatoes are generally thought to benefit from wind pollination, *Xylocopa calens* and *Halictus* spp. improved the weight and sizes of the fruits. The seed weight per pod of green grams and bambara nuts obtained from un-bagged flowers was higher (43% and 61%, respectively) than that obtained from bagged flowers, implying that cross pollination is quite important. Similarly, there was a 56% increase in the fruit weight and size of capsicum due to cross pollination.

There is, therefore, a need for further research to determine the pollination requirements of other crops not considered by this study. Research should also be done to determine ways of enhancing crop pollination in the farmland. Farmers should be advised to manage bee pollination in order to improve their crop yields. This could be done through campaigns for better prices of crop commodities produced in systems that encourage the growth of bee pollinator's populations. In Kenya, the prices of some high-valued crops such as pyrethrum (*Chrysanthemum* spp.) are based on the content of pyrethrin in flowers. Likewise, sunflower farmers could be paid depending on the content of seed oil. This would encourage farmers to improve populations of different bee species on their farmland.

4 FARMERS’ KNOWLEDGE OF BEES AND THEIR NATURAL HISTORY IN KAKAMEGA FARMLAND

This chapter presents the study on the interaction of farmers and bees in Kakamega farmland. Individuals of different bee species were shown to decline as the distance from the forest into the farmland increased (Chapter 2). This relationship is an indication of the role of the forest as an important habitat for bees that pollinate crops in the farmland (Chapter 3). However, the diversity of the bees was not influenced by the distance. Gikungu (2006) showed that the diversity of bees was higher in the open farmland than in the forest. Both diversity and abundance are important factors to consider while managing pollination. This is because different crops are pollinated efficiently by different bees (Chapter 3). The number of the effective pollinator is important as it ensures the crop receives sufficient pollination.

It is likely that the bee population in the farmland did not provide sufficient pollination of crops. This is mainly due to the low numbers of the pollinators, indicated by the observed low activity density of bees that visited the bean flowers (Chapter 2), and by the fact that some crops (e.g., passion fruits) were not visited by their effective pollinators (Chapter 3). The factors responsible for a low numbers of bees in a farmland are many, including the influence of human activities (Richards and Kevan 2002). This is especially so when such activities take place without considering their effect on bees.

Bees construct their nests in wide variety of areas, e.g., in the earth, dead wood or tree branches, and they do so using a wide range of materials for nest construction such as mud, resins, or leaves. The areas where they construct their nests are also used by humans for many different activities such as cultivation, grazing, firewood or timber. As such, bees can be decimated by humans, knowingly or unknowingly through elimination of their preferred nesting sites (Kremen et al. 2002). Faced by lack of safe sites, bees will usually relocate to secure sites. Depending on the new location of the bee nesting areas in relation to the crop fields, pollination could be affected. Insufficient pollination would result in low yield of crops dependent on bee pollination and thus a reduction in farmer income. The role of bee pollination in supporting wildlife also cannot be ignored. For example, shrubs that prevent soil erosion and that are relied on by many different life systems may be at risk when bees decline (Barclay and Moffett 1984; Levin and Waller 1989).

Conservation and sustainable use of pollinators especially in agricultural landscapes requires the participation of farmers, who are the end-users (consumers) of the pollination service (Gurung 2003). This should be through physical means and by use of their expertise, which is usually coupled with their knowledge. The farmer knowledge base can be used in combination with scientists' expertise to improve local practices in integrated farm management systems and in developing proper policies for pollinator conservation. Studies elsewhere have reported understanding of the potential and drawbacks of the local knowledge system as a prerequisite to constructive collaboration between farmers, scientists and extension service providers (Marcia and Katrina 2000; Gurung 2003).

This present study was done with the assumption that farmers take time to observe useful insects, e.g., bees, as well as harmful ones such as crop pests, and hence can differentiate different insect species. Most folk entomology studies have found this to be true and have used this fact to form part of the reasons for folk classification (e.g., Bentley and Rodriquez 2001). This study was not intended to elucidate the reasons behind classifications of bees by farmers in Kakamega, but to assess their knowledge about the natural history and importance of bees as crop pollinators. This chapter will therefore provide information on the level of understanding of the Kakamega farmers about temporal and spatial needs of bees. The findings of this study form the base for the contingent valuation of crop pollination service by bees (Chapter 7).

4.1 Materials and methods

The data required to meet the objectives of this study were collected through a survey schedule. A formal questionnaire (see Appendix 10.2) was developed and administered to a random sample of 352 households that were selected from a total of 19,972 households. This is the population that dwelt in close proximity to Kakamega forest within a distance of up to 10 km from the forest edge. A multistage random sampling was done, whereby a sample of 22 villages was drawn from 210 villages, and then from each village 16 households were selected. The enumeration was done in January and February 2006.

Four enumerators were trained about the issues of pollination and pollinators and how to carry out the enumeration process. They also understood the local language, and therefore it was easy for them to communicate with the respondents. Furthermore, they were graduates of agriculture-related fields and had experience of enumeration from previous studies. A pretest was done to help refine the questions and have hands-on experience on what was to be expected. This also helped to improve the confidence of the enumerators. The initial questions were intended to record the respondents' socio-demographic characteristics that would help to explain differences of the farmers' knowledge.

The next set of questions addressed the respondents' knowledge of different bee species (the crop flower visitors), their nesting requirements and food resources. It was expected that farmers would have knowledge of honey bees (*Apis mellifera* L.) and stingless bees (*Meliponula* spp.) because of their cultural use. For example, honeybees are kept in the farmland for honey and other hive products while stingless bees produce honey that may be used in the locality for specific reasons such as therapeutic purposes. Therefore, no effort was made to describe these two kinds of bees, e.g., by use of pictures. But pictures of locally occurring insect species (solitary bees, butterflies, beetles, locusts, flies, etc.) were presented to the respondent to help in identification of the bees. The pictures had been taken from a previous study in the farmland (chapters 2 and 3). Respondents were asked to identify bees among the insect pictures (see Figure 4.1). This was done to capture their acquaintance of bees other than honeybees and stingless bees, which had been introduced earlier. The pictures were randomly arranged and numbered such that the enumerator could record the insect number that a respondent pointed as bee. Some preserved specimens of the insects (bees inclusive) were also provided in a preservation box to present 'real' specimens when the need arose.

Another section consisted of questions about the respondents' knowledge of the natural history of bees. Respondents were asked to state where bees (the insects they had pointed correctly as bees) constructed their nests and what they fed on. They were also asked to give a list of flowers they perceived were attractive to bees and whether those plants were in their farm's live fence. Extra questions were asked to determine how the farmers utilized bees. Respondents were asked to state whether they (the household) kept honeybees (*Apis mellifera* L.) and the number of hives they had. They were also asked whether they kept stingless bees for honey production. Respondents were finally asked whether they knew pollination and its role in crop production, this being part of bee utilization activity. The question was introduced indirectly, i.e., by asking them whether they thought there were benefits accruing (related to crop yields) when bees visited their flowers. By replying in the affirmative, the respondent would then be asked to state the benefit. Two follow-up questions were asked to confirm their answer: First, they were asked to state whether a crop flower was important for crop productivity (this was done using examples of crops that require flowers for reproduction). The second question was to capture their knowledge on whether such a flower has to be fertilized to bear fruit or seed.

Finally, respondents were reminded of the mechanism of pollination, the role of bees in effecting pollination and the economic worth of pollination in crop production. These introductory remarks set off the final questions of the survey schedule. Respondents were asked to state their perception of the effect of pollination on production of their crops. Two levels were created: Pollination was perceived as either very important or not so important. They were ultimately asked whether they would be willing to improve bee pollination in order to guarantee adequate pollination of their crops. Those who replied in the affirmative were asked to list the main ways of doing so, while those who refused were asked to state reasons for their opinion.

a b c d

Figure 4.1: Use of visual aids during interview sessions with the respondents in Kakamega farmland, Western Kenya, 2006 (a- pictures of different insect species being shown to a farmer; b- a farmer pointing at a bee; c- demonstration of pollination process to the farmer by the enumerator, and, d- emphasis on the effect of pollination on yield)

4.1.1 Data analysis

The results provided here are for all the 352 respondents and were analyzed by use of SPSS statistical software version 14. Descriptive statistics are provided (e.g., frequencies, means, median). Means were separated by standard deviation (SD) and significance tested at 95% level. Logit regression analysis was done to determine factors that influenced the knowledge of pollination of farmers.

4.1.2 Logit model and study hypothesis

The Logit model is one of the useful models used when the dependent variable is categorical. This is because for such a variable, the ordinary least squares (OLS) regression method is inefficient as it cannot produce the best linear unbiased estimator (Gujarati 1995; More and McCabe 2000; Kennedy 2003).

Logistic regression allows one to predict a discrete outcome from a set of independent variables that may be continuous, discrete, and dichotomous, or a mix of any of these. The dependent variable in this study, the knowledge of pollination, has binary values, i.e., yes or no response. Therefore, the dependent variable can take a value of 1 (yes) with probability of success (the respondent knew pollination), P, or the value 0 (no) with the probability of failure (not having knowledge of pollination), $1-P$. The independent variables usually can take any form, as the logistic regression model makes no assumptions about their distribution.

Logistic regression equation is the transformation of P:

$$P = \frac{e^{(\alpha+\beta_1 x_1+\beta_2 x_2+...+\beta_i x_i)}}{1+e^{(\alpha+\beta_1 x_1+\beta_2 x_2+...+\beta_i x_i)}}$$

where α is the constant of the equation and β is the coefficient of the predictor variables, x. An alternative form of the logistic regression equation is:

$$\text{logit } [P(x)] = \log\left[\frac{P(x)}{1-P(x)}\right] = \alpha + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_i x_i$$

Since logistic regression calculates the probability of success over the probability of failure, the results of the analysis are in the form of odds ratio. For example, in the case of pollination, we know the characteristics of the respondents, e.g., age, education, gender, etc. and we want to know the probability of a respondent, with known values of those characteristics, having knowledge of pollination. The odds ratio will be:

$$odds = \frac{P}{1-P}$$

The odds of an event is the probability that the event occurs to the probability that it fails to occur. The probability of an event is not equal to its odds. For example, assume the probability of a respondent knowing pollination is 0.90 (i.e., a no answer has 0.10 chance), the odds of yes is $0.90/0.10$ which is 9 to 1 (= 9). For a no, it will be 0.10/0.90 which is 1 to 9 (= 0.11). This is not statistically appealing, as the odds of yes should be opposite to the odds of no (for a normal distribution to occur). The odds lie between 0 and $+\infty$, with 1 as a neutral value for which both outcomes are equally likely, hence they are asymmetric. This makes it impossible to construct a linear equation for predicting probabilities. The solution to this problem is to use log *odds*, which is the natural logarithm of the odds. Log *odds* are symmetric and lie within $-\infty$ to $+\infty$ and the value to which both outcomes are equally likely is 0. Therefore, coefficients from the logistic regression equation can be interpreted in the usual way, i.e., they represent the change in the log odds of the response per unit change in the predictor.

Several hypotheses were therefore constructed for selecting variables to include in the model. This involved considering findings from other socioeconomic surveys, and considering the objectives of this study. For example, education was chosen as an independent factor as it was hypothesized that people with longer years in school are likely to be aware of the existence and functions of pollination due to the lessons learned in school, or exposure to reading, audio and visual materials. Age and gender were also seen as likely factors due to farming experience, while it was assumed that knowledge of bees and nectar or pollen may be a prerequisite to knowing about pollination. It was also thought that respondents belonging to households visited by agricultural officers may be more likely to know pollination, while household heads and spouses have more conduct with other farmers and share farming experiences.

4.2 Results

4.2.1 Sample characteristics

Most of the respondents interviewed had basic formal education (Table 4.1), with over 60% of both gender having had more than six years of schooling. The mean number of years spent in school by female respondents was lower than that of male respondents, as expected. The average age of the respondents was 40.9 years. However, the mean age of males was slightly higher than that of the female respondents, as expected a priori. Age difference is a common phenomenon in a household as most husbands are older than their spouses. Also most of the respondents (61.6%) were female, who happen to be the main participants in farming. Few respondents (13.0%) said they had been visited by a government extension officer at least once in one year. This was much lower than expected. Most of the respondents said they got information on farming issues from family members or relied on their own experience, confirming the low conduct time with extension officers.

Table 4.1: General characteristics of the respondents interviewed at Kakamega farmland, Western Kenya in 2006

Variable	Males	Females	Total respondents
Gender (percent)	38.4	61.6	
Mean age (years)	43.6	39.3	40.9
Mean number of years in school	7.5	5.7	6.4
Percent households visited by extension officer in 1 year			13.4% households

N: male-135; female- 217

4.2.2 Knowledge of bees

Almost all the respondents knew honeybees and stingless bees (Table 4.2), which they mentioned without being shown pictures. Both gender had equal understanding of honey bees. However, male respondents had better knowledge of stingless bees than the female respondents. With the aid of the pictures, at least 98.0% of all the respondents pointed correctly to a bee belonging to different species of solitary bees (Table 4.2; see also Figure 4.2). It was observed that among the solitary bees, three males of *Xylocopa* spp. were identified by many respondents as a bee (53.4%) and were lumped together (see Figure 4.2). Females of *X. calens* and *X. incostans* were also mostly identified as bees (49.5% and 42.9% of the total respondents respectively). Female respondents were more familiar with solitary bees than the male respondents. Most of them recognized bees amongst the other insects in the pictures. The percentage of male respondents was only slightly higher amongst those who identified pictures of female *X. incostans* and *Halictus* spp. as bees. When asked, most respondents said they could differentiate bees from crop pests, with male respondents being more affirmative (96.3%) than female respondents (94.0%), although such difference was not statistically significant.

Table 4.2: Percentage of respondents who were familiar with different bees that visit crop flowers in Kakamega farmland, Western Kenya, 2006

Bees	Correct identification		
	Male	Female	Total respondents
Apis mellifera, honeybee	99.5	99.5	99.4
Meliponula spp., stingless bee	99.5	94.9	96.6
Xylocopa spp. (male)	52.6	53.9	53.4
Xylocopa calens (female)	38.5	49.8	45.5
Xylocopa incostans (female)	45.2	41.5	42.9
Megachile spp.	34.1	36.4	35.5
Xylocopa nigrita	28.9	37.8	34.4
Ceratina spp.	32.6	32.3	32.4
Xylocopa flavorufa (female)	11.9	14.7	13.6
Halictus spp.	12.6	12.0	12.2

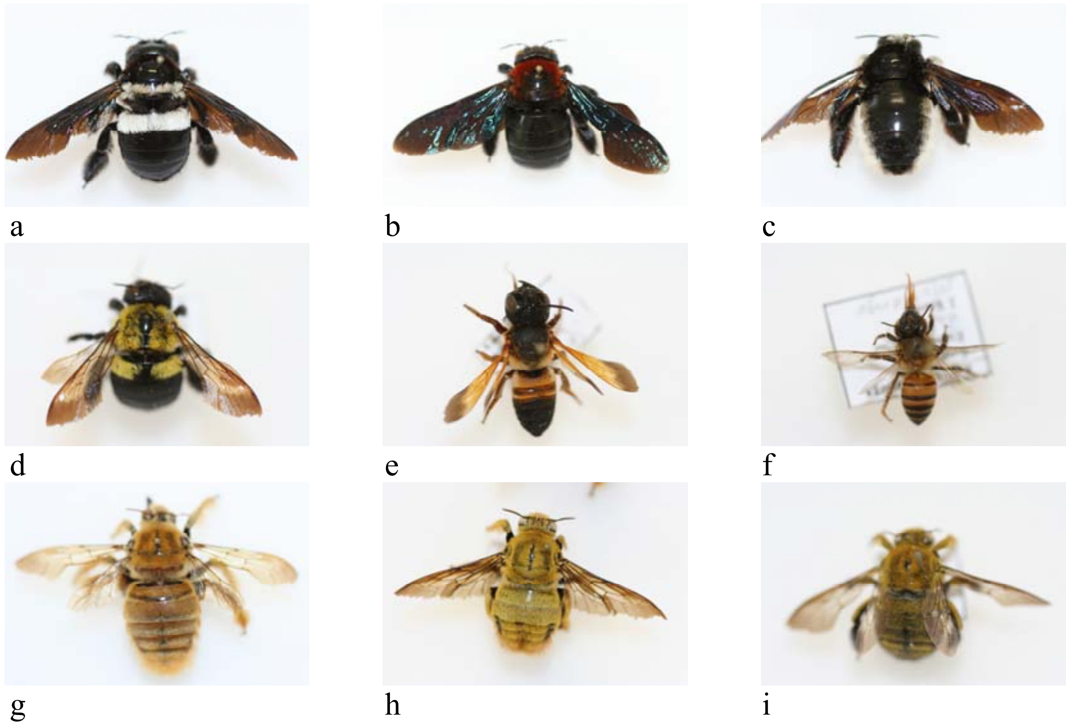

Figure 4.2: Insect species identified correctly as bees by the respondents in the Kakamega farmland, Western Kenya, 2006 (a- *X. incostans*, b- *X. flavorufa*, c- *X. nigrita*, d- *X. calens*, e- *Megachile* spp., f - *A. mellifera*, g h i - males of different species of *Xylocopa*)

4.2.3 Knowledge of bee natural history

Most of the respondents listed several sites where they claimed bees (the already recognized) constructed their nests (Table 4.3; see also Figure 4.3). Apart from honey bees, all other bees were reported to mainly build their nests in the housing structures, e.g., roof poles, rafters or mud walls. Other areas mentioned by the respondents were ground, tree branches and dead wood (logs). However, male respondents were more familiar with the nesting sites than females. It was only the stingless-bee nest in the house structures (mainly mud walls) that had more responses from the female than from the male respondents. Although all claimed that stingless bees could dwell on the ground or in tree branches, most of them were convinced that these bees dwelled mainly in the housing structures (85.0%). Few respondents were of the opinion that stingless bees nested in ground. In fact, male respondents (43.0%) were more convinced than their female counterparts (31.9%).

Among the respondents who recognized solitary bees when displayed with other insects, 97.8% of the male respondents indicated they knew their nesting sites while 90.8% of the females were affirmative. Most respondents said solitary bees preferred to nest in house structures. This was indicated by 79.3% and 73.7% of the male and female respondents, respectively. Other areas reported as sites for solitary bee nesting were tree parts, ground and dead wood, although these options received less affirmative responses from the respondents.

Table 4.3: Respondents knowledge of different bee nesting sites [a] in Kakamega farmland, Western Kenya in 2006

Nests	Affirmative responses		
	Percent male	Percent female	Percent total
Stingless bee			
House parts [b]	83.0	86.6	85.2
Ground	31.9	15.2	21.6
Tree branches	26.7	12.0	17.6
Solitary bees			
House structures [b]	79.3	73.7	75.9
Ground	44.4	34.6	38.4
Tree branches	43.0	40.1	41.2
Dead wood	43.0	28.6	34.1

[a] each nesting site was listed independent of the other hence should not be equated to 100; [b] includes roof poles, rafters, walls, furniture

About 73.0% of the respondents indicated that most bees that were seen to construct their nests on the ground were honeybees and stingless bees (see nests, Figure 4.3). The land use in such areas was mainly cultivation, as reported by 36.4% of the respondents. Other uses were grazing or land had been left fallow.

a b

c d

Figure 4.3: Nests of different bee species reported by farmers in Kakamega farmland, Western Kenya in 2006 (a- house mud wall showing entrance of a stingless bee nest and a worker, b- bare crop field showing ground nest; c- log with a nest, d- nest of *Nomia* spp. and the bee constructing it)

More than 79% of the respondents said they knew bees collect nectar and/or pollen when visiting crop flowers. However, the male respondents had a higher positive response (88.1%) than the female (73.7%). The knowledge of nectar and pollen also varied among the respondents. Male respondents were more acquainted with floral resources of the bees (pollen and nectar) than female. For example, 69.6% of the male respondents knew nectar compared to 56.2% female. This was same for pollen, where 53.3% of the males affirmed their knowledge while only 34.6% of the females did so.

4.2.4 Utilization of bees by farmers

Among the respondents, only 12.2% said their households were involved in beekeeping. Most of those households had one or two bee hives (69.1%), but up to 12 hives per household were reported (Figure 4.4). Of the households involved in beekeeping, 69% said all the hives had bee colonies. Likewise, of all households, 80% preferred to set their hives near a crop field in order to maintain a certain distance from the homestead. This was a risk management option to avoid or reduce occurrences of members of the household being stung by bees. Questions about who does the actual beekeeping (duty sharing) in the household were not asked.

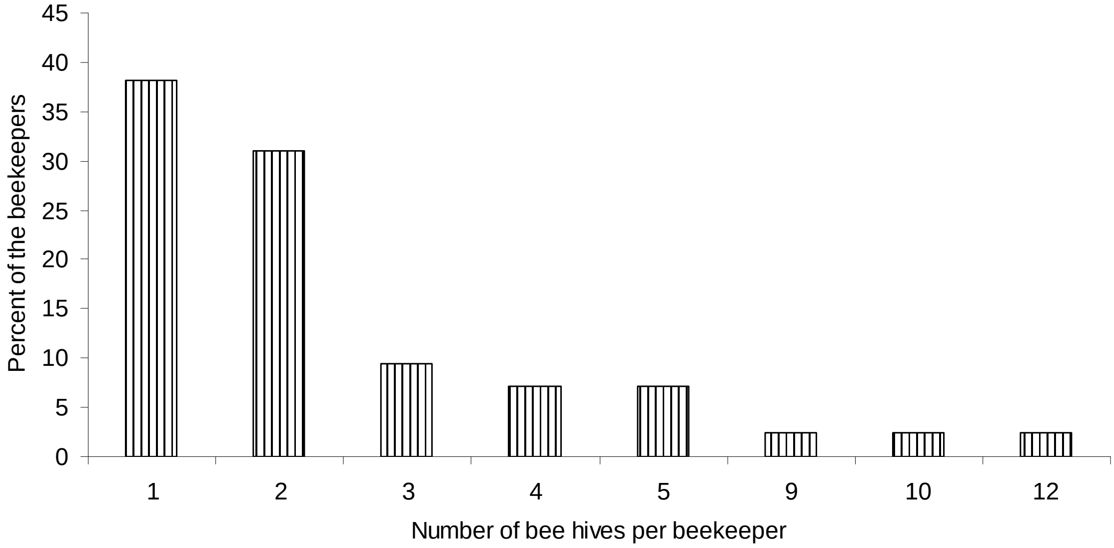

Figure 4.4: Number of honeybee hives owned by households in Kakamega farmland, Western Kenya, January and February 2006

Most of the respondents (65.3%) said they harvested honey from stingless bees although they did not rear them, while the rest did not harvest because the harvesting activity was done by children (70.2%) as a part-time or leisure activity, and the honey did not have a domestic use (12.5%).

Although many farmers (98.0%) said they always saw bees visiting crop flowers in the flowering period, only 47.2% acknowledged that crops benefit through pollination. However, male respondents had a better understanding of pollination (58.5%) compared to the female respondents (40.1%), although this was not significant (Table 4.5). Factors that could possibly have influenced the knowledge of pollination by farmers were selected for logit regression (Table 4.4).

Table 4.4: Respondent variables selected for preliminary logit regression

Variable	Description
EDU	Years of formal schooling of the respondent, years
AGE	Age of the respondent, years
GENDER	Gender of the respondent, 1 male, 0 female
DBP	Ability to differentiate a bee from a crop pest, 1 yes, 0 no
RHHS	Position in the household, 1 household head/spouse, 0 otherwise
KHB	Knowledge of bees, 1 yes, 0 no
RELIGION	Religious affiliations, 1 catholic, 0 otherwise
KNP	Knowledge of nectar and/ or pollen, 1 yes, 0 no
SOI	Source of information about farming, 1 extension services, 0 otherwise

After excluding variables with no effect on the model from the final logistic regression analysis, it was shown that four factors significantly influenced the knowledge of pollination (Table 4.5). Respondents who spent more years in school were more likely to know pollination. Similarly, those who had been visited by extension officers at least once in a year were also likely to respond affirmatively to the pollination question. Other factors that influenced farmer knowledge of pollination were the ability to differentiate bees from crop pests and the knowledge of nectar and/or pollen. Gender and age did not significantly influence knowledge of pollination.

Table 4.5: Logit regression values of factors that determined respondent knowledge of pollination in Kakamega farmland, Western Kenya, 2006

Variable	Coefficient	SE	Significance
Constant	-2.999	0.034	0.000
AGE	0.007	0.008	0.328
GENDER	0.377	0.247	0.127
EDU	0.136	0.034	0.000
KNP	0.518	0.310	0.094
DBP	1.147	0.638	0.072
SOI	1.059	0.363	0.004

-2 log likelihood = 433.883; chi square = 52.96; probability (chi square) = 0.000; pseudo R^2 = 0.186

To better understand the respondents' knowledge about the importance of flowers and flower fertilization, they were asked to state whether a crop, e.g., avocado or beans, would bear fruits or seeds without flowers. Most of them (96.3%) gave a negative answer. This response was same across the gender. When asked whether the flower requires fertilization in order to produce the fruit or seed, only 35.5% were certain that this was necessary, while 27.3% said fertilization was not required. The rest

(37.2%) were indifferent. This knowledge of flower fertilization differed across the gender, with male respondents showing a higher knowledge level. For example, 45.2% of the males said such flowers require fertilization, while only 29.5% of the female counterparts replied in the affirmative. While most female respondents were indifferent (38.7%), most males were affirmative. This difference in the knowledge of pollination and flower fertilization across the gender may be due to education, as the male respondents had spent more years in school than their female counterparts.

4.2.5 Possibility of bee conservation in the farmland

Most of the farmers (60.2%) did not use chemical pesticides to manage crop pests. Among those who reported to have used a pesticide, most of them (92.0%) used insecticides targeting pests that occur before blooming stage. They mainly applied the pesticide either early in the morning before 08:00 h (68.1%) or late in the evening after 18:00 h (22.6%). However, the pesticides they were using are quite toxic to bees (e.g., pyrethroids and carbamates) and require a long time to break down. Most of the respondents used a combination of cultural practices in pest management, e.g., smoking, ash or use of hand, while others never applied any control measure (23.9%). Smoking is done by burning selected shrubs (dry and/or green), which are known to produce thick smoke. The smoke is directed to the infested crops to suffocate or repel the pests. Ash is applied in powder form or dissolved in water and sprayed. It targets both below and above ground pests. Hand picking is also practiced where pests (or infested parts) are removed from the crop and killed (or burned). Weed control is done by mechanical means, using hand-operated tools (Jembes). This practice has a negative effect on ground-nesting bees, some of which prefer to construct their nests on crop fields just before and during the flowering period.

Most of the households in the farmland have live fences (93.5%), which usually merged with their neighbors' fence (95.7% of those with live fence). Farmers identified many plant species (Table 4.6 and Appendix 10.3) that they maintained in their live fences. Most of the households used the fence for boundary marking (86.6%) and as a source of fuel (66.5%). Plants that have spines and can easily intertwine were also given priority of establishment (33.0%). Other main reasons given were fence plants as a source of medicine (20.5%) and animal fodder (20.5%). The fence is mainly managed through trimming (88.4%) and weeding (15.1%).

Table 4.6: Main plant species in live fences in Kakamega farmland farms, January and February 2006, Western Kenya

Plant species reported by respondents			Percent respondents
Botanical name	English name	Luhyia name	
Lantana camara (shrub)	Lantana	Lantana	84.4
Tithonia diversifolia (shrub)	Tithonia	Lihua lilulu	43.5
Croton macrostachyus (tree)	Croton	Musutsu	30.7
Psidium guajava (tree)	Guava	Shepera	27.3
Markhamia lutea (tree)	Markhamia	Lusiola	25.0
Caesalpinia decapetala (shrub)	Cat's claw	Luavari	22.7
Cypressus lustanica (tree)	Cypress	Mutaragwa	22.2
Dracaena fragrans (shrub)	Dracaena	Tsikhubu	21.0
Eucalyptus saligna (tree)	Eucalyptus	Mukambi	18.5
Agave sisalana (shrub)	Sisal	Likonga	14.2
Euphorbia viminale (shrub)		Shinakotsi	13.6
Bridelia micrantha (tree)		Shikangania	11.4
Plectranthus barbatus (shrub)		Virhokho	10.2

Respondents (94.4%) reported that the plants (in the fence) usually flowered at different times of the year such that there were flowers present all year round. More than half of the respondents (55.7%) indicated that bees preferred fence flowers to crop flowers when flowering coincided. When asked what they would do to improve bee population sizes on their farms, most of them said they would favor constructing honeybee hives (60.5%) and planting more shrubs in their fence (51.1%). It was suggested to respondents that trap nests could be an option for improving bee populations (see Figure 4.5). After the demonstration of how trap nests can be constructed using local materials, and their usefulness as alternative nests for bees, only 39.1% of the respondents said they could construct such nests, although some thought it would be easier to buy them if someone would volunteer to construct these.

Figure 4.5: A locally made solitary bee trap nest presented to respondents during an interview in Kakamega farmland, Western Kenya in 2006

4.3 Discussion

Farmers in Kakamega were able to identify bees among the insects provided, and this implies they have some basic knowledge of bees that occur in the farmland. The knowledge of eusocial bees (*A. mellifera* and *Meliponula* spp.) could be mainly related to their continued utilization for honey and other hive products. Other studies elsewhere have shown that the cultural value (in terms of utility) plays a role in folk knowledge especially by enhancing their acquaintance with a species (e.g., Bentley and Rodriquez 2001). It seemed that no cultural role was played by the solitary bees that can be said to contribute to the knowledge. However, farmers may be familiar with the bees due to the frequent visits of bees to crop and fence flowers. The sound that emanates from the wing muscles as the bees fly from flower to flower can cause human 'disturbance' and make farmers to be familiar with the bees out of the mere curiosity of knowing who makes such sound. Although respondents were able to point to different bees, they were unable to differentiate males of *Xylocopa* species. This could be due to the lack of reason in doing so, as Bentley and Rodriquez (2001) found in their study of reasons behind folk classification by Honduran folks. The observation by the farmers tallies with the empirical evidence in the present study (Chapter 2) which reported *X. calens* as being the most common solitary bee visiting the flowers of beans (*Phaseolus vulgaris* L.) closely followed by *X. incostans*. The *Xylocopa* spp. were more easily identified than other species. This may be due to their relatively large body size and abundance in the farmland compared to the less common *Megachile* spp. and small-sized *Halictus* spp. Such traits (occurrence, body size) have also been expressed by other studies elsewhere as determinants of folk knowledge (e.g., Atran 1987; Berlin 1990, 1992; Bentley 1992ab, 1993, 1994). It was surprising that farmers in Kakamega farmland were able to differentiate bees and insect pests, unlike in Central Kenya where farmers were reported to lump bees and pests together (API 2004), although this could have been influenced by the questionnaire design used in that study.

Apart from *A. mellifera*, which is managed, other bee species were reported to construct their nests in house structures. This may imply that the farmland lack safer sites for bees to construct their nests. The farmers, on the other hand, view bees as domestic pests. Households would most likely not be able to tolerate destruction of their furniture by bees as they construct their nests. However, crop management activities in the farmland are not perceived as leading to decimation of bees foraging on the crops. But this does not imply that the status quo will hold. Therefore, there is a need for educational campaigns to advise farmers on best farm management options for growth of bee populations. For example, during flowering periods, pesticide application should be applied in the evening when bees have already retreated to their nests. Only pesticides that have very short pre entry period should be applied, and mainly early in the morning if evening applications are not possible. Other activities such as fuel wood collection and grazing could possibly influence bee populations through reduction of bee nesting, resting or hiding sites. Farmers can be advised about the management of bee forage and especially to only use plants for their fuel wood or timber that do not house bee nests.

The fence 'corridors' should also be managed to provide habitats or 'stepping stones' and connectivity for pollinators between the forest and interior of the farmland. Most of the plant species listed by the farmers were reported by Gikungu (2006) as main food sources for different bee species, e.g., *Croton* spp., *Acanthus pubescens, Caesalpinia decapetala*. Most of them are also reported by MOA (2006) as good sources of nectar and pollen for honeybees. In other parts of the country, e.g., Baringo district, beekeepers perceived *Croton* spp. as an important nectar plant (Gichora 2003). There are also many abundant flower shrubs, e.g., *Justicia flava* that were not mentioned by farmers because these species do not require farmer intervention for establishment. In most cases, these shrubs are weeded out by farmers while in essence they provide bees with pollen and nectar at different times of the year. Therefore, the flora richness of the area can be managed effectively to provide forage for bees during periods when crops are not flowering. The management of crop pollinators in the farmland should also aim at attracting bees to the crop flowers, e.g., by planting shrubs or trees that do not flower at the same time with the crops. Activities such as fence weeding should be discouraged to provide undisturbed environments for ground nesting bees. One of the advantages of increasing the population sizes of different bees is the assurance that some bees will visit crop flowers, particularly when crops and non-crop plants are flowering at the same time (Kevan et al. 1990). The management of the fence should, however, take care of the needs of the farmers, so that their main goal of having the fence is not affected.

Because many farmers were willing to conserve bees, they could be trained on how to make and utilize trap nests for solitary bees. This could involve methods on how to drill holes of specific sizes on untreated blocks of wood or making simple nests such as bundling pithy stemmed plants (like bamboo) together. The aim is to make use of locally available resources. It is also possible to train specialists, e.g., carpenters, so that they can offer the services to willing farmers. Bees are known elsewhere in the world to nest in snail shells and abandoned nests of mud dauber wasps (Sphecidae) (O'Toole and Raw 1991) and these facilities may be available in the farmland.

A relatively large number of farmers were aware of flower requirements for fertilization compared with farmers in Central Kenya (API 2004) and Coastal Kenya (Pakia 2005), who were unable to perceive sexual processes in the fruit or seed set of a crop. Generally, farmers in the present study showed knowledge of pollination, which is comparable to the 51.0% beekeepers noted by Gichora (2003) in Baringo district, Kenya, who were familiar with cross-pollination. This information may be required by extension officers to know the level of understanding of the farmers while developing teaching aids on the importance and management of pollination.

4.4 Conclusions and policy implications

Farmers had a good knowledge of bees. About 98% were familiar with different bee species. Most of them also knew their nest sites and food resources. However, only about 50% knew the function of pollination in crop production. Only a small number of the farmers (12%) were beekeepers. Most of the farmers (84%) were willing to conserve bees for pollination purposes mainly through beekeeping projects, hedgerow management and use of solitary-bee trap nests. The farmer knowledge revealed in this study can, therefore, be used in activities geared towards conservation of bees in Kakamega. This can be successful if end users know exactly the benefit of doing so. Education was reported to impact on the farmers' knowledge of pollination. People who spend more years in school had a higher regard of the role of pollination than those who spent only a few years in school. As such, the government should emphasize on policies that bring information to the farmers. The role of extension services was found to significantly improve respondents' knowledge of pollination, and hence the government should increase and empower the extension department. This will help in enhancing information provision to the farmers through, e.g., frequent visits, making bulletins or using other channels such as radio or television. The government should continue to support a school curriculum that instructs the young people (future farmers) on the importance of bees for their wellbeing. The current fencing system can support bee conservation if well managed and therefore, initiatives should be introduced to tap this avenue.

5 TECHNIQUES USED TO MEASURE ECONOMIC VALUE OF ECOSYSTEM SERVICES

In this chapter, I briefly describe techniques and methods that have been used to value ecosystem goods and services. In the strict sense, ecosystem goods are the tangible products we extract from an ecosystem such as food products (e.g., fruits, vegetables etc.), while services are the intangibles we enjoy such as waste assimilation, pollination, etc. In this chapter, the two terms will be used interchangeably. Other terms, e.g., environmental services, environmental resources, etc. also refer to the ecosystem goods/services. Essentially, this chapter provides background information required for understanding easily chapters 6 and 7, which describes valuation of pollination services using different methods. In this chapter, two main approaches to economic valuation of ecosystem services are differentiated: the market-based (revealed preferences) and non-market-based (stated preferences) methods.

5.1 Concept of ecosystem services

Before elaborating on the issues of ecosystem services, we need to understand the underlying concept of ecosystem function. This is a concept that was craved in the 1960s to facilitate analysis of the benefits that accrue from the ecosystem to the society (Odum 1969; Hueting et al. 1998). The concept defines the capacity of an ecosystem to provide services (i.e., goods and services) that satisfy human needs directly or indirectly (de Groot 1992). The ecosystem benefits as classified by the Millennium Ecosystem Assessment (MA 2003) include the provisioning services such as food and water, regulating services such as climate regulation and biological control of pests, supporting services such as soil formation and nutrient cycling, and cultural services such as recreational, spiritual and other nonmaterial benefits. In this classification, pollination is considered as one among the regulating services. However, in other classifications, e.g., the UNEP-coordinated global environmental outlook process (GEO-4; cited in Hein and Mburu 2006), it is conveniently and rightfully considered as a production service.

Biodiversity and ecosystems are closely related concepts. Biodiversity is the variability among the living organisms and the ecological complexes of which they are part (MA 2003). It includes diversity within and between species and diversity of ecosystems. Products of biodiversity include many of the services produced by ecosystems. Therefore, changes in biodiversity can influence all other services provided by ecosystems. For example, pollination service relies on several biotic and abiotic agents. The change in the biotic agents, which are part of the biodiversity, impacts on the pollination provision.

The demand for ecosystem services has increased over time such that trade-offs among services has become the rule. When a country decides to increase its food supply by, e.g., converting a forest to agriculture, such action may reduce the supply of the ecosystem services to one that may equal or surpass the benefits that accrue from the conversion to agriculture. However, as the awareness of the economic importance of the lost value of ecosystems increases, many nations are now considering the effects of any development project on the ecosystem. Such nations have established environmental management authorities to advise the executive on the matters of environment. Therefore, research on the economic value of the benefits we derive from different ecosystems is in high demand.

5.2 Values of ecosystem services: current paradigms

The value of ecosystem services is frequently ignored or underestimated in nearly all of the decision-making processes of governments. This is probably because of the many different disciplines, philosophical views and schools of opinions that are involved in assessing the value of ecosystems (MA 2003), making such evaluation difficult. There are two distinct paradigms that explain the value derived from the ecosystem: the utilitarian and non-utilitarian concepts.

The utilitarian (also known as anthropocentric) paradigm is based on the principle of human welfare (preference satisfaction) (OECD 2002; MA 2003). It is thought that people derive utility from the use of ecosystem services either directly or indirectly (i.e., use values). Within this concept, it is also considered that people may value ecosystem services that they are not currently using (non-use values). The non-use values define cases where humans ascribe value to knowing that a resource exists even if they never use that resource, and/or when the humans want to keep the resource as it is for future generations even if they do not use it themselves (Krutilla 1967; McConnell 1983; NOAA-CSC 2007).

The non-utilitarian paradigm holds the view that something can have an intrinsic value (i.e., it can be of value in and for itself) irrespective of any utility that an individual can derive from it (Callicot 1989; OECD 2002). This concept usually proceeds from a variety of ethical, cultural, religious and philosophical bases. However, there are usually differences on the specific entities that are deemed to have intrinsic value, as well as on the interpretation of what it means to have intrinsic value (Botkin 1990; MA 2003).

In this chapter, focus will be on the utilitarian paradigm. A wide range of methodologies have been developed to attempt quantification of the benefits of different ecosystem services. However, the choice of a valuation technique in any given instance is dictated by the characteristics of the case and by data availability. It is widely acknowledged that valuation is inseparable from choices and decisions made about nature (e.g., Bingham et al. 1995; Mitchell and Carson 1989). Societies are faced daily with trade-offs about nature and are forced to make choices. The process of valuation therefore begins when any decision has to be made, and even though it is difficult to measure the value of ecosystems, attempts have been made. Experience has shown that better choices are realized when information is available. Hence, the valuation exercises generate the much needed information. In some countries such as the USA, information generated from nature valuation is accepted as part of evidence in courts of law and forms a strong base for compensation calculations, e.g., the values obtained from a contingent valuation study after the Exxon Valdez oil spill (Carson et al. 2001).

5.3 Economic value of ecosystem services

As previously pointed out, the economic value of ecosystem services is based on the utility human beings derive from them. The utility may be gained or lost depending on the situation. For example, a person who walks in a national park, or who picks fruits in a forest gains utility from the ecosystem. A utility gain could also be achieved by harvesting, e.g., timber that is offered for a price in the market. Institutions that manage parks or forests also gain utility as they offer their services at a price. Likewise, utility is gained by crop growers when crops are pollinated by bees or other pollinating insects. In the absence of these or other gains, the utility that would have been gained is said to be lost.

Ecosystem services portray two kinds of properties: private-good and/or public-good characteristics. Public goods are those services that have two main features: non-rivalry and non-excludability. Rivalry refers to whether one agent's consumption is at the expense of another's consumption, while excludability refers to whether agents can be prevented from consuming (Perman et al. 2003, p. 126-134). Therefore, non-rivalry means that the use of the good by one individual does not diminish the use that others can make of the good. Sometimes terms such as depletability or divisibility have been used to describe this characteristic (e.g., Freeman 2003, p. 3). Non-excludability means that once the good has been provided to one individual, others cannot be prevented from making use of it whether they pay for it or not (Freeman 2003). Examples of public goods are: street lighting, air, scenic view, etc. On the other hand, private goods do not possess such characteristics and their uses are restrictive. In between the private and public goods are other 'intermediate' goods. Those goods that are non-rivalrous but excludable are known as club goods, e.g., television waves. Those goods that are rivalrous but non-excludable are known as common pool resources, e.g., deep-sea fishing (see also Perman et al. 2003, p. 126). The definition of the good therefore depends on the valuer and the current provision of the good to the target economic agent. For example, in some countries pollination is managed and traded in the market, hence it can be said to be a private good (though not pure private good), while in other regions it is not managed and farmers rely on nature (hence public good).

Where ecosystem services have private-good properties, it is assumed that market forces can shape their utilization in a sustainable manner to ensure it is available to the agents. But most ecosystem services have public-good characteristics, especially non-excludability, which leads to market failure as they are produced at sub-optimal levels. This implies that market forces cannot be used in their management. In cases where the private market fails to provide the optimal level of public good, the assurance of its provision requires collective action by the users in terms of setting the rules for its management and use. In many instances, this also fails, especially where good-will of the agents is demanded. The failure leads to the so-called tragedy of commons, where the resource is utilized to its depletion, with everyone experiencing the loss at the end (e.g., Hardin 1968). Governments therefore play an important role to assure sustenance of public resources. Because there are many competing needs a government has to address, valuation of the ecosystem services enables the government to make informed decisions about their management. Government management (allocation of the required resources) of ecosystem services are, therefore, guided by how the government rates such goods vis-à-vis other competing needs (see also Samuelson 1954; Hoppe 1989; Varian 1993; Colell et al. 1995; Holcombe 1997; Gravelle and Rees 2004).

5.4 Typology of ecosystem values

Economists have devised a general term that encompasses all the values derived from the ecosystem services. These different values are aggregated to get total economic value (TEV) of that ecosystem service (Figure 5.1).

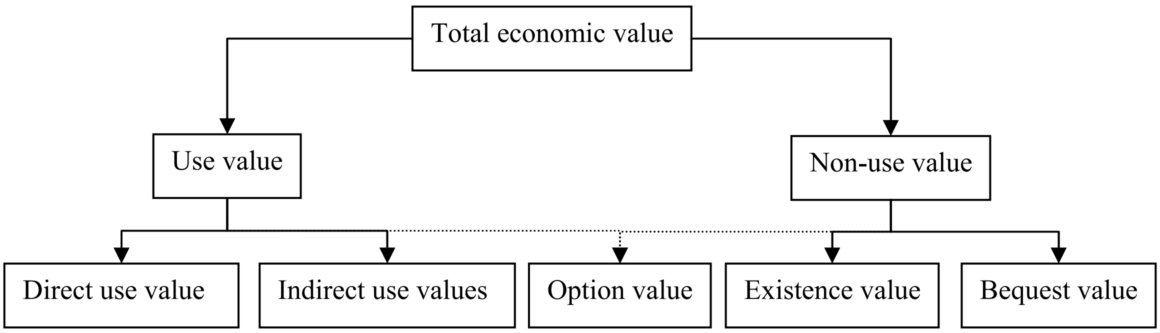

Figure 5.1: Typology of economic values derived from an ecosystem service
Source: various (e.g., Mitchell and Carson 1989; Birol 2002; OECD 2002; Perman et al. 2003)

The direct use values are those derived from direct utilization of an ecosystem service, including both consumptive uses (e.g., wild fruits) and non-consumptive uses (e.g., recreation). The indirect use values are indirectly utilized through the functions of an ecosystem, e.g., carbon sequestration, water storage, biological control of pests, pollination. Existence values are those that are derived from people who are willing to pay to prevent a good from extinction (i.e., to maintain the good in its natural habitat) even if there is no actual, planned or possible use. The bequest values are those from people who want to preserve the good for their future generation (i.e., to maintain the good in its natural habitat). Between the use and non-use values lies the option value. These are values from people who are unsure of the use of a given good and would want to keep it in case they might need it sometime in the future, e.g., for pharmaceutical purposes.

5.5 Measurement of the economic value of ecosystem services

5.5.1 Theoretical background

Economic valuation of the benefits that accrue from ecosystems is based on the preferences of an economic agent[10]. Preference forms a strong base in economic analysis of values that an economic agent places on a good (Freeman 2003). It is assumed that people have well defined preferences among alternative bundles of goods, which consist of quantities of both marketed and non-marketed goods. It is also assumed that they know their preferences and that these preferences have the property of substitutability among the market/non-market goods that make up a bundle (Freeman 2003). Substitutability implies that if the quantity of an element in an individual bundle is reduced, it is possible to increase the quantity of some other element so as to leave an individual not worse off because of the change. This property is important, as it establishes trade-offs that people make between pairs of goods that matter to them. For example, they may choose less of one good and substitute more of another. In doing so, they reveal the value they place on those goods. Such values are expressed in terms of willingness to pay (WTP) for the good or willingness to accept compensation (WTA) to forego its use.

Individuals make choices and preferences in their everyday life with the intention of satisfying their welfare/well-being. That is why the standard economic theory is based on the welfare effects of the changes in the prices people pay for the goods they consume. This is also similar to measuring welfare effects of changes in quantities and qualities of ecosystem service flows. The change in the provision of an ecosystem good can affect individuals' welfare in many ways, e.g., through changes in the prices they pay for goods bought in the market, prices they receive for their factors (inputs) of production, quantities or qualities of non-marketed goods, or changes in the risks they face (Freeman 2003).

There are two important assumptions required when measuring the welfare effects on an individual due to changes in price of goods. The first is known as non-satiation (more is better). This implies that an individual will prefer a bundle with large quantities of an element to that with less (*ceteris paribus*). The second is the

[10] Economists usually refer to the entities they study as economic agents. They may be producers or consumers, individuals or firms.

substitutability among at least some components of a bundle (Freeman 2003). This means that if the quantity of one element is decreased, it is possible to increase quantity of another element sufficiently to make an individual indifferent between the two bundles. If these assumptions are held, an ordinal preference function (i.e., the utility function) can be used to represent them. This is done by assigning a number to each bundle as a function of the quantities of each element of the bundle, which can be formally expressed as:

$$u = u(X, Q, T)$$

where u is the utility function of the individual, X the vector of quantities of market goods, Q the vector of public goods and services, and T the vector of time spent in various activities that yield utility to the individual (see Freeman 2003, p. 43-94). This ordinal utility function has no unit of measurement and hence cannot add or otherwise compare utilities of different individuals.

But let us consider an individual whose utility is a function of only private goods (that can be bought/sold in the market) and that his/her preferences and tastes (i.e., utility function) are given and do not change. This individual is faced with a set of prices for these goods and is assumed to choose quantities of goods that maximize his/her utility, given constraints of price and fixed money income, I. This can be expressed as:

Maximize $u = u(X)$ subject to

$$\sum^{i} p_i . x_i = I$$

where X is the vector of quantities $(X = x_1, ..., x_i, ..., x_n)$. The solution to this problem leads to a set of ordinary demand functions:

$$x_i = x_i\ (P, I)$$

where P is the vector of prices $(P = p_1, ..., p_i, ..., p_n)$. If we substitute the expressions for x_i as functions of P and I into direct utility function, we get the indirect utility function (i.e., utility as a function of prices and income) assuming optimal choices of goods, i.e.,

$$u = v\,(P, I)$$

Likewise, the expenditure function can also be used to solve the problem of individual choice. The function is derived from formulating the dual of the utility maximization problem. An individual is assumed to minimize total expenditure, e,

$$e = \sum^{i} p_i . x_i$$

subject to a constraint on the level of utility attained,

$$u(X) = u^o$$

where u^o is the maximum utility attained with the solution to the primal problem. The solution to this expenditure minimization problem leads to a set of functions that give optimal quantities for given prices and utility. These are the Hicks-compensated demand functions that show the quantities consumed at various prices assuming that income is adjusted (compensated), so that utility is held constant at u^o (see Freeman 2003). Substituting these demand functions into the expressions for total expenditure yields the expenditure function, which gives the minimum amount of expenditure required to achieve a specified utility level, given market prices,

$$e = e\,(P, u^o)$$

where e is the amount of expenditure and u^o is the specified utility level.

Both the indirect utility function and expenditure functions are quite important in measuring the value of ecosystem services, and their applicability varies depending on the good considered and the situation. Literature on environmental economics and ecological economics provide more details on the underlying theory of the measurements (e.g., Pethig 1994; van Kooten and Bulte 2000; Uno and Bartelmus 2002; Freeman 2003; Perman et al. 2003).

After formulating the basis of the valuation of ecosystem goods, another important step is to determine the source of the data about the preferences of the economic agent, which will be used for the valuation. So far, two sources can be distinguished: an indirect source where people's behavior is observed in a real-world setting where they have to live with the consequences of their choices, or, a direct source based on the responses of people to hypothetical questions (see Mitchell and Carson 1989, p. 74-87). The use of indirect sources is called the revealed preferences (RP) method, and the use of direct sources is known as the stated preferences (SP) method.

5.5.2 Classification of the valuation methods of ecosystem services

Different methods have been devised to measure ecosystem values although they still continue to be improved. As mentioned earlier, the methods are divided to two broad categories to accommodate the different sources of data: the revealed preferences and stated preferences methods. The RP methods are mainly market based while SP methods are non-market based. The RP methods are only capable of measuring the use value of an ecosystem good, while SP methods can estimate both use and non-use values. There are several approaches used for valuation in each category (Figure 5.2).

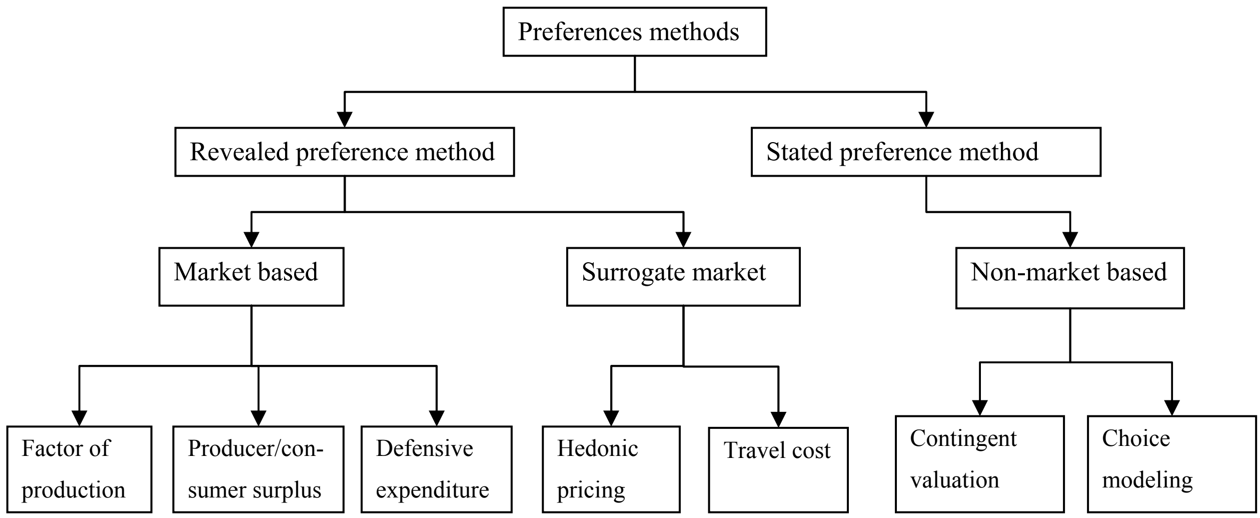

Figure 5.2: Techniques that can be used to value ecosystem services
Source: various (e.g., Freeman 2003; Perman et al. 2003; NOAA-CSC 2007)

Revealed preferences methods

Factor of production method

The factor of production method (FP) is also known as the production function or change in productivity method. It is used to estimate the economic value of ecosystem services that affect the production of commercially marketed commodities, i.e., where the ecosystem service is used as a factor or input in production along with other inputs. A change in the service will affect the output of the commodity, and this can be monetized to measure the marginal value of the ecosystem service (Perman et al. 2003). The value is therefore derived from observation of consumer and producer surpluses of the harvestable product, or that of the input substitutes of the good. This method is limited to those services that are used in, or have effects on the inputs required for the production process of commodities sold in the market. Pollination in agriculture supports commodity production. This method can therefore be applied in measurements of the value of pollination in crop production (see Chapter 6). There are four main possibilities where environmental goods can affect production (see Pethig 1994, p. 23-57). The first is where the good acts as a fixed factor. This can be formally expressed as:

$$y = f(x_1, ..., x_i, ..., x_n, q)$$

where y is the output, x is other inputs, and q is the ecosystem good. An example of this kind of relationship is the pollination service. A second instance is where the good affects the specific input that is used in the production, i.e.,

$$y = f(x_1, ..., x_i\ (q), ..., x_n)$$

where the environmental good affects x_i. The third case is where the environmental good affects the output, y. This can be stated as:

$$y = q\ f(x_1, ..., x_i, ..., x_n)$$

This implies that q neutrally affects the whole production. The final way has been described as a situation where good affects a specific input indirectly, e.g., by limiting its use. This is expressed as:

$$y = f(x_1, ..., x_i, ..., x_n)$$

with the added constraint $q(x_i) < q*$

For example, if q is water quality and x_i is the pesticide, $q*$ will be the upper limit for the pesticide concentration in the surface or underground water. These different applications imply that economic contribution of the ecosystem good to the production requires methods adapted to each specific case (see also Baumol and Oates 1975).

Producer/consumer surplus

The producer/consumer surplus method uses the standard economic method of measuring the net economic benefit of a good/service in a market, by examining the consumer and producer surpluses (e.g., OECD 2002; Freeman 2003; Perman 2003). Consumer surplus is the difference between what a consumer is willing to pay and the price offered for the good. Producer surplus is the difference between what a producer is paid for a good and what it costs to supply it. The total economic benefit of the good is, therefore, the sum of the consumer and producer surpluses. This method relies on complicated econometric techniques and time series data to relate the effect of a change of the ecosystem good on the consumer and producer welfare. It assumes there are no market distortions, which is rare in actual markets because of taxes, subsidies, monopolies, etc., implying that the market price does not reflect the true value of the ecosystem good.

The method is applicable to those goods that are traded in the market. Other than using those goods that are affected directly by the ecosystem good, it is also possible to value the ecosystem service if it has a substitute that is traded in the market. The price of the substitute good can be used as a proxy/shadow price for the value of the ecosystem resource, because it reflects the amount it is worth in terms of expenditures saved. For example, medicinal plants can be valued by using the value of the conventional medicine that would otherwise have been used for treatment of similar ailments (see Mugabi 2001). Where the ecosystem good is not traded and has no substitute, the use value can be calculated by measuring the time taken by an individual to harvest it, e.g., fuel wood. The labor and other costs used in preparing these services can be used to estimate their worth. This method can be used to measure the value of bee pollination, but it is limited due to lack of time series data that can help estimate producer and consumer surpluses of the service or its substitute.

Defensive expenditures

Defensive expenditures methods are used to measure the cost of actions taken to either avoid or counteract the loss of the ecosystem good (NOAA-CSC 2007). Counteraction may involve replacing the ecosystem good or providing a substitute. Other definitions are the preventive expenditure, damage avoided and replacement costs approaches. The assumption is that such cost involved should reflect the worth of the ecosystem service to the users. The methods are most applicable in areas where such actions have been or will actually be made. It is assumed that a rational economic agent will consider the level of damage after the impact is reduced and the mitigation measures required before taking the action. These will always be less than the original level of perceived damage. An example is the use of flood control barriers to offset negative impacts associated with the loss of wetland flood control services. This method is also applicable to the measurement of the value of pollination services, especially where steps have been taken to overcome or prevent damage caused by lost bee pollination (see Emerton et al. 1999 for more applications).

Hedonic pricing

The hedonic pricing method evaluates ecosystem services that directly affect the market prices (Mitchell and Carson 1989; OECD 2002; Freeman 2003; Perman et al. 2003). It has mainly been applied in the housing market. Data are taken over a period of time on the changes of price as the quality of the environment changes. For example, differences in values of properties are used to measure willingness to pay high prices for houses located near environmental amenities or with a good scenic view. The method can also be applied in agriculture, e.g., for measuring the value of irrigation water by observing the cost of land rents in schemes with and without access to irrigation water systems (e.g., Faux and Perry 1999).

Travel cost

The travel cost method measures the value of recreational sites by assessing the travel costs incurred by the visitors, e.g., out-of-pocket, time, park fee, etc., who come from different areas. The costs are considered as the willingness to pay for the recreational benefits provided by the site. Econometric models such as random utility models have been developed to compare the value of recreational sites that have different qualities. They aid in estimation of preferences among the competing recreation centers, and provide information on the probability that an individual will visit one site out of several sites based on site characteristics (see Herriges and Kling 1999; van Kooten and Bulte 2000; Freeman 2003).

Stated preferences methods

Contingent valuation

To date, contingent valuation (CV) is the most used SP method to value public goods. It is a direct elicitation method in that individuals are asked to state their willingness to pay (WTP) to have more of the good or willingness to accept compensation (WTA) in order to forgo the good. The method is so called because the values it reveals are contingent upon the constructed, hypothetical market (Mitchell and Carson 1989). The information about WTP/A is collected through questionnaires that are administered through telephone calls, mails or face-to-face interview schedules. The elicitation could be through open-ended questions, dichotomous choice questions or bidding games. Open-ended questions ask directly how much the respondent is willing to pay for the good in the hypothetical market. Dichotomous choice questions ask respondents whether they are willing to pay a certain value. In bidding games, a respondent is presented with a random value (starting point) and asked whether s/he is willing to pay the amount for the provision of the good. If yes, a higher value is quoted and asked whether s/he will pay. This iterative bidding continues until the respondent reveals his/her maximum WTP. Based on the survey responses, mean and median WTP/A values are estimated for a change in the environmental good (Mitchell and Carson 1989). This method can be used to measure value derived from virtually any ecosystem good, including pollination (see Chapter 7).

There are three important procedural steps required of CV studies. The first step involves documentation of the target group of the study. This is the population that is likely to be affected by the public good that is to be measured. Sampling a larger population than the user group is also possible for estimating the non-use values. Sample selection, therefore, depends on the objective of a given study. The second step is the choice of the method of elicitation: whether by mail, face-to-face or telephone. This depends on the target group, available resources or cultural context. The next step is the construction of the hypothetical market. This involves three key parts: firstly, the description of the good offered. All information on the nature of the good and its impact on the welfare of the respondent is provided. This is followed by construction and description of the market scenario. At this stage, respondents are informed in detail how the good will be presented for purchase, i.e. the context in which the good can be purchased. This should be in a way that is plausible, understandable and meaningful to all respondents, who in most cases have varying life experiences and educational backgrounds (Mitchell and Carson 1989). The outcome of this stage strongly influences the quality of the results, and the scenario must appeal to the respondents. In describing the scenario, the researcher indicates clearly whether it is a WTP or WTA concept. The choice of either depends on the current ownership right of the good in relation to the respondents (Carson et al. 2001). The WTA value is applied when the respondents have the ownership right and if not, the WTP value is used. However, the market scenario can be designed to reflect on any of the concepts. Finally, a payment vehicle is chosen, i.e., how the respondent is supposed to pay for the good (see Pearce and Turner 1990), e.g., by taxes, entry fees, one-time fee, etc. Contingent valuation studies require supplemental data on the social and economic characteristics of each respondent such as education, age, income, gender, family size, etc. These details are used as parameters in the demand function/bid equation that is estimated later.

There are several biases that are likely to occur while carrying out a CV survey (see also FAO 2000; Carson et al. 2001; Birol 2002; Freeman 2003). Starting point bias is where the WTP value given by respondent is anchored on the first suggested bid price. It occurs in the bidding game CV exercises. Interviewing bias is linked to the interviewer where his/her attitude may influence the values given by the respondent. Non-response bias arises when people who do not answer the questions do not belong to a random part of the population but to those with particular attitude. Strategic bias is the deliberate under- or over-statement of an individual's WTP value. For example, people may understate the value if they believe that the fee that they will pay for the good is influenced by their response to the CV question. On the other hand, people may overstate their value if they think that the CV questions are purely hypothetical and hence presume a high value would increase chances of the policy being accepted. There is also the '*yea*' saying bias, which occurs when respondents give positive WTP answers because they feel nice about donating to a social good although they believe the good itself is unimportant. Insensitivity to scope or embedding bias occurs when a respondent expresses some WTP for some part of the good as s/he does for the whole. Payment vehicle bias arises when a respondent gives different WTP values depending on the specific payment vehicle chosen rather than expressing the actual value of the good. Information bias implies that the WTP value expressed by an individual is not a reflection of previously held preferences but is constructed in the interview procedure. Hypothetical bias contends that respondents may be prepared to reveal true values without strategic bias but are not capable of knowing these values without participating first in a market place. This is probably the most serious criticism of CV methods.

Due to the growing interest in CV studies, guidelines and protocols have been developed to detect and reduce the occurrence of the biases (see Carson et al. 2001). For example, it has been suggested that the key scenario elements presented should be understandable, meaningful and plausible to the recipient. The WTP questions should also be clear and unambiguous, and respondents should be familiar with the good being valued. Familiarity with the good being valued implies that the respondent has had prior valuation and choice experience with respect to consumption levels of the commodity to enable him/herself to state reasonably well informed values. The likelihood that this is the case is usually very low. Carson et al. (2001) contends that this might be an extreme demand from the economists' side, because even the economic theory presumption that an individual acting in a real market makes an informed decision out of experience does not always hold true. They compare values derived from many CV studies (ranging from US$ 5 to US$ 250) with similar marketed goods. In their arguments, they conclude that the market goods do not receive an advertisement time as high as the 40 or more minutes spent advertising a good in a CV study.

Finally, two issues arise concerning the results of the CV studies, i.e., their validity and reliability (Carson et al. 2001; Freeman 2003). There are two types of validity: construct and convergent validity. Construct validity means how well the value is predicted by factors that would be expected to be predictive a priori. For example, it is expected that direct users of a good would be willing to pay more than those who do not use the good; income has also been known to have a positive effect, while age has a negative effect, especially in developing countries. As such, most of these expectations are a synthesis from previous studies, and therefore it would be important to examine each particular study. Convergent validity is when values of the good are available using two different techniques, e.g., comparing values derived using CV with those from RP methods such as hedonic pricing or travel cost. Reliability is an index of reproducibility and stability of the measurement. Stability of WTP measurements over time is very important for policy purposes. Replication of results with similar questions administered to independent samples at different points in time may not give similar answers due to many factors such as financial situations, changes in spending, etc.

Choice modeling

The choice modeling (CM) methods infer the WTP/A values indirectly from the rankings or ratings of the choice sets. The method seeks peoples' preferences for the individual characteristics/ attributes of the goods and services. The method is based on the notion that any good can be described in terms of its attributes and the levels that these take (see Adamowicz 1995; Adamowicz et al. 1998; Hanley et al. 1998). There are about four formats used in CM methods. These include choice experiment, contingent ranking, contingent rating and paired comparisons methods. The choice experiment method asks respondent to choose between two or more alternatives as compared to status quo. Contingent ranking asks them to rank a series of alternatives, while contingent rating asks for scores on a scale of 1 to 10. The paired comparison method asks the respondent to score pairs of scenarios on a similar scale as the contingent rating. It is only the choice experiment that has an attribute with monetary value. The CM methods are therefore similar to the CV method, as they also use surveys to generate estimates of both use and non-use values. But while CV produces a single value for a change in an ecosystem good, CM provides independent values for the individual attributes of the good, and the information generated shows which attributes of the good are significant determinants to the value people place on it. The determinants are also ranked and value provided for a change in more than one attribute over time. The method finally provides the total economic value of the environmental good (see Bateman et al. 2001 for more details). Just as in CV, the attributes used in CM are hypothetical choice sets, (For more information, see Lancaster 1966; Birol 2002).

5.6 Value of crop pollination service by bees

Both the RP and SP methods are applicable for measuring the value of the crop pollination service by bees. However, as mentioned earlier, the determining factor is mainly the data source. This is mostly reflected in the way the good is being utilized. In this study, the crop pollination service by bees in the Kakamega farmland was determined by two methods: the factor of production and contingent valuation (chapters 6 and 7, respectively).

6 MARKET VALUE OF CROP POLLINATION BY BEES IN KAKAMEGA FARMLAND

In this chapter, I address the value of bees in pollinating agricultural crops. We have already learned in the previous chapter that bee pollination service (henceforth pollination) can be viewed as a private or public good, depending on the target. For example, earlier studies done to measure the value of bee pollination in USA, Canada or Europe used revealed preferences (RP) methods because pollination is traded in the market (i.e., bees can be rented for pollination of crops). There are specialized firms that rear bees in those countries for this purpose. For example, Koppert Ltd trades *Bombus terrestris* L. for European and Asian markets, and *B. impatiens* Cresson in North and South American markets (Koppert Ltd. 2007). Even the locals who are not farmers in those areas buy bees (e.g., bumble bees in a box) for their home gardens. In such cases, the pollination service is paid for and is obtained on the market.

Crop growing in the developing countries is mainly practiced by small-scale farmers. They do not manage pollination in any way and they only rely on pollination by feral bees (also known as feral pollination), supported by nearby habitats. Pollination in such situations is thus a public good that is used in crop production. It is a positive externality of the conservation and management activities of the surrounding landscape. There are, however, some examples in developing countries where large-scale (plantation) farmers have taken measures to mitigate the perceived insufficient pollination. In Kenya, for example, horticultural firms (e.g., Homegrown (K) Ltd., VegPro (K) Ltd.), coffee firms (e.g., Kakuzi Ltd.), etc., have initiated beekeeping projects within their farms, where they keep honeybees for pollination of their crops. Therefore, because of the different sources of bees that pollinate crops, it is possible to use different methods to measure the welfare change of a farmer as a result of change in pollination.

In situations where bees are available and are rented for pollination purposes, the consumer/producer surplus method is applicable. Although most of the studies on the value of pollination have been done in areas where such markets exist, few have used this method (Cheung 1973; Olmstead and Wooten 1987; Gill 1991; Southwick and Southwick 1992). Using this method, the value of pollination is measured indirectly by observing the demand and supply of bees rented for pollination. The value of pollination would be the sum of the producer and consumer surplus of bee rentals in a market. In other instances, the effective bee pollinator (s) has disappeared and crop growers have had to find other ways of pollinating their crops. They end up employing people to cross pollinate. The value of bee pollination calculated this way would be equal to the cost of hiring such labor. This type of method is the so-called preventive/defensive method, and it also measures the value of pollination indirectly by observing the behavior of the growers as they adjust to avoid, or respond to, the loss resulting from insufficient pollination. The method is also applicable to those crop growers who decide to keep bees to improve pollination services (e.g., the Kenyan plantation growers). The cost they incur to set and run the bee colonies reflects the value of pollination.

The factor of production (FP) method uses data from observations of the supply and demand of the commodity supported by bee pollination (Kevan and Phillips 2001; Gordon and Davis 2003). Studies that have used this method measured the change of the consumer and producer welfare as affected by the change in commodity output as a result of a change in pollination. Some have extended this dimension to include industries supported by bees or commodities resulting from pollination (Gordon and Davis 2003). As the commodity attained after pollination can be traded in the market, it implies that pollination supports an economic activity. We can, therefore, say that pollination is an input of production. Among the revealed preferences (RP) methods, FP method was selected to measure the effects of the change in pollination on the welfare of the farmer, because the current situation in the Kakamega farmland does not allow applicability of the other methods. For example, bees are not traded for pollination and farmers have not been reported to respond to the dwindling bee population through implementing defensive actions.

6.1 The factor of production method

The factor of production (FP) method, otherwise known as the productivity method (or production function approach) has been used to value many different ecosystem services and environmental resources in the past. In agriculture, for example, it has been used to measure the value of wetlands in providing clean water for irrigation/fish, which in turn affects the commodity output (e.g., see van Kooten and Bulte 2000, p. 100-151).

Take, for example, the case of the value of wetland in agriculture. Clean (un-polluted) water for irrigation supports production of a crop. A change in the water quality results in a change in the inputs used for water treatment. Both the wetland and traded inputs (for water treatment) substitute each other in making water clean for irrigation. If the wetland is in a good condition, the use of the marketed inputs is reduced, hence the cost a grower incurs to purchase them is lowered. At the same time, the businessman (producer of the marketed inputs) gets less, as fewer inputs are purchased (*ceteris paribus*). Therefore, by observing the supply and demand of the traded inputs, the value of the wetland can be deduced. On the other hand, the value of wetland in fish production is measured differently. Clean water supports the production of fish, which is traded in the market. Therefore, a change in the quality of water affects the supply of fish. The wetland has no substitute, and its value can be measured through observation of the supply of and demand for the fish. The production function is the formal representation of such relationships between the change in the environmental service as an input and the change in production of the marketed output (see also Ellis and Fisher 1987).

The value of crop pollination that was measured in the present study is effected by bees. We relate bees to the wetland, and pollination to clean water. Pollination supports crop production (can be equated to fish production), which produces a commodity that fetches a market value. When measuring the contribution of pollination to the crop yield, other inputs used in the crop production such as fertilizer remain constant and are said to be fixed, and only changes in the pollination ‘quantity’ affects the commodity output.

The flexibility of the FP method makes it suitable for valuing pollination of crops by bees in Kakamega. However, it relies on empirical evidence from experimental studies to provide the physical link between the change in pollination as an input and the change in the commodity output due to the different levels of pollination (see Chapter 2).

6.2 The valuation context

The evaluation used in this study is based on the notion that bee pollination supports crop production, which is an economic activity in the Kakamega region. Therefore, bee pollination contributes to the welfare of the farmers through improved yields, both in quantity and quality. This increases economic empowerment of a farmer through increased income. Using the normal crop production function, we can describe the relationship of pollination and the crop commodity it supports. The output (y) (also referred here as a commodity) of a crop that is depended on bee pollination services can be expressed as a function (f) of the pollination service (q), other purchased inputs of production (x) and fixed costs (k, e.g., of land, capital) (see also Freeman 2003, p. 269-296). This can be stated formally as:

$$y = f(x, q, k)$$

Pollination has no substitute in the market in Kakamega. Therefore, we try here to measure the direct relationship of pollination and crop yield. We therefore require information to map the change in the pollination service, Δq, into a change in the commodity, Δy, for constant levels of x and k. If we can then convert Δy into a monetary measure, we would have valued the change of pollination service as it affects production (Perman et al. 2003). This kind of measurement is known as effect on production or a dose-response valuation technique. Studies that have used such a model are mainly in developed countries such as the UK (Carreck and Williams 1998) and USA (Morse and Calderone 2001). The method is especially useful where it is difficult to construct curves of both demand (of commodity consumers) and supply (of commodity producers) or if the intention is to get a rough estimate of pollination. However, in using the FP method, we consider the demand and supply functions of the commodity as influenced by a change in pollination (see Gill 1991). In the present study, the demand side will be neglected and we will only concentrate on the supply side. The reasons behind this will be explained later in this section.

Ideally, if q was an argument in the utility function, we would have to estimate the value of change in pollination, Δq, in consumption as well as in production in order to calculate the total societal value of pollination. This is similar to the determination of consumer and producer surpluses of the commodity before summing them to get the societal value. In this study, we assumed that a change in pollination of crops by bees will not affect the overall market of the commodity in Kakamega, as the market is perfectly competitive and the players continue to source commodities from other areas. If this is true then, the price and demand of the commodity will not change. Therefore, it follows that there will be a negligible change in the consumer surplus of the commodity, y, due to change in pollination, Δq, and only changes in the producer surplus explains the societal benefit from bee pollination. Producer surplus (PS) shows the difference between what producers are willing to be paid per unit of the commodity produced and what they actually get from the market. The societal value gained from bee pollination is the difference between the PS of the commodity when bees are present and PS when bees are absent. This is similar to the net benefit derived from pollination of crops by bees, which is the total revenue minus the variable costs associated with the use of bee pollination service. In Figure 6.1, it is assumed that an individual farmer will face a 'supply shock' as a result of total loss of bees (from Q* to Q), hence the supply of the commodity moves from S_2 to S_1. Considering the variable costs, i.e., at S_1, PS is A while variable costs is the area E+B; at S_2, PS is A+E+C and variable costs is B+F, the societal benefit lost when there is no bee pollination is C. Therefore, the societal value measured is the area C because it is the difference between the producer surplus at S_2 and the new producer surplus at S_1. This is also similar to the societal gain from use of bee pollination (from Q to Q*), which results in a supply shift from S_1 to S_2.

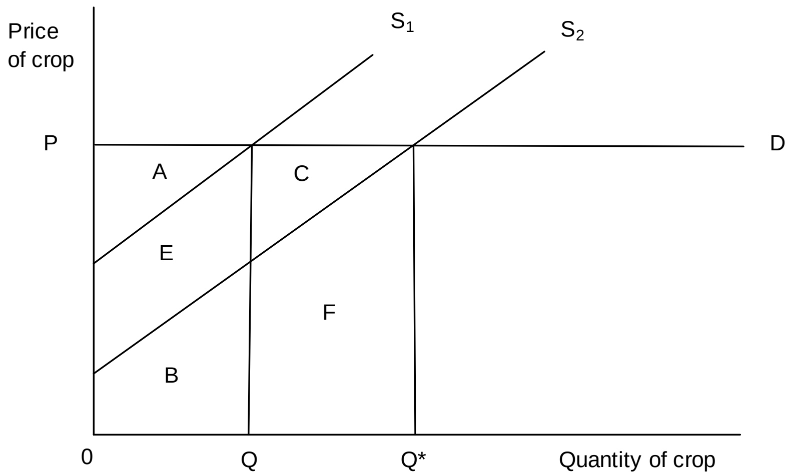

Figure 6.1: Producer and consumer surpluses for a commodity produced using pollination service provided by bees. Source: Gill (1991)

Therefore, the change in the income (ΔI) of the individual farmer brought about by the change in bee pollination, Δq, is determined by subtracting the variable costs of harvesting (c) from the monetized commodity change, Δy. This can be expressed formally as:

$$\Delta I = \Delta y(p - c) \tag{6.1}$$

where p is the average farm gate price per unit quantity of the commodity.

The assumption that bee pollination in the Kakamega farmlands has no impact on the regional price of the commodities enables us to easily measure the income change for a farmer due to pollination change.

Finally, assuming a farmer has several crops that require bee pollination, the income change experienced by the farmer due to bee pollination is the aggregation of ΔI from each commodity.

6.3 Data collection

The data that were used for the analysis were taken from various sources. First, the empirical data providing the physical link of the bee pollination service with commodity yield were taken from the study of the crop pollinators and pollination in Kakamega farmland (Chapter 3), which provides information on the percentage increase in crop yield due to bee pollination. Pollination dependency ratio, pdr, of a crop was calculated as:

$$pdr = \frac{Y_{ub} - Y_b}{Y_{ub}} + qcv \tag{3.1}$$

where pdr is the ratio that represents the level of dependence of a crop to bee pollination. It ranges from 0.0 (no need of bee pollination) to 1.0 (bee pollination is essential). Y_{ub} is the yield with bee pollination, Y_b is the yield without bee pollination while qcv is a value representing quality improvement of a commodity due to bees

(Table 3.7). The pdr is the physical linkage, which is required to calculate benefits of pollination that accrue to farmers.

To determine the change of farmer income as a result of change in bee pollination of a crop, we use the market price of the commodity. This implies that pdr should reflect the current market transactions. Therefore, the ratio will be adjusted for some crops (beans, cowpea and sunflower), because it was realized that the qcv does not influence the market price of these commodities in the local market, hence it will be equated to zero, while pdr of other crops (bambara nuts, green grams, tomatoes, capsicum and passion fruits) will not be adjusted (Table 6.1).

Table 6.1: Adjusted values of qcv and pdr for analysis of the value of crop pollination by bees in Kakamega farmland, Western Kenya in 2005

Crop	qcv [a]	pdr [a]
Beans	0.0	0.40
Cowpea	0.0	0.41
Green gram	0.0	0.43
Bambara nuts	0.0	0.61
Tomatoes	0.1	0.25
Capsicum	0.1	0.66
Passion fruit	0.1	0.28
Sunflower	0.0	0.57

[a] *see equation 3.1;* qvc *quality coefficient value;* pdr *pollination dependence ratio*

Therefore, Δy is calculated as:

$$\Delta y = y(pdr)$$

i.e., the amount of the commodity (kg) that was attributed to bee pollination was calculated as the product of the total amount of the commodity harvested (kg) by the ratio that describes the dependence of that commodity on bee pollination.

The annual crop yield data, y, of each crop for the Kakamega farmland were obtained from the Ministry of Agriculture, Kakamega district reports (MOA 2006). These data are comprised of annual yield (kg), total area of production (ha) and annual average farm-gate price for each crop. The data of the year 2005 were used, because they had information of most crops (8), which was not the case for the data of the previous years. The crops used in this chapter are beans, cowpeas, green grams, bambara nuts, capsicum, tomatoes, sunflower and passion fruits. It was not possible to use more crops for analysis due to the lack of information on the physical link of the commodity with changes in pollination. This information is available in countries elsewhere in the world but cannot be used for the case of Kakamega because the data may be unrealistic. Production yield data was also missing for some crops (squash), which limited its inclusion in the model.

6.4 Results

The area dedicated to crop production by farmers in the Kakamega farmland in the year 2005 was different for each crop (Table 6.2). Beans had the highest area under production while capsicum had the lowest. It is, therefore, not surprising that beans had the highest annual value compared to the other crops. However, for a single unit of production (ha), capsicum provided the highest returns to the farmer followed by passion fruit. Although bambara nut had the lowest annual value and returns, its returns per hectare were higher than those from all other crops except capsicum and passion fruits.

The contribution of pollination to the income of the farmer depends on the impact it has on the crop yield. Where the impact is high, the change of income is also high. The magnitude of monetized change of the commodity output as a result of change in pollination at the societal level is explained by the annual area of production and the farm-gate price for each crop. For example, while at the farm level the magnitude of pollination impact is high on the income generated from capsicum and passion fruits, at the society level, the impact of pollination is highly felt in the production of beans. The benefits (in terms of income change) that accrued to the Kakamega farmers as a result of bee pollination of eight crops was about 37% (US$ 3.19 million) of the annual market value of these crops 2005.

Using an average farm size in the region of 0.7 ha (MOA 2006), we can develop several scenarios (36) to assess change in the annual net benefit that a farmer may experience due to change in bee pollination of the different crops (Table 6.3). We assume that farmers in Kakamega will utilize the normal two seasons of cropping, hence they will plant twice. With this assumption, and bearing in mind that the farmer has 0.7

ha to utilize for crop production, it can be seen that farmers will earn amounts ranging from US$ 183 to US$ 3540 per household per year, with an average of US$ 1025. Passion fruits are usually planted along fences (even beside trees that offer support to the passion fruit plants) by many local farmers and therefore do not need extra space. However, farmers who may plant passion fruits in the normal field area may not wish to plant them along the fences, thus this was not considered in the model where farmers were expected to plant them in the field. The lower value attained when cowpeas are planted does not mean that this crop has a low economic value in Kakamega. It is because farmers plant cowpea as a leafy vegetable and not for seed production. The productivity is lowered due to leaf harvesting. The crop performance in other parts of the country is higher than of most legumes, and if Kakamega farmers would grow this crop for seed production, the scenario would change.

Table 6.2: Amount and value of production of selected crops attributable to bee pollination, in Kakamega farmland, Western Kenya 2005

Crop	*pdr*	Annual area of production (ha)	Annual production, y, (kg x 10^3)	Annual value (US$ x 10^3)	Δy (kg x 10^3)	p (US$)	c (US$)	ΔI /year (US$ x 10^3)	ΔI / ha /year (US$)
Beans	0.40	22970.00	14888.00	7933.33	5955.20	0.533	0.026	3019.29	131.45
Cowpeas	0.41	429.00	140.90	37.33	57.77	0.265	0.026	13.81	32.18
Green grams	0.43	26.00	11.00	7.87	4.73	0.715	0.026	3.26	125.35
Bambara nuts	0.61	14.00	7.80	5.20	4.76	0.667	0.026	3.05	217.94
Capsicum	0.66	3.00	7.00	11.07	4.62	1.581	0.003	7.29	2430.12
Tomatoes	0.25	323.00	4169.00	236.00	1042.25	0.057	0.03	52.28	161.86
Passion fruit	0.28	42.50	467.50	306.67	130.90	0.656	0.003	85.48	2011.24
Sunflower	0.57	27.00	12.80	6.67	7.30	0.521	0.023	3.64	134.64
Total		23834.50		8544.14				3188.10	

Price for each crop is an average of farm gate prices of 2005; source: MOA (2006)
Δy *production attributable to bee pollination (kg);* p *annual average farm gate price;* c *cost of harvesting per unit kg;* ΔI *change in income due to change in bee pollination;* pdr *pollination dependence ratio*
US$ 1.00 = KSh. 75.00. For calculation of the different parameters, see derivation of equation 6.1

Table 6.3: Increase in income (US$) of a farmer that can be attributed to sufficient bee pollination service annually (2 seasons) in Kakamega farmland, Western Kenya, 2005

	Season 2							
Season 1	Beans	Cowpeas	Green grams	Bambara nuts	Capsicum	Tomatoes	Sunflower	Passion fruit
Beans	184.03	114.54	179.79	244.57	1793.10	205.32	186.26	1499.89
Cowpeas		45.05	110.27	175.08	1723.61	135.32	116.77	1430.40
Green grams			175.49	240.30	1788.83	201.05	181.99	1495.62
Bambara nuts				305.12	1853.64	265.86	246.81	1560.43
Capsicum					3402.17	1814.39	1795.33	3108.95
Tomatoes						226.60	207.55	1521.17
Sunflower							188.50	1502.12
Passion fruit								2815.74

In addition to the above combination, passion fruits are perennial and are mainly planted on fences hence do not occupy the farm space for other crops. Therefore a value of US$ 137.76 should be added to each value in the cells (except for passion fruits);
Assumptions: a farmer has 0.70 ha to cultivate and 1 m width of the fence around the farm
1.00 US $ = 75.00 KSh;

6.5 Discussion

The approach used in measuring the value of crop pollination by bees in this study was different from that used in previous studies in two aspects. The first aspect is the nature of provision. Pollination in Kakamega is a public good and is not managed in any way, unlike in other countries, where pollination is managed and to some extent is traded on the market. Therefore, the amount calculated represents the value of feral pollination. The second aspect is the crops of interest. All previous valuation studies of pollination address the role of pollination on crops grown for commercial purposes and in large scale operations. The crops dealt with in the present study are grown by small-scale farmers primarily to satisfy daily household requirements and not necessarily for profit maximization. Although Kakamega farmers (50%) have little knowledge on the role and functions of pollination in crop productivity, (Chapter 3), their actions, though not intentional, may be contributing to presence of bees in the farmland. The assumption that any change in pollination of crops by bees in Kakamega does not impact on the market demand of commodity, supports the conclusion that the consumer surplus will be zero or negligible. This implies that the value of pollination is determined by the producer surplus, i.e., the total revenue minus the variable costs (Varian 1993).

The magnitude of the change of net benefit gained by farmers as a result of change in pollination highlights its role in crop production and the wellbeing of the farmer, as well as the whole of society. The monetary value calculated by this study compares well with studies done elsewhere in the world, e.g., Robinson et al. (1989) and Morse and Calderone (2001) who measured the value of honeybee pollination in USA agriculture. However, in their method, they neither measured consumer surplus nor did they subtract the variable costs associated with the change in pollination of crops they had used in their model. The method they used was the effect on production, which is different from the FP method applied in the present study. Southwick and Southwick (1992) attempted to measure both consumer and producer surplus resulting from bee pollination of US crops. In a similar way, this study also measured producer and consumer surplus of crop commodities resulting from bee pollination. Consumer surplus was assumed to be negligible and, therefore, the net benefit derived by farmers from bee pollination of their crops was explained only by producer surplus. The valuation was purposely to show that bees, as the main crop pollinators, affect the farmers' welfare. While past studies only measured the value of honeybees, this study provides the value of different bee species. For instance, the value of bean pollination is due to the large *Xylocopa* species, while *A. mellifera* contributes to the value of sunflower pollination only. It is therefore notable that solitary bees, which are not managed in Kakamega, are vital in crop production. *Apis mellifera* management in Kakamega is mainly for production of honey and other hive products. The government policy encourages honeybee keeping for honey markets but does not emphasize their role in crop production. One of the reasons could be the lack of evidence of the economic value of bee pollination in crop production. In this study, the economic gains of beekeeping were not compared with the value derived from pollination. Previous studies did so mainly because in their research situation honeybees were kept by professional beekeepers mainly for renting to crop growers, and the honey business came second. Therefore, it made sense for these studies to do cost-benefit analyses of the beekeeping industry. It was also felt that the beekeeping industry was declining and could result in insufficient pollination, therefore the studies target was to influence policies to support beekeeping. Finally, all those studies measured the value of honeybee pollination and not that of other bees. The intention of the present study was to show that different bee species are all important in crop production and need to be conserved. Honeybees play an important role, but there is as yet no indication of their decline in the study area. In contrast, there are not enough solitary bees, which seem to provide pollination of most crops (Chapter 2). We need policies that encourage conservation of the different bee species. Another aspect of this case is that the value measured in this study reflects on the role of feral pollination of crops in a developing country compared to rented pollination in developed countries. We can assume that total loss of bees in Kakamega would affect the income of the farmers in the same magnitude.

This study used producer surplus to explain the societal benefit of bee pollination in Kakamega with the assumption that the market is perfectly competitive and hence the demand for the crop does not change. However, it is often impossible to have perfect markets. Therefore, in future, measurements of consumer surplus may be warranted to avoid undervaluation of the pollination service. This would also involve measurements of the long-term effects on the producers and consumers of the commodity due to changes in the pollination by bees (see Kevan and Phillips 2001). For example, when pollination is limiting, market supply may reduce and prices increase. This will affect the demand for the commodity, and some consumers may change to a cheaper substitute. If the producer faces losses due to poor pollination, s/he may decide to change to other crops that do not require bee pollination, or to a different enterprise.

The main shortcoming of the FP method is the inability to determine the total economic value of pollination for crop production, i.e., the use and none-use value. Another shortcoming is that the aggregated value is only limited to crops for which we have empirical evidence of the magnitude of the influence of bee pollination on their yield. For example, the value determined here was for only 8 crops, while there are many more crops that require bee pollination and play a major role in the welfare of the farmers in Kakamega. However, no information is available on the pollination needs of these crops and production figures are also lacking. For instance, no information could be provided for squash (*C. pepo)* although there is evidence of its requirements for bee pollination (Chapter 3). Even with such shortcomings, this method has drawn interest from researchers and seems to be much preferred for valuation of pollination services, mainly in developing countries (FAO 2000). This may be because it does not require direct response from the users (farmers), who may not be aware of its existence (i.e., it avoids the pitfalls of the stated preferences methods), but relies on observation of their behavior in the real market setting. However, as we shall see in the next chapter, it is possible to overcome most of these hurdles while using stated preference methods.

6.6 Conclusions and recommendations

This study attempted to estimate the monetary value contributed by the feral bee pollination service in production of crops and to measure the related welfare effect for the Kakamega farmers. The results show that the highest net economic benefit of bee pollination per unit area was gained from capsicum and passion fruits, in Kakamega in 2005. However, considering the total area of production in the district, the highest net economic gain due to bee pollination was derived from beans. More than 37% of the net benefit gained by farmers for the eight selected crops was as a result of bee pollination. The measured economic value shows that pollination impacts on farmers' well-being. Therefore, efforts should be made to manage pollination in Kakamega through conservation of bees, which is not currently done there. Although the FP method does not show how this can be done and whether it is viable, the findings from this study can be used in creating awareness to farmers and other stakeholders on the importance of pollination. The government can also use the findings to back up policies that may be required to conserve bees or verify importance of bee pollination. Supporting research aimed at increasing the knowledge on the pollination requirements of different crops, pollinator requirements and development of methods for improving the bee population sizes is necessary. The government should improve information collection and storage services so that in future this information is available to support various analyses when required.

7 VALUE OF CROP POLLINATION BY BEES FROM FARMER’ PERSPECTIVE IN KAKAMEGA FARMLAND

As a nature service, pollination is important in the reproduction processes of plants. Other than wind, water and gravity, which are also agents of pollination, animal pollination has recently received much attention from scientists due to the perceived threat of declining animal pollinators, particularly bees. Bees are the main pollinators of many agricultural crops, while other animal pollinators are only effective on a small range of crops. Their decline is mainly due to factors associated with human influence or neglect (CBD 2001). An indirect factor for this decline is also the fact that the economic value of pollination is least understood and appreciated by policy makers and other stakeholders in developing economies.

Earlier studies only measured the value of bee pollination as a private good. This may be because it is easier to infer the value from market transactions. However, many queries have been raised on this bias, particularly because the value calculated has been for the honeybee, which is known to be a generalist pollinator and not an efficient one of many crops. This bias is not only observed in the researchers but also by the crop growers. For example, Sanford (1995) complained that many squash growers in California, USA, continued to rent honeybees for their crops while the local populations of squash bees, *Peponapis* spp., were most likely providing sufficient pollination to the crop. The underlying problem in such a scenario is the nature of provision of the good. Renting honeybees provided ‘security’ to the farmers, as they were assured of pollination. On the other hand, *Peponapis* spp. were provided by the healthy ecosystem that was not managed by the farmers and thus a public good. In Kakamega, pollination is not managed and hence it is a public good, too. The farmers have no option for renting bees for pollination as this service is not traded on the local market.

Stated preferences (SP) methods have not been widely applied in valuation of agriculture biodiversity compared to the non-agriculture biodiversity simply due to the assumptions that the respondents may not have a sound knowledge of the complexities of ecosystem processes and functions and their quantitative contribution to agriculture (Birol 2002). However, some efforts have been made using choice experiments models, e.g., to measure consumer perceptions of genetically modified foods (Kontoleon et al.

2002). The SP methods have, however, been used to value many kinds of ecosystem goods and services where pollination is included as a part of the ecosystem but not on its own (e.g., Costanza et al. 1997; Losey and Vaughan 2006).

This study, therefore, is the first attempt to value the contribution of pollination in agriculture using the contingent valuation method. At the same time, it is also an attempt to measure the value of pollination by use of non-cash payments, and in a developing country. This method is suitable because the pollination service in the research area is not traded on the market, although it is quite important considering the different kind of crops grown there that require animal pollination.

The last section of this chapter provides a discussion of the findings from this chapter and the previous chapter (Chapter 6). It will be shown that although the two methods measured the value of bee pollination they captured different facets of the pollination.

7.1 Contingent valuation method

The contingent valuation (CV) method is one of the SP methods used in valuation studies, and it is popular due to its capability to measure values of both marketed and non-marketed ecosystem services. This is made possible by its reliance on data derived from the consumers of the good, who state their willingness to pay (WTP) to have the good, or willingness to accept compensation (WTA) for the loss of the same. The general basic economic ideas that support this kind of valuation are discussed in Chapter 5. In this chapter, specific information not addressed previously will be mentioned. Basically, the CV method relies on a hypothetically constructed market where individuals are allowed to make transactions. The contingent market provided includes the good itself, the institutional context on how it will be provided and how it will be financed (Carson et al. 2001; OECD 2002). The main aim of the CV exercise is to achieve values close to those that would be revealed in an actual market if it existed. The contingent market is therefore very important in the valuation process.

The CV method has been used successfully in many countries to measure the value of different ecosystem services and biodiversity (e.g., Bandara and Tisdell 2004; Ellingson and Seidl 2007; Tisdell et al. 2007). It has not been used in agriculture, unlike other SP methods such as choice modeling due to reasons mentioned earlier.

7.2 Valuation context and empirical procedures

To use the CV method, we first considered the current farming status in the Kakamega farmland. Some inputs required by Kakamega farmers to support crop production in every cropping season can be purchased on the local market while others cannot. The value of the marketed inputs can easily be inferred from the market transactions (indirect measurements). Pollination is one of the inputs, which is not traded, but nature assures the continued supply to service the crops. Therefore, although farmers do not pay for pollination, they continue to benefit from it. This implies that the service is used in production but farmers do not factor it in their cost appropriation. It is a pure public good in Kakamega, but the provision by nature has been declining mainly due to a reduction in bee population sizes (BIOTA 2004). This was confirmed by the low number of bees that visited crop flowers in Kakamega farmland (Chapter 2). Because pollination is a public good there, the assurance of its benefits depends on the collective responsibility on the part of the farmers in terms of its management. Such an action would only take place if farmers have the feeling that the benefits they will derive from pollination are higher than the cost of managing it. The decision each individual takes to or not to manage pollination involves a valuation process, as noted earlier. Contingent valuation is capable of determining how much farmers value pollination of their crops by bees. The choice of capturing this value by either willingness to pay (WTP) or willingness to accept compensation (WTA) literally depends on the ownership rights of an economic agent (household) (Mitchell and Carson 1989; Perman et al. 2003). Farmers in Kakamega were assumed to have the right to the actual level of provision of the pollination service, but they had to pay if they wanted improved (additional) pollination (higher ‘quantity’ of pollination). Therefore, they were asked to state their maximum WTP to have the new or improved pollination service.

In economic terms, WTP can be described as the amount of money that can be deducted from the respondent’s income when increasing the provision of the public good and keeping his/her utility constant. This can be formally expressed by use of an indirect utility function that includes the ecosystem good as a variable (section 5.5.1). This indirect utility function is assumed to be for a utility maximizer, who is constrained by a budget, i.e.,

$$V = v\,(P, q_i, I)$$

where P is the vector of prices for all goods, q is the ecosystem good (herein pollination) with level i, and I is income. This study valuates pollination change, i.e., improved pollination service (additional 'quantity' of the pollination good). The decrease in income that maintains an individual at the same utility level as before the change in pollination 'quantity' is the measure of welfare impact. This indifference point can be measured as:

$$v\,(P, q_0, I) = v\,(P, q_1, I - y)$$

where 0 and 1 are the original and improved pollination, q, respectively, and y is the maximum WTP value (the value that was elicited from the respondents).

The utility of the respondent was also hypothesized to depend on the individuals' characteristics that influenced the trade-off a respondent was prepared to make between income and pollination quantity. Therefore, a vector, Z, representing the characteristics of an individual can be added to the previous equation (see also FAO 2000):

$$v\,(P, q_0, I; Z) = v\,(P, q_1, I - y; Z)$$

In this study, the WTP values provided by the respondents were averaged to produce an estimate of a mean WTP. This can be expressed as:

$$average\,WTP = \frac{1}{n}\sum_{i=1}^{n} y_i$$

where n is the sample size and y is the reported (observed) WTP amount.

The median value is sometimes the most relevant estimator in presenting the economic gain from a public good. Policy makers are keen on the median value, as it represents the amount many people are likely to pay, compared to the mean value, which is sometimes prone to influence by extreme values (and/or outliers) given by some respondents. However, median values are most often presented in CV exercises that use referendum-format questions compared to open-ended formats (Mitchell and Carson 1989).

The value of WTP responses given by the respondents in this study were checked to see whether they relate in a predictable way and to find out which variables influenced the magnitude of the WTP value. This was done by regressing the reported WTP values (regressands) against the socioeconomic attributes (regressors) of the respondents, by use of the Tobit model.

The Tobit model was devised by Tobin (1958) and assumes that the dependent variable has a number of its values clustered at a limiting value, usually zero. The model uses all observations, both those at the limit and those above it, to estimate a regression line. It is usually the most preferred model over others, which estimate the regression line only with the observations above the limit. The stochastic model underlying the Tobit model can be expressed by the following relationship:

$$y_i = \begin{cases} y^*_i & if \ y^*_i > 0 \\ 0 & if \ y^*_i \leq 0 \end{cases} \qquad (7.1)$$

where y_i is the observed dependent variable, and y^*_i is the unobserved latent variable, which is expressed as:

$$y^*_i = \beta X_i + u_i$$

with $u_i \sim N\,(0, \sigma^2)$

where X_i is the vector of the independent variables, β is the vector of unknown coefficients, N is the number of observations, and u_i is an independently distributed error term assumed to be normal with zero mean and constant variance σ^2.

This model assumes that there is an underlying stochastic index equal to y^*_i, which is observed only when it is positive, and hence qualifies as an unobserved, latent variable. This latent unobservable variable y^*_i is linearly dependent on X_i through β. The β parameter therefore determines the relationship between the independent variable (or vector) X_i and latent variable y^*_i. The normally distributed error term u_i captures the random influences on this relationship. The observable variable, y_i, is equal to the latent variable, y^*_i, whenever y^*_i is above zero, but it is equal to zero when y^*_i is equal to, or less than, zero (see Equation 7.1).

Estimation of the relationship parameter β by use of the ordinary least squares method is usually inconsistent compared to the likelihood estimation obtained using the censored Tobit model (see McDonald and Moffit 1980). In this study, the regressand, WTP (y_i), is known (observed) for some respondents (who gave a non-zero value), but this is not so for other respondents (who gave zero values). The assumption is that the y_i of those who gave the zero amount was not observed, hence we use y^*_i. However, regressors (X_i) for the two groups are available, thus making the Tobit model the most suitable to carry out the regression analysis.

Socioeconomic factors were recorded during the enumeration process based on the previous experience of other CV studies in other parts of the world, and considering the mode of payment vehicles used by this study (see section 7.4). For example, income and education have been reported by many studies to influence the magnitude of the WTP value (e.g., Boyle and Bishop 1987; Heinen 1993). It was expected that respondents who had spent more years at school would be willing to pay more, as they may appreciate the role of pollination services better than the less educated. Large households were expected to provide more days of labor, as they may have spare labor compared to small-sized households. Older respondents and females were expected to provide meals due to lack of energy (for labor provision) and time, respectively. A negative correlation between age and education would also be expected since most CV studies done in developing countries show that older people are less educated than younger ones (FAO 2000). It was expected in this study that young people would pay more for the pollination service than the older ones. Religion was also expected to impact on the choice of payment vehicle as most Catholics in the farmland usually attend weekly prayer meetings and other associations which could have constrained their payment. In the research area, women are the main household members involved in farming activities and were expected to have a better understanding of the impact of the enhanced pollination service to the crop yields especially after sensitization exercises. It was also expected that households nearest to the forest would pay less because of their proximity to the forest, which is a main habitat for the bee pollinators of crops.

7.3 The contingent market and elicitation method

Before introduction of the WTP scenario and questions, background information had to be sought to know the level of understanding of the respondents on the good being valued (bee pollination service) and provide the missing information about the good to the respondents (see also Chapter 3). Farmers that were not aware of or did not know the importance of pollination were, therefore, first sensitized about the service before the hypothetical market and other questions were presented to them.

Although the limited knowledge of respondents about the good being valued is cited as the weakest part of the CV valuations by most CV critics, there are many arguments that have been floated to counter this. For example, Carson et al. (2001) argues that in the real market, an agent does not need to have prior knowledge and experience of the good before purchasing. Similarly, they argue that the time spent sensitizing respondents on the good is far higher compared to goods of equivalent value in the actual market. In the present study, providing respondents with all information about pollination and its role in crop production gave an assurance that respondents would provide an informed response and there would be a reduced information bias.

The scenario that was used to provide the pollination service to the consumers (respondents) was designed such that the hypothetical market presented would be as close as possible to a real market and appeal to the respondents to make transactions. This is important, as it renders the WTP results reliable and useful to policy makers. Considering the target group, this study used a nature conservation project where the respondents were asked to pay for conservation of bees in order to guarantee them improved pollination of their crops. The hypothetical market consisted of a planned pollinator garden (habitat management), where activities such as construction and maintenance of nesting, feeding, resting and hiding sites of different bee species was to be carried out. Also included was construction and maintenance of corridors for the bees in the farmland, e.g., management of the live fences to make them suitable bee habitats. The respondents were to participate in such duties. This scenario was pre-tested and qualified as the best model to value the pollination service as an input of crop production in the region using the CV technique.

In order to guarantee the validity of the valuation exercise, the scenario was described and presented as clearly as possible to each respondent using the local language. This involved not only careful description and explanation, but also graphical visualization e.g., use of pictures, graphs or illustrations. Open-ended questions were used to elicit the amount each respondent was willing to pay for the pollination service. This format has been successfully used by other studies elsewhere to value public goods (e.g., Tanguay et al. 1995; Huang and Smith 1997; Allport and Epperson 2003; Lipton 2003). The stipulation of this contingent market was done cautiously so as not to overwhelm the respondent with a lot of information and cause confusion (as advocated by OECD 2002).

After they had listened to the scenario, but prior to the introduction of the payment question, respondents were asked whether they were willing to pay for the pollination service in the hypothetical market. This enabled them to register protest bids or their true zero WTP value by refusal to pay for the pollination service without feeling uneasy or intimidated in doing so. Those respondents who agreed to pay were then asked to state the preferred method of payment out of the two alternatives presented to them. This was followed by elicitation of the maximum amount they were willing to pay; those who did not accept were asked to give reasons for their action.

7.4 Payment vehicle for the WTP

Kahneman and Knetsch (1992) indicated that the most important criterion for the success of the method of payment is that it should be believable. For this study, two vehicles of payment were chosen and presented as clearly as possible to the respondents. The respondents were asked either to provide own labor up to midday (half a day) to the nature conservation project (pollinator garden) or lunch-time meals to the workers employed in the project. Both vehicles were expressed on a weekly base either in half-days of labor or number of lunch-time meals provided. The respondents were not allowed to pay in cash, because they were oversensitive to this mode of payment and would always complain about lack of money. The meal or labor payment vehicles were selected because they are common transactions in the research area and were not new to the respondents. Normally, casual laborers in the research area have an alternative to work for food or money. When a lunch-time meal is provided the wage rate is US$ 0.67 (Ksh. 50.00) per day, but this amount doubles when there is no request for food. Thus, the respondents were reminded that the cost of one day of labor up to midday is equivalent to the cost of a single lunch-time meal and each amounts to US$ 0.67.

It was also emphasized that the only gain from the payment was improved pollination of their crops and the expected crop yield gain. Respondents were told explicitly that the payment was weekly and continuous (long-term) in order to restore and ensure long-term maintenance of pollinators and hence pollination service. This helped to eliminate the temporal embedding problem (Carson et al. 2001), as the respondents knew the commitment required of them if they agreed to pay. Respondents were reminded of this before the WTP question. The bias that respondents could provide answers for all crop pollinators rather than just bees was also addressed through the development of adequate survey design and provision of appropriate information about the pollination service in a simple and logical sequence (see Appendix 10.2).

7.5 Sampling design

The study was conducted within the farmland surrounding the Kakamega forest. It included households living up to a distance of 10 km from the edge of the forest. All households living in this perimeter were documented just before beginning the enumeration process. A total of 19,972 households in 210 villages were listed as the target population. For reasons of cost effectiveness and better questionnaire administration, multistage random sampling was done on two levels to get a sample of 352 households to be interviewed. Thus, 22 villages were randomly selected (first level) and for each village 16 households randomly sampled (second level) (see Appendix 10.1b). This size of the sample taken was deemed large enough to take care of the protest bids. A formal questionnaire was developed to generate information about the socio-demographic characteristics of the households, respondents' perception of pollination as a production input and their willingness to pay for enhanced pollination service. The administration of the questionnaire was done through face-to-face interviews in January and February 2006. Four university graduate enumerators who understood the local language and had enumeration experience from previous studies were used to conduct the interviews. They were first trained intensively on the enumeration process and study objectives. A pre-test survey was done to assess how well the survey worked as a whole, to improve the language used in the narrative and help to fine-tune the questions. Usually, a village elder was approached to introduce the enumerators to the respondents in each village. This made the respondents feel comfortable with the enumerators. Generally, the respondents were hospitable, receptive and interested in the survey, which was shown by the high number of positive responses compared to the low number of non responses received.

7.6 Data analysis

LIMDEP-NLOGIT 3.0 software was used to run the Tobit regression and perform the analysis of the descriptive statistics of the survey respondents. Means and frequencies of the different parameters are provided. Standard deviation (SD) was used to separate means and significance of the means was tested at the 95% level.

7.7 Results

7.7.1 Socioeconomic characteristics and awareness of pollination

The median age and mean age of the sample respondents are almost equal (Table 7.1), implying that the distribution of age is not skewed but normally distributed. Many respondents were household heads/spouses (84.6%) and married (81.2%). This is an added advantage to the reliability of the survey results, since the respondents, as the main decision makers, would consider household constraints when they state their WTP. About 61% of the respondents were females. Furthermore, 65.6% of the respondents had more than 6 years of formal education. The respondents showed uneasiness when revealing their income but not so when asked about their expenditures. Therefore, expenditure was used as a proxy to estimate income.

While most (99.0%) respondents knew about bees, only about half of the sample (47.0%) knew about pollination and its importance before sensitization was done (Table 7.1). After explaining the process of pollination and the role of bees in pollination and hence crop yield gain, respondents were asked again to state whether they understood what pollination was and its importance as an input of crop production. Most of the respondents (78.8%) were affirmative, stating that pollination was very important to them. It is, however, important to note that even those who did not understand its importance (mainly due to low education level) were willing to support its conservation after being told that the service exists to support crop production. Thus, the willingness of the respondents (98.0%) to pay for the pollination service may be due to, among other factors, their appreciation of its role in crop production and their knowledge of its mere existence. The importance of pollination in the region was given extra weight by the indication that most respondents were growers of crops that require animal pollination. Bee pollination, therefore, was well perceived as a contributing factor to crop yield gain and a worthwhile investment to enhance crop production.

Table 7.1: Demographic and socio economic characteristics of the respondents interviewed in Kakamega farmland, Western Kenya, 2006.

Variable	Description		SD
GENDER	Percentage of respondents who were male	39.1%	0.489
MARITAL	Percentage of respondents who were married	81.2%	0.392
HHD_S	Percentage of respondents who were either household head or spouse	84.6%	0.361
AGE	Number of years since birth	40.8 median: 40.0	15.765
EDU	Mean number of years of formal schooling	6.5	4.083
HH_S	Mean number of individuals in a household	5.9	2.497
EXP	Mean monthly expenditure per household (US$)	110.6	88.372
CG	Percentage of respondents who grew crops	99.4%	0.076
LSK	Percentage of respondents who were livestock keepers	94.2%	0.229
KOB	Percentage of respondents who had some knowledge of bees	99.1%	0.093
KOP	Percentage of respondents who had some knowledge of pollination	46.4%	0.499
PERC_POL	Percentage of respondents who perceived pollination as very important after sensitization	78.8%	0.409
OFF_INC	Percentage of respondents who were engaged in off-farm income generating activities	58.3%	0.494
RELIGION	Percentage of respondents who were Catholics	30.7%	0.462
DIST_FOR	Percentage of households who were within 5 km distance from the forest edge	55%	0.491
Willing to pay	Percentage of respondents who were willing to pay for pollination	98.3%	0.131
PV	Percentage of respondents who chose to pay pollination through provision of half-days of labor	65.5%	0.476
WTP_Labor	Average weekly number of half-days of labor provided by respondents	2.53	1.154
WTP_Meals	Average weekly number of lunch-time meals provided by respondents	2.62	1.356
average WTP	Average weekly number of half-days of labor or lunch-time meals provided by the respondents	2.52	1.260

N = 352 (general descriptive) and 345 (willingness to pay and payment vehicle values)

7.7.2 Willingness to pay

Out of the 352 respondents, 98% were willing to pay for the pollination service (Table 7.1). This high number of respondents willing to pay suggests that they felt enhanced pollination service would contribute positively to their welfare. It also confirms that the market scenario presented was well understood and appealed to them. Among those who were willing to pay, 65% chose labor as the preferred payment vehicle. Since the lunch-time meals cost the same as half-day labor, the choice of labor by a majority of the respondents did not necessarily imply that this payment vehicle was cheaper. Rather, this choice must have been influenced by other factors, some of which are captured with econometric model results (Table 7.3).

Respondents who did not participate in the valuation exercise (who refused to pay for improved pollination) gave varying reasons, which enabled their classification as either true zero value of pollination or a protest zero (Table 7.2). Respondents who gave protest values were excluded from the estimation of the WTP function unlike those who gave a true zero value for improved pollination service. The protest was probably due to the unconvincing market scenario, which did not satisfy them.

Table 7.2: Reasons given by respondents for refusing to pay for enhanced pollination service in interviews in Kakamega farmland, Western Kenya, 2006

Reason	No. of respondents	Zero value
I keep honeybees	1	True zero
I have no time to participate	4	True zero
I fear more charges at later stages	1	True zero
The household head has to determine	4	Protest zero
I am old and have no energy	3	Protest zero

Respondents were reminded of the temporal dimension of their payment and were requested to take into consideration their daily schedules and budgetary constraints when stating the WTP payment value. The mean WTP value per week was 2.53 half-days of labor and 2.56 lunch-time meals for those households who provided labor and meals (Table 7.1). After including the true zero values of the respondents, the average household WTP for the pollination service averaged 2.52 half-days of labor or number of lunch-time meals per week. This is equivalent to 131.04 half-days of labor or lunch-time meals per year. Thus, the monetized mean household WTP value for pollination services is US$ 87.80 per household per annum. The median annual household WTP value, which might be more appealing to the policy makers, since it is the amount many individuals are actually willing to pay for pollination service, is US$ 69.68. If the sampling frame of 19,972 households that live within 10 km of the edge of the Kakamega forest is considered, the aggregated annual economic value of pollination service is US$ 1.75 million (or US$ 1.39 million considering the median value). This high value shows that the community feels pollination has a role to play in their wellbeing and livelihoods. It is further an indication that people are highly motivated in tapping the benefits of pollination services.

7.7.3 Determinants of WTP value

With the highly positive response to the principal WTP question, it is necessary to assess factors that might have contributed to this result. In addition, it is important to analyze factors favoring either of the payment vehicles chosen by the respondents. Thus, different factors that influenced the respondents' mean WTP value and that corresponding to a particular payment vehicle were determined by use of selected demographic variables in three different Tobit regression analyses (Table 7.3).

The results of the Tobit model show that only education and off-farm income significantly determined the magnitude of the average WTP. Accordingly, respondents with more years of schooling were likely to pay higher WTP values for the pollination service, while those with off-farm sources of income were likely to pay less. The household expenditure (depicting household income) did not significantly influence the magnitude of the WTP value although it had the expected sign. The influence of the location of the household (distance) relative to the forest on the average WTP value was not significant, though the variable had the expected sign. Respondents belonging to households far from the forest were likely to pay more for bee conservation than those close to the forest. This could imply that those households near the forest considered the contribution of the forest as a pollinator habitat. Their acceptance to pay for pollination management could also indirectly imply they would be willing to conserve Kakamega forest although this was not captured directly.

Factors that had a significant influence on the magnitude of WTP generated through the two different payment vehicles were gender, household size and age. They show, however, different directions of influence and levels of significance. Male respondents were likely to pay more in terms of labor while their female counterparts were likely to pay more in terms of meals. Usually, males in the study area have fewer household chores compared to their female counterparts, and this could be the reason behind their choice of labor. Females, however, spend most of their time in crop fields and perform nearly all of the household chores, e.g., laundry, meal preparation, etc. and may not have time to work in the proposed pollination garden. Therefore, it would be easier for them to pay for the pollination service through provision of meals.

As hypothesized, respondents belonging to larger households were likely to pay more in form of labor and less in terms of lunch-time meals. This is mainly because there is an incomplete market for labor in the research area. Thus, compared to small-sized households, larger households may have spare labor and thus, it would be easier for them to provide labor than meals. Also, as expected a priori, members of older households may not be vigorous enough to provide labor for the pollination garden. They are, therefore, likely to pay more in terms of meals but less in terms of labor. The influence of the proximity to the forest had no significant influence on the WTP value although those respondents closer to the forest were more likely to provide meals than labor, while those further away were more willing to provide labor.

Table 7.3: Coefficients and standard errors from Tobit regression analyses where willingness to pay (WTP) value for pollination service was regressed on socioeconomic variables

Explanatory variable	WTP_Labor	WTP_Meal	average WTP
Constant	1.7045	-2.0360	2.7265
	(0.6475)***	(1.2207)*	(0.3774) ***
RELIGION	0.3043	-0.2744	-0.0584
	(0.2723)	(0.5045)	(0.1525)
PERC_POL	0.0602	-0.1752	-0.0254
	(0.3116)	(0.5523)	(0.1721)
Dist_For	0.1653	-0.4496	-0002
	(0.2588)	(0.4800)	(0.1448)
GENDER	0.7164	-1.2174	0.0302
	(0.2762)***	(0.5154)**	(0.1540)
MARITAL	-0.1603	0.9380	0.1967
	(0.3198)	(0.6165)	(0.1793)
AGE	-0.0223	0.0265	-0.0059
	(0.0089)**	(0.0158)*	(0.0049)
EDU	-0.0144	0.0768	0.0327
	(0.0334)	(0.0598)	(0.0187)*
HH_S	0.1301	-0.2838	-0.0344
	(0.0568)**	(0.1034)***	(0.0309)
TOT_EXP	-0.4783E-04	0.7278E-04	0.6389E-05
	(0.2541E-04)*	(0.3461E-4)**	(0.1176E-04)
OFF_INC	-0.5079	0.4591	-0.2412
	(0.2609)*	(0.4815)	(0.1459)*

Standard errors in parentheses. Labor WTP and meal WTP refer to WTP generated using half-days of labor and lunch-time meals, respectively.
** , **, ***; significant at 10, 5 and 1 % level; WTP_Labor: Log likelihood = -593.4472, p 0.000; WTP_Meal: Log likelihood = -425.0300, p 0.000; average WTP: Log likelihood = -571.1626, p 0.000; N = 345; 6 observations left censored at 0*

7.8 Discussion

The number of respondents interviewed was deemed to be large enough to represent households living around Kakamega forest and take care of protest bids. Most respondents interviewed were female, who are the main participants in farming activities and understand better the impact of an enhanced pollination service to their crop yields. This is the reason why they were convinced by the pollination market scenario to pay for the pollination service, although before sensitization, they had shown little knowledge of pollination compared to their male counterpart (see also Chapter 3). A recent study done in 2006 in the Kakamega farmland showed that female households were practically the main labor providers in their households (Canwat 2007, unpublished data). The author reported that about 55.5% involved in land preparation were females compared to 45.5% males in the months of January and February, which was also the time the present study was performed. Canwat (ibid.) also showed that on average, 86.8% of the household chores (water collection, fuel wood collection, cooking, laundry etc.) were done by females.

The affirmation by the majority of the respondents of their willingness to pay for an enhanced pollination service shows their feeling and beliefs that the service could improve their wellbeing. The payment vehicles selected suited the local community and the average WTP would likely change if a different payment vehicle, e.g., cash, were used. The payment vehicles used are common in the farm transactions and were not new to the respondents.

The main driving factors of the magnitude of the WTP value were education and alternative source of income. The findings that education had a positive effect on the magnitude of payment agree with other studies that have documented that an educated society may be willing to pay more for nature conservation in developing countries. For example, Heinen (1993) reported that an increase of one more year in school would raise the WTP value required to conserve wildlife in India by 5%. Although total household income (proxied by total expenditure) in the present study had the expected positive sign, it did not significantly influence the average WTP. This may be because we did not ask for the WTP in monetary terms. Using other forms of payment vehicles thus makes the results obtained to differ partly (not fully) with what has been reported in several other CV studies as far as the role of income in influencing WTP is concerned (see, e.g., Boyle and Bishop 1987; Bandara and Tisdell 2004). The level of household income, however, significantly influenced the amount paid in terms of labor and meals though in different directions. As the results indicate, increase in household income would make households be willing to pay more in terms of meals but less in terms of labor. Related to the level of income is the source of the income. Normally, respondents in the research area with off-farm income sources also earn higher incomes. Thus, since the opportunity cost of labor is higher for households with off-farm income sources, such respondents are more likely to be willing to pay less in terms of working (providing labor) in the hypothetical pollination garden. From the perspective of the average WTP, it is most likely that households with off-farm income sources tend to pay less for pollination because their interests and investments in farming are low.

The household WTP value is seen as fair and not exaggerative considering the income of the people in the region and that it was through non-cash payments. However, if the same amount of time (about 2 cumulative months) is compared to what this would actually mean in a developed country, e.g., Germany, it would be similar to paying US$ 3720 annually (or US $310 a month) by the low income earner. Taken literally, it would be unconvincing to assume that a household in Germany (or any other developed country) could pay such a sum. The monetized values are extremely high compared to most values derived from other studies done elsewhere in the world. However, from the expenditure point of view, the average household WTP was equivalent to spending US$ 7.32 monthly. This would increase their household expenditure by 6.2% a month (5.0% if median value is considered), which is economically acceptable. The use of such consumption figures may, however, not provide the real increment in the cost of production incurred by the households, as consumption may be affected by other factors such as remittance. The findings show how careful we should be when converting in-kind payments to monetary values, especially if the findings are to be used for benefit transfer analyses.

The valuation exercise carried out in this study using the SP method has many implications for the conservation of pollinators in Kakamega and Kenya in general. As noted earlier, pollination is a pure public good in the current farming system in Kenya. Farmers have free access to the pollination service and the use of it does not prevent others from enjoying its benefits. But the continued access and enjoyment of the service depends on the quality of the surrounding ecosystem. In the example of the Kakamega farmland, changes and management of the farmland landscape to provide favorable conditions for growth of pollinator populations will be necessary, e.g., optimization of the fence rows, which are unique features of the farmland. The economic value generated in this study reflects the value of pollination from the perspective of the users (consumers, growers) unlike the RP methods, which rely on assumptions based on observable market transactions. This is the strength of this valuation exercise and it is clear that policies are required to support the needs of the farmers in terms of improving provision of pollination services in the agricultural landscapes.

Finally, some factors inherent in the CV method, usually in form of the so-called biases (see section 5.5.2), might have influenced the values derived from the respondents. In carrying out the CV survey, the design and presentation of the questions were done in a way to minimize occurrence of the biases. However, the study was not done to allow later measurement of possible biases, hence it can only be speculated that there are a few biases. The hypothetical scenario bias, which occurs because the scenario has weak penalties (no true payment) for inaccurate information (Randall et al. 1983), was minimized by proper scenario development (that provided a realistic market situation) before presenting it to the farmers (Mitchell and Carson 1989). It was, however, difficult to exclude respondents who did not take the valuation exercise seriously, thus conveying untrue values for pollination. Farmers were given the full information to allow them make a well informed decision. However, the main problem that might have influenced the WTP value is what Kahneman and Knetsch (1992) identified as the purchase of 'moral satisfaction'. This phenomenon suggests that the good being valued is not really the good described in the CV question, but rather a good embedded within it. This embedded good is described as the satisfaction in giving to a good cause. However, some economists (Harrison 1992; Smith 1992) have shown that moral satisfaction is just another name for utility, and that respondents simply maximize their utility by paying for some changes in the good.

7.9 Conclusions and policy recommendations

This study was conducted among households living around the Kakamega forest in Kenya not only to assess their perceptions on the importance of pollination but also to elicit their WTP for the improvement of this ecological service. It is clear that most farmers were aware of the existence of pollination and understood its importance in crop production. This was especially after sensitization and information provision about pollination. Thus, policies to support their needs in terms of improving provision of pollination service in the agricultural landscapes of the research area are required. Such policies are likely to favor conservation of the Kakamega forest, which is a key reservoir for pollinators in the region.

The high positive response of the households to the WTP question implies that the hypothetical market presented to them was appealing. The valuation exercise carried out using the contingent valuation method has numerous implications for the conservation of pollinators in Kakamega. The magnitude of the WTP, in particular, shows that there is a strong economic argument for conserving pollinators in the research area. The economic value also reflects the value of pollination services from the perspective of the users (consumers, growers), something that could not have been accomplished through application of the RP methods, which rely on assumptions based on observable market transactions. This is the strength of this valuation exercise in the context of developing countries where pollination markets are lacking.

The results of this study indicate that educating local households impacts positively on nature conservation and especially on the pollination service. Policy makers, and government and non-governmental agencies, should therefore continue with efforts to support education, e.g., by maintaining the free primary education. Further, enhancement of farming activities (without degrading nature) as a source of income generating opportunities and activities for the rural people would also play an important role in nature conservation and in the provision of pollination services.

The study also tested two in-kind payment vehicles - provision of labor or meals - which were found to be more appealing than making monetary contributions to the hypothetical project. Thus, projects designed to allow public participation in the conservation of pollinators are likely to succeed if they are planned to allow in-kind payments. Although the results show that contribution of labor was preferred to lunch-time meals, it is difficult to rule out the application of the latter. This is because there are some particular groups of households, e.g., the higher income earners and elderly people, which are likely to provide larger payments when given the option to pay meals. This calls for an appropriate choice of the in-kind payment vehicle, since its effectiveness would depend on the group of local households being targeted for a particular pollination conservation initiative.

7.10 Value of crop pollination by bees: inference from factor of production and contingent valuation methods

Chapters 6 and 7 presented procedures on the measurement of the value of pollination of agricultural crops by bees each using different method: the factor of production (FP) method and the contingent valuation (CV) method, respectively. Although these two methods were devised to measure the value of crop pollination by bees, they captured different facets of pollination. From economic perspective, the FP method measured the total social value attributed to pollination of crops by bees, while the CV method measured the expenditure farmers (consumers of pollination service) were willing to incur to secure increased pollination of their crops. These differences are expounded below.

Starting with the FP method, it is imperative to know what the values obtained mean. It should be noted that these values relied on the experimental data (described in Chapter 3) based on two scenarios of pollination: with bee pollination and without bee pollination. The scenario with bee pollination was based on the farmer practice, because bees were not augmented. Therefore, the crops were visited by the local population of bees, which also applies to the farmers' crops. The experiment thus enabled determination of the 'supply shock' of a commodity after theorized removal of bees. Theoretically, the societal benefit that is lost because of such a shock is usually the sum of the lost consumer and producer surpluses. However, the FP method concentrates on producer surplus, and consumer surplus is neglected. This can be legitimized if the demand and price of the commodity on the local market do not change as a result of changed pollination quantity (Figure 7.1). Therefore, it was producer surplus that explained the expected societal benefit gained from bee pollination. Producer surplus is conceptually the difference between what the producers actually receive after selling the good and the amount they would be willing to accept for a unit of the good. The 'supply shock', which was experienced by a farmer following the removal of bees (Figure 7.1) is represented by a movement in the supply curve for an individual crop from S_2 (situation where bees are available) to S_1 (situation where bees are not available). Area C is the appropriate socially significant loss after the removal of bee pollinators and is the loss that was measured in this study. It was used to assess the societal value of crop pollination services conferred by bees in the Kakamega region, which in 2005 amounted to an average of US$ 1025 per household annually. This is the amount a farmer would loose if there was total loss of bees for pollinating the crops.

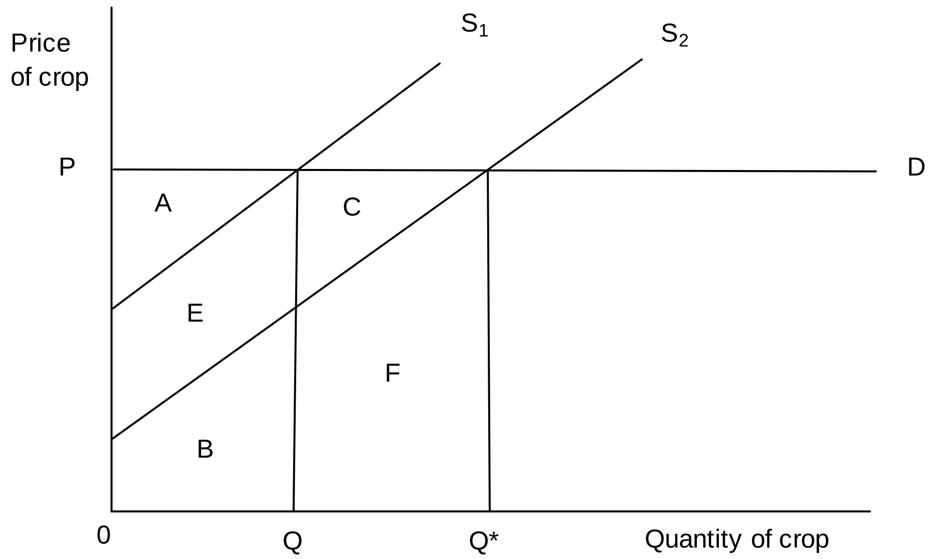

Figure 7.1: Consumer and producer surpluses for a commodity produced using bee pollination services. Source: Gill (1991)
(at S_1, PS = A, while variable costs, VC = E+B; at S_2, PS= A+E+C and VC= B+F)

In contrast to the FP method, CV method generated the value of pollination from a different perspective. In economic terms, it captured the amount that farmers were willing to pay to have additional benefits of bee pollination. This is similar to measuring the marginal benefit from 'consumption' of pollination service. Conceptually, marginal benefit is the additional benefit obtained from increasing consumption by one more unit (in our case, it is not one unit in the strict sense, but just an improved level). It is thus the amount farmers were willing to pay in order to enjoy the benefits of additional units of pollination (Figure 7.2). This amounted to an average of US$ 88 per household annually. The value represents the tradeoff between the pollination and the things that they could have purchased with the amount paid for the improvement. Bee pollination service in Kakamega is a positive externality of the maintenance of the surrounding habitats. This marginal benefit valuation, therefore, helps to determine the benefits that will accrue to the society if the externality (pollination) is increased. In Figure 7.2, the total benefit accruing to the society after improving the pollination level from 0 to q_1 is the area A+B. This is similar to the measurement of consumer surplus, except that in a benefit measure the costs incurred to secure pollination are not considered. Hence the entire area (A+B) is used to measure benefits, rather than just the area A.

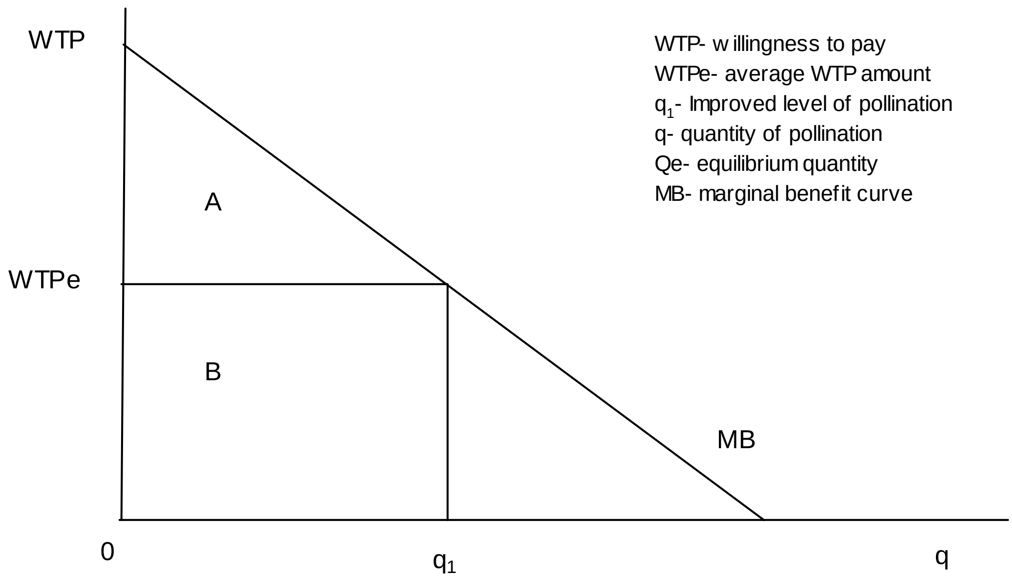

Figure 7.2: Marginal benefit curve derived from the WTP for increase in bee pollination of crops in Kakamega farmland, Western Kenya, 2006

Based on the law of diminishing marginal returns, it is expected that the marginal value of pollination would decrease, and finally diminish. It could, therefore, be argued that the marginal value obtained from the CV method is consistent with this theory of diminishing returns. The value for overall pollination is much higher than the value for the marginal unit.

Having shown how the two methods measured the value of pollination, it becomes clear that the values generated cannot be directly compared, principally because they measured different values of pollination. The FP method measured the benefit to the society as a result of bee pollination, while CV measured the marginal benefit of additional units of pollination.

Although the economic valuation exercises show that bee pollination is economically beneficial to the Kakamega society, the methodology does not provide guidance on the optimum level of pollination that farmers can be advised to adopt. This was beyond the scope of this study. However, it is possible to achieve this by carrying out experimental assessments purposely to support the calculation of marginal analysis of the optimum level of pollination. This would warrant controlled experiments in which different population of bees would be supplied per unit area to provide a certain level of pollination. This would be followed by calculations of net benefits, dominance analysis of different levels of pollination, and finally the calculation of marginal rates of return between different pollination levels (see Perrin et al. 1988; Evans 2005). Results from such experiments would benefit commercial farmers interested in spending their money on the most beneficial level of pollination. In the current farming system in Kakamega, this is not possible, as pollination is a pure public good and not managed in any way by farmers. The challenge is how to conserve bees for pollination considering their public-good nature. Due to the public good character, the government should not assume farmers will conserve bees, but should subsidize bee conservation in the area. This can be done in several ways as will be discussed in the next chapter.

8 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

8.1 Summary

This study was conducted to provide strategies for conservation of bees that will guarantee sufficient pollination of crops in the Kakamega farmland. To achieve this, the following objectives were addressed: i) determination of the diversity and activity density of bees visiting crop flowers, ii) assessment of the effects of bee pollination on crop yield, iii) appraisal of the farmers' knowledge on bee pollinators and pollination, and iv) measurement of the net economic benefit derived by farmers from pollination of their crops by bees.

8.1.1 Main findings

Individuals of bees belonging to more than 20 species were observed visiting crop flowers in the farmland (Chapter 2). The number of bee species near the forest and far from the forest was not significantly different. However, the population of some bee species (e.g., *X. calens*) was significantly different. Their activity density was higher near the forest than in the farmland. These findings imply that pollination of crops in the farmland is not entirely dependent on the bees coming from the forest, although the forest plays an important role as a habitat for bees. The results indicate that the farmland landscape might be complementing/ supplementing the forest in terms of provision of habitats for bees.

The dependency of 9 selected crops (beans, cowpeas, green grams, bambara nuts, capsicum, tomatoes, sunflower, passion fruit and squash) on bee pollination varied (Chapter 3). The effective bee pollinators were also different. Solitary bees were pollinators of most crops, while honeybees were only effective pollinators of two crops, sunflower and squash. Even for sunflower, recent research has shown that presence of solitary bees improves effectiveness of honeybees. The change in yield for each crop due to change in bee pollination was different. For example, although tomatoes require specific bee behavior for pollination (buzzing), the yield increment was 15% compared with flowers protected against bee visits. However, bee-pollinated flowers had more seeds that resulted in bigger fruits. This was also noticed in squash, which could only produce fruits after cross pollination. The higher the number of bee visits, the bigger the fruit, which may have been due to the increased amount of pollen deposited on the stigma, which resulted in fertilization of more ovules, thus triggering the growth of the fruit mesoderm. Apart from increased yield, some legumes and sunflower had increased seed protein content and seed oil content, respectively. Bee pollination, therefore, enhances the nutritional status of the commodity in addition to other advantages. This could be due to the effects of cross pollination.

After talking to farmers, it was found that almost all of them knew more than one bee species (Chapter 4). In addition, half of them knew the function of bee pollination in crop production. After sensitization and reminding them about the issues of bees and bee pollination, farmers were willing to manage pollination in their surroundings in several ways, but none suggested bee rentals. This implied that any strategy advocated for bee conservation in the farmland should aim at using cost-effective methods affordable to farmers. The knowledge and understanding of pollination was highly influenced by the farmers' education.

Two different approaches were taken to measure the economic benefits farmers derive from crop pollination by bees. In the first instance (Chapter 6), the economic benefit of bee pollination was calculated using data from the experimental study (Chapter 3) and observation of the producer surplus of the yield attained after pollination. It was found that almost 50% of the market value of 8 selected crops (squash excluded) in Kakamega was due to bee pollination. This translated to almost 40% as the net benefit (after subtracting variable costs) that farmers would loose annually if there were to be a total loss of the bees that pollinate such crops. The second case (Chapter 7) valued crop pollination by bees from the perspective of farmers. Farmers were asked to state how much they would pay for an increase in bee pollination, as they had already some knowledge of the function of pollination in crop yields. The extraction of the value was through a hypothetical market that was based on non cash payments. Of all farmers, 98% agreed to pay for pollination. This was around US$ 90 per household annually when the payments were monetized using the local currency rate. The magnitude of payment was influenced by education of the farmer and whether the farmer had external sources of income. Education increased probability of a farmer paying higher amounts for pollination.

The findings, therefore, show that the populations of different bee species pollinating crops in the farmland are few and warrant conservation. The willingness of the farmers to conserve pollination was confirmed by the high responsiveness to the payment question, and the magnitude of payment realized. The agricultural landscape in Kakamega is well endowed and its management can lead to improvement of bee population sizes. Such conservation strategy can help the people to appreciate nature, and aid in protection of the nearby forest. This would be so especially if inhabitants are taught that bees benefit from the presence of different plants, and that forest provides high floral diversity that may be required by bees at different times of the year. The economic gain derived from bee pollination provides additional reasons for bee conservation.

8.1.2 Crop pollination management in Kakamega farmland

When considering pollination management in Kakamega, we have to bear in mind that pollination has public good traits in the area. Therefore, the channels used should appeal to the managers, in our case, the farmers. Stakeholders will play different roles to achieve the preferred landscape management level for conservation of bees.

Most of the strategies recommended here are based on the findings of this study although projects in other parts of the world that have employed landscape management to improve bee population for pollination purposes will be considered. The first issue to consider is the role of the government in the conservation process. Education was reported to have a positive impact on knowledge and payment of pollination by farmers (chapters 4 and 7). The first step towards bee conservation would be, therefore, creation of a policy on education. The government should continue to support education of the school children to form a strong foundation for future farmers. The role of nature in agricultural production should be emphasized. Farmers should be informed of the role of pollination in their farming activities. As long as the community understands and associates its economic empowerment with pollination, it will be willing to manage it for its own benefits. The government can meet this through public meetings organized by the extension department. This implies that the government should empower and increase the capacity of the extension department. Connected with extension is the source of information. Usually extension officers receive current trends of science from different researchers. Therefore, the government needs to support (channel resources to) research activities that are aimed at determining needs of the different bees that should be taken into consideration in the new landscape structure.

One of the unique features observed in the farmland was the presence of hedgerows (live fence) that are rich in different plant species. If well managed, these hedgerows could form areas of floral and structural diversity to accommodate the temporal and spatial needs of different bees. The floral diversity in the hedgerows would ensure bee forage is available throughout the year especially during off-season periods. Floral diversity should be maintained in these structures, by having mixtures of annuals, biennials and perennial bee forage plants. Mowing/trimming should be done only after flowering and only occasionally to prevent dense structures, which are not attractive to bees. Research is needed to find out the required forage for different bees, including management of their nesting requirements, and on their spatial needs, e.g., sites for nesting, resting, hiding or breeding. In addition to hedgerow management, the government should set some land aside that would be left undisturbed for bee habitats. Although land is scarce in the area, the government can steer utilization of land parcels, e.g., using compensation schemes or through purchases. Such parcels should be strategically placed in the farmland. These would complement the hedgerows, which are managed by individual farmers. Use of hedgerows in conservation of bees and other pollinating insects has been done in other countries, e.g., UK (Matheson 1994), and Poland (Banaszak 1992). A closely related strategy is the use of trap nests for the cavity nesting solitary bees. Bees differ in their body sizes. As such, the trap nests should be made of different sizes. Use of local materials, e.g., bamboo reeds should be emphasized to reduce the costs incurred by the farmers. It is also possible to drill holes of varying sizes in a block of wood. Again, research is necessary to design suitable trap nests that will be advocated to farmers.

Another important strategy for the conservation of bees is the management of farmer cropping practices. Attention needs to be paid to tillage practices and pesticide usage. Minimum tillage favors ground-nesting bees, as it has minimum disturbance of soil. However, it is not highly practiced in the farmland, although it improves soil fertility. Soil scientists and agronomists should suggest minimum tillage in the area and advice farmers accordingly. Unwise use of pesticides in agriculture has played a key role in the decimation of bees and other pollinating insects worldwide (Bohart 1972; Kevan and Baker 1983; Kevan et al. 2007). The most destructive pesticides are the insecticides and herbicides. Herbicides can kill bees, destroy their nesting sites and their forage. However, few farmers reported their use, although in future we cannot rule out high application in the farmland. Insecticides were also not reportedly used by the farmers, but future use cannot be ignored either. The effect of insecticides on bees is usually high when applied in the blooming period. If it is absolutely necessary, then farmers should time the application to coincide with the period when bees are not foraging. They should use those insecticides that have a low toxic effect on bees. This information is available from the Ministry of Agriculture offices, and farmers should be advised accordingly. Most pesticides also carry cautions about their use and effects on bees, although it is not known whether local farmers read labels before using a pesticide. It is, however, important to note that although not all pesticides or their methods of application are equally damaging, a few are selective enough to effectively eliminate the harmful pests without causing damage to bees (McGregor 1973; Johansen and Mayer 1990). Therefore, use of cultural, physical and mechanical methods within an integrated pest management system may be the most appropriate strategy. These are not new in the farmland, as most of the farmers said they practiced them. The bee conservation strategies have also the advantage of creating conditions that may favor the existence of natural enemies of crop pests.

Livestock management also plays a significant role in bee conservation. In extreme cases, i.e. overgrazing, may lead to a decrease in diversity of bee flora. Of course, there are even more important devastating effects of overgrazing, e.g., soil erosion followed by desertification (Petanidou and Ellis 1996). The ministry of livestock development in Kakamega has projects that advise farmers on the management of animals, and this should continue. However, in terms of bee issues, the department emphasizes only beekeeping (honeybees and stingless honeybees) for honey and wax. In essence, the pollination component of bees should receive more attention.

The application of these strategies and others that may be revealed by future research in the farmland would result in better habitats for supporting bee life. The anticipated increase in bee populations in the area will result in sufficient pollination of crops and improve the wellbeing of the community. This will address food security in the area, which is a main concern by the government. Another advantage of these strategies is their potential role to help people appreciate and conserve nature. This would ease the pressure on the nearby forest. However, farmers should always be updated and equipped with knowledge to enable them to continue to apply good bee conservation practices.

8.2 Conclusions

The following key findings can be reported from this study:

1. Individuals of some bee species, mainly *X. calens,* were influenced by the distance of the field from the forest. However, bee diversity was not different.
2. *Apis mellifera* was the main pollinator of sunflower and squash. Bees belonging to *Xylocopa* and *Megachile* species were the main pollinators of cowpeas, beans, passion fruit and tomatoes.
3. Beans, cowpeas, green grams, bambara nuts, capsicum, sunflower, tomatoes, squash and passion fruit benefit from bee visits through enhanced yield.
4. Total decline of bee pollinators in Kakamega may result in a loss of net benefit of about 37% of the total annual market value of the 8 crops (squash not considered) in the Kakamega farmland.
5. Farmers in Kakamega were familiar with bees and the function of pollination in crop production. They were willing to support conservation projects that aim at improving bee pollinators in the farmland, especially by use of low cost methods.
6. Education and information from extension services influenced farmer knowledge of bees and pollination.
7. Farmers were willing to pay for pollination services, by spending an estimated US$ 88 per household annually. The level of education and having off-farm income generating activities impacted on the WTP value given by respondents.

8.3 Recommendations and policy implications

1. Bee management is crucial for sustaining benefits obtained from the pollination service they provide to agriculture. In the Kakamegan case, this

may require changes in the farming and associated activities aimed at promoting the increase in the population of different bees. The government can support research that shows how the farmland landscape can be maintained to suit bee needs without making farmers worse off. The government needs to invest in projects aimed at improving provision of pollination services in the agricultural lands. This can be done by first supporting research on crop pollination and pollinators.

2. Creation of awareness on the importance of pollination should also be undertaken. The government should thus empower the extension department to meet this challenge, and methods used to advocate pollination, just as other inputs, should be designed.
3. The government should focus on education especially on the role of pollinators and sustainable utilization of pollination services in crop production and in general the importance of nature. This can be done through an improved school curriculum that provides pollination issues within the larger 'inputs of crop production' section.
4. Policies that support programs that can improve the welfare of the people impacts positively on nature conservation and hence should be initiated.

Finally, there are several ways in which this study has contributed to academic dialogue. The first is through the on-going deliberations on the declining trend of populations of bee pollinators worldwide. The second critical issue addressed is the understanding of the economic value of crop pollination by bees. The research also demonstrates the applicability of the contingent valuation method in a developing country set up. Finally, the study highlights the role of farmers in managing agro-biodiversity.

This study did not investigate the factors that may be causing low bee activity density in crop flowers, and folk classification of bees. In addition, the ecological value of bee pollination was not investigated. The strategies that may be applicable for conservation of bees were also not investigated further. Future research about these issues would hence complement the findings of this study.

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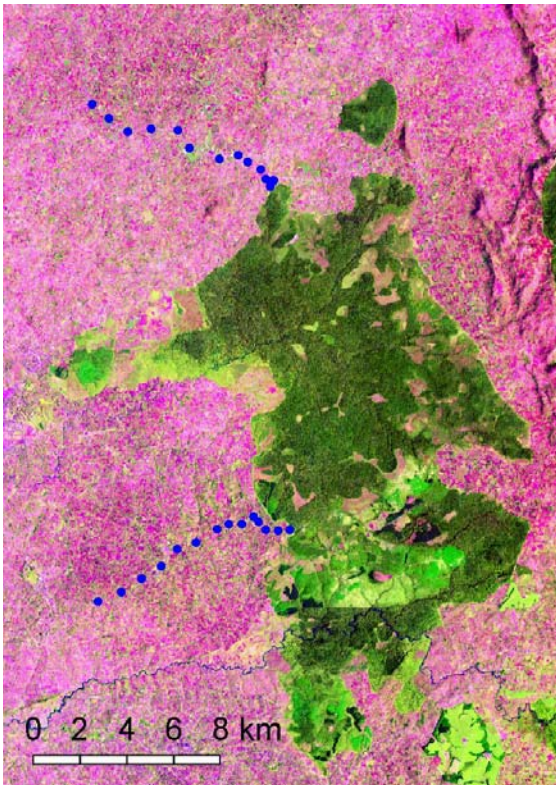
10 APPENDICES

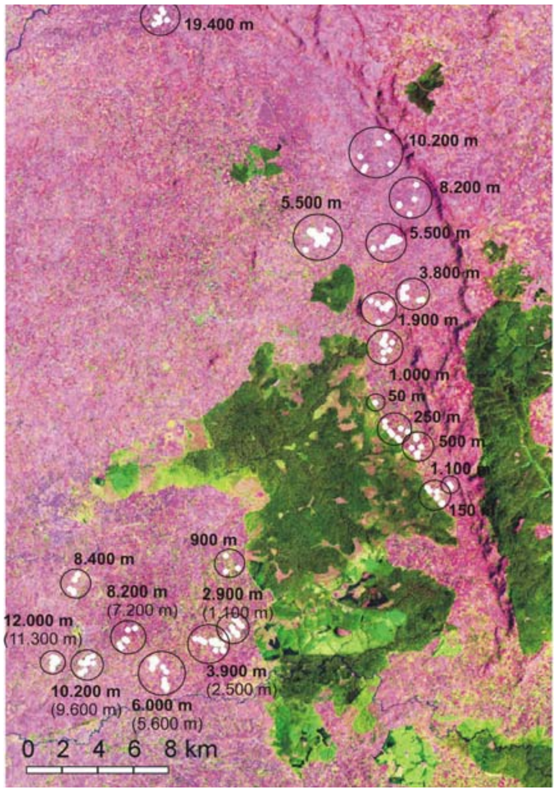
Appendix 10.1: GIS map a) showing the observation sites for bees visiting bean flowers in transect done from the edge of Kakamega forest towards the farmland, b) showing the some households points involved in the questionnaire schedule in January and February 2006 in Farmland surrounding Kakamega forest, Western Kenya, and its fragments (Landsat ETM+ (7) satellite image, 05 Feb 2001, spectral bands 5/4/3, contrast enhanced; source: BIOTA-East Africa, G. Schaab, Karlsruhe University of Applied Sciences, Germany)



a

Key

vegetation/forest
farmland
stream
transect observation sites



b

Key

vegetation/forest
farmland
stream
households in same village

Appendix 10.2: Questionnaire used for the assessment of farmer' knowledge of crop-pollinator interactions and contingent valuation of pollination service in Kakamega farmlands

No.

Start time ____
End time ____

A. Identification

1. Name of the enumerator _________________________ Date:_______
2. Area: Location_________Sub location _______ Village _____Coordinates: _______
3. Name of respondent ______________________ Gender: Male [ ] Female [ ]
4. Marital status: Married [ ] single [ ]
5. Relation to household head ***(if not the hhh)***_________
6. Age ***(or, when were you born?)***: __________________
7. Level of education ___________ Total years in school ______
8. Have you had any training? Yes [ ] no [ ] discipline: _______ years spend _______
9. Household size ***(no. of people eating from same kitchen)*** ______________________

B. Household Expenditure and Economic Activities

10. In the past 1 month, how much did you spend:

Item	Value produced	Value purchased

11. In the past 1 year, how much did you spend for clothing? ___ repair/ maintenance___
12. In the past 3 months, how much did you spend for education? _____________
13. Any other expense for the past 1 month? ____________________________________
14. Do you keep livestock? Yes [ ] no [ ] list:__________________________________
15. Do you grow crops? List:____
16. What off-farm activities do you carry out? ___________________________________
17. Where do you get information about farming practices?________________________

C. Pollinators, Pollination and Flowers

18. Do you know honeybees? Yes [ ] No [ ] ***(if no, go to 20)***
19. Do you keep them? Yes [ ] No [ ] ***(if no, go to question 20)***
    a. If yes, how many hives? ________
    b. Are all hives colonized? Yes [ ] no [ ] how many un-colonized? ____________

c. Where are your hives located?________________

20. Do you know bees other than honey bees which make honey? Yes [ ] No [ ]
    a. If yes, list: ____
    b. Where do they live ***(nest)***? ____
    c. Do you harvest their honey? Yes [ ] No [ ] If no, reasons:__________________
21. Do you know other bees which do not make honey? **(*Picture collection of different bee species and other insects should be provided to the farmer to assist him/her in listing what he/she knows as the bee, if need arises; and also to proof that the farmer really know bees, from other kind of insects*)**Yes [ ] No [ ]
    a. If yes, list: ____
    b. Do you know where they live ***(nest)***? Yes [ ] no [ ] If yes, Where?__________
22. When do you start to notice bees visiting your crops? ____________________
    a. Do bees prefer different crop flowers? Yes [ ] No [ ] List:_________________
23. Are bees present all year round in the farm or in the surrounding shrubs? Yes [ ] No [ ]
24. Do you also notice other insects visiting the crops during flowering? Yes [ ] No [ ] list:____________
25. Can you differentiate non pest and pest plant visitors during flowering period? Yes [ ] No [ ] List: Non pest visitors ________Pest visitors ___________________________
26. Do you know what bees eat/drink from a flower? Yes [ ] No [ ] List:____________
27. Do you think the crop ***(or flower)*** benefits from the bee visits? Yes [ ] No [ ] List:__
28. Do you think that without flowers you can get fruits ***(avocado)*** or seeds ***(beans)***? Yes [ ] No [ ]
29. Do you know whether a flower ***(e.g. of beans, avocado)*** require fertilization to produce seeds/pods/ fruits? Yes [ ] No [ ] I am not sure [ ]

    (After this question the enumerator explains to the farmer the mechanism and importance of pollination and pollinators, before proceeding with the other questions. Several pictures of fruits/yield from well pollinated and poorly pollinated crops are shown to the farmer to add more weight on the positive impact of insect pollination; cases of the farmer's crop being enhanced by pollination should be described and emphasized)

D. Pollinator natural history

30. Do you use pesticides for pest control? Yes [ ] No [ ]
    a. If **YES**, type(s): ___when? ______ time of application? ____________
    b. What **OTHER METHODS** do you use for pest management?______________
31. What kind of fencing do you use around your field/homestead?___________ ***(if no live fence, go to 35)***
32. If live fence:
    a. Is it around whole farm? Yes [ ] No [ ]
    b. Does it merge with neighbors' fence? Yes [ ] No [ ]
    c. What are the plant species in its composition? List: __________
    d. What are the reasons for the species maintained on the fence?______________
    e. How do you manage the fence?__________________________
33. Do the plant species ***(in the fence composition)*** flower? Yes [ ] No [ ] ***(if No, go to 35)***
    a. If yes,
        i. Do they all flower same time? Yes [ ] no [ ] ***(if yes, go to ii)***
            1. If no, do you observe some flowering same time with your crops? Yes [ ] no [ ]
            2. For those which flower same time with crops, do you notice bees visiting their flowers? Yes [ ] no [ ]
        ii. Do bees prefer the crops more than the shrubs when they flower same time? Yes [ ] no [ ]
        iii. Do you notice other insects apart from bees visiting the flowers this period? Yes [ ] No [ ] list; ____________________________________
34. Where do you get your fuel wood from?_____________________________
35. Do you notice the following from the fuel wood ***(tick all seen)***?
    a. Holes, but no caterpillar or adult inside [ ]
    b. Holes, caterpillar [ ], pupae [ ], adult inside [ ]
    c. No holes seen but insect found [ ]
    d. None of the above [ ] ***(if d, go to 38)***
36. Are these signs from: Particular plant [ ] All plants in general [ ]?
    a. If particular species, list:_____________________________________

37. Do you notice some bees getting in/out of ground holes? Yes [ ] No [ ]
    a. If yes, which bees? Honey making bees [ ] solitary bees [ ]
    b. What is the ground cover type?____________________
    c. What is the use of this land? ___________________________
38. Would you like to increase pollinators in your farm? Yes [ ] no [ ]
    a. If yes, in which ways? _____________________________________
    b. If no, why? ____

E. Value of Pollination

39. A project will be designed by various stakeholders (government ***(to register the project, offer training, facilitation)***, NGOs & CBOs ***(facilitate, organize)***, and farmers ***(to participate)***) to increase the number of pollinators in your village. Local farmers will be requested to contribute to the success of this project. The project would involve setting land a side for pollinator garden ***(appropriate area that can supply your pollination needs)*** in the village, managing the garden through construction and maintenance of nesting, sleeping, mating, resting or hiding sites and making pollinator corridors in the village. Farmers will be asked to participate in two ways: ***Either:*** contribute own labor (***i.e. working for a number of days per week, no food provided) or*** provide meals for those working in the project ***(i.e. provide meals weekly) (farmer is explained that participation is weekly and cost of a single meal is equal to 1 day of labor = KShs. 50 and no payment in cash is accepted)***.

If farmers participate, the project will continue and it is expected that in the next few years, farmers will be getting more yields from crops requiring insect pollinators ***(farmer is explained on the impacts of this e.g. enough food for consumption,, increased commodity quantities for selling, stable farmer' financial income etc).***

    a. Would you be willing to participate to its success Yes [ ] no [ ]
        i. If yes, what will you be willing to contribute? labor [ ] meal [ ]
    b. **IF NO,** why? ____
    c. **IF LABOR**, what is the maximum number of days would you be willing to spend working in the project? _________

d. **IF MEAL**, what is the maximum number of meals would you be willing to provide to the project?________________

Appendix 10.3: List of plant families and representative species mentioned by farmers to occur in their live fences during a survey in Kakamega, western Kenya in 2006

Family	**Botanical name**	**Luhyia name**	**English name**	**Type**
Acanthaceae	*Acanthus pubescens*	Marakalu		Shrub
Agavaceae	*Agave sisalana*	Likonga	Sisal	Shrub
Agavaceae	*Dracaena fragrans*	Tsikhubu	Dracaena	Shrub
Aloeaceae	*Aloe vulgaris*	Shikakha	Aloe vera	Shrub
Anacardiaceae	*Mangifera indica*	Muembe	Mango	Tree
Anacardiaceae	*Rhus natalensis*	Mukangula/ musangula		Tree
Apocynaceae	*Funtumia africana (F. latifolia)*	Mutondo	Bush rubber	Tree
Araliaceae	*Polyscias fulva*	Mwanza/ mwanzu/ mramwa	Parasol tree	Tree
Arecaceae	*Phoenix reclinata*	Lishindu	Palm	Shrub
Asclepiadaceae	*Mondia whytei*	Mukombelo		Climber
Asteraceae	*Tagetes spp*	Navutsaka	Marigold	Shrub
Asteraceae	*Tithonia diversifolia*	Lihua Lilulu	Tithonia	Shrub
Asteraceae	*Vernonia angustifolia*	Musururitsa		Shrub
Asteraceae	*Vernonia auriculifera*	Lisabakhwa/ lisavakhu		Shrub
Basellaceae	*Basella alba*	Inderema		Climber
Bignoniaceae	*Jacaranda mimosifolia*	Jakaranda	Jacaranda	Tree
Bignoniaceae	*Markhamia lutea*	Lusiola/ siola/ sialo	Markhamia	Tree
Bignoniaceae	*Spathodea nilotica*	Mutsulia/Mutsulyo/ mutsulya	Nandi flames	Tree
Boraginaceae	*Cordia abyssinica*	Mugomari/mukomari	Cordia	Tree
Canallaceae	*Wurbugia ugandensis*	Mupachi		Tree
Caricaceae	*Carica papaya*	Lipaipai	Pawpaw	Tree
Clusiaceae	*Harungana madagascariensis*	Musila		Tree
Combretaceae	*Combretum binderianum*	Mulaa/ viraha/ shilahaa		Tree
Combretaceae	*Combretum molle*	Mukhoji/mukhanji		Tree
Convolvulaceae	*Ipomoea spp*		Morning glory	Climber
Cucurbitaceae	*Cucurbita spp*	Liseveve/lihondo	Pumpkin	Shrub
Cupresses	*cypressus lusitanica*	Mutaragwa/ mutarakhwa	Cypress	Tree

Appendix 10.3: continued

Family	Botanical name	Luhyia name	English name	Type
Ebenaceae	*Diospyrus abyssinica*	Lusuu/lusui	Giant diospyros	Tree
Euphorbiaceae	*Bridelia micrantha*	Shikangania/ Munyerenyende		Tree
Euphorbiaceae	*Croton macrostachyus*	Musutsu	Croton	Tree
Euphorbiaceae	*Croton megalocarpus*	Musine		Tree
Euphorbiaceae	*Erythrococca atrovirens*	Shirereswa/shirietso		Shrub
Euphorbiaceae	*Euphorbia viminale*	Shinakotsi		Shrub
Euphorbiaceae	*Ricinus communis*	Mabonobono	Castor	Tree
Euphorbiaceae	*Sapium ellypticum*	Misaso/musasa		Tree
Fabaceae	*Acacia mearnsii*		Wattle tree	Tree
Fabaceae	*Acacia spp*	Mgongochuma		Tree
Fabaceae	*Caesalpinia decapetala*	Luavari/sikhoni	Cat's claw	Shrub
Fabaceae	*Cassia dydincobotrya*	Libinu/lubini/ muvino		Shrub
Fabaceae	*Erythrina abyssinica*	Murhembe/muyembe		Tree
Fabaceae	*Leucaena leucocephala*	Mulukina/lukhule	Lucaena	Shrub
Fabaceae	*Sesbania sesban*	Tsikhule/lukhula		Shrub
Fabaceae	*Tephrosia vogelii*		Tephrosia	Shrub
Flacourtiaceae	*Casearia battiscombei*	Shitandamasi	Casearia	Tree
Flacourtiaceae	*Dovyalis caffra*	Kaiyava	Kayapple	Shrub
Flacourtiaceae	*Dovyalis spp*	Induli		Shrub
Flacourtiaceae	*Oncoba spinosa*	Likunga		Tree
Lamiaceae	*Plectranthus barbatus*	Shivokha/ shilokha/virokho		Shrub
Lauraceae	*Persea americana*	Mukato	Avocado	Tree
Loganiaceae	*Nuxia congesta*	Luvambu		Shrub
Maesaceae	*Maesa lanceolata*	Mushevesheve	False assegai	Shrub
Maliaceae	*Azadirachta indica*	Mwarobaini	Neem	Tree
Malvaceae	*Hibiscus accidental*	Irundu/ shikambi	Hibiscus	Shrub
Menispermaceae	*Stephania abyssinica*	Malende/ malande		Climber
Mimosaceae	*Entada abyssinica*	Musembe		Tree
Moraceae	*Ficus benjamina*			Tree
Moraceae	*Ficus thonningii*	Mugumo/ mukumu	Fig tree	Tree
Myrtaceae	*Eucalyptus saligna*	Mukambi	Eucalyptus	Tree
Myrtaceae	*Psidium guajava*	Shepera	Guava	Tree
Myrtaceae	*Syzygium guineensis*	Musioma		Tree
Nyctaginaceae	*Booganvillea spectabilis*		Bougainvillea	Shrub
Passifloraceae	*Passiflora edulis*	Shikoshe	Passion	Climber
Pinaceae	*Pinus patula*		Pinus	Tree

Appendix 10.3: continued

Family	Botanical name	Luhyia name	English name	Type
Proteaceae	*Grevillea robusta*	Musiyenze/musienze	Gluvelea	Tree
Rhamnaceae	*Maesopsis eminii*	Mutere/mtere	Umbrella	Tree
Rosaceae	*Eriobotrya japonica*	Shipalapandi	Loquarts	Tree
Rosaceae	*Rubus rotundifolia*	Vushererwa/ bushererwa		Shrub
Rubiaceae	*Vangueria apiculata*	Mukhomolo		Tree
Rutaceae	*Clausena anisata*	Shirimbari		Shrub
Rutaceae	*Teclea nobilis*	Lutari		Tree
Rutaceae	*Zanthoxylum gelletii*	Sikhuma	Fagara	Tree
Sapotaceae	*Manilkara butugi*	Litolo/lutolio		Tree
Solanaceae	*Solanum incanum*	Shirandalo/solanu/ ndulandula	Sodom apple	Shrub
Solanaceae	*Solanum mauritianum*	Lipota		Shrub
Urticaceae	*Urtica dioica*	Isambakulu	Stinging nettle	Shrub
Verbenaceae	*Clerodendron buchholzii*	Esieche/lutseshe		Shrub
Verbenaceae	*Lantana camara*		Lantana	Shrub
Verbenaceae	*Lantana trifolia*	Shimamena		Shrub

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