POLLINATION SERVICES FOR SUSTAINABLE AGRICULTURE

EXTENSION OF KNOWLEDGE BASE
ADAPTIVE MANAGEMENT
CAPACITY BUILDING
MAINSTREAMING

TOOLS FOR CONSERVATION AND USE OF POLLINATION SERVICES

INITIAL SURVEY OF GOOD POLLINATION PRACTICES

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GLOBAL ACTION ON POLLINATION SERVICES
FOR SUSTAINABLE AGRICULTURE

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1. INTRODUCTION

Recent studies have documented that about two-thirds of the crop plants that feed the world, plus many plant-derived medicines, rely on pollination by insects or other animals to produce healthy fruits and seeds. For human nutrition the benefits of pollination include not just the abundance of fruits, nuts and seeds, but also their variety and quality. The contribution of animal-pollinated foodstuffs to human nutritional diversity, vitamin sufficiency and food quality is substantial.

Just as the agricultural community is taking stock of the contribution of pollination to orchard, horticultural and forage production, populations of managed pollinators (the honeybee *Apis mellifera* and its Asian relatives) are experiencing new and poorly understood threats. Fortunately, with a greater appreciation of the role of pollination in food production, comes a greater understanding of the major contribution of wild pollinators — of the slightly more than 100 crop species that provide 90 percent of national per capita food supplies for 146 countries, 71 crop species are bee-pollinated (but relatively few by honeybees). Several others are pollinated by thrips, wasps, flies, beetles, moths and other insects. Biodiversity in agricultural landscapes can provide important pollination services and serves also as a critical form of insurance against the risks of pests and diseases amongst managed pollinators.

The specific practices that farmers can undertake to promote pollinators on their farms, however, are less well understood or appreciated. In fact, the conventional process of agricultural development may often be inimical to sustaining pollinator populations. As farm fields have become larger, and the use of agricultural chemicals that impact beneficial insects - pollinators, along with natural enemies of crop pests - has increased, pollination services show declining trends. There are urgent reasons to identify, in multiple agro-ecosystems and ecologies, pollinator-friendly management practices that serve to enhance yields, quality, diversity and resilience of crops and cropping systems.

The Food and Agriculture Organization of the United Nations (FAO) along with its partners in Brazil, Ghana, India, Kenya, Nepal, Pakistan and South Africa, will be developing demonstration sites of pollinator-friendly good agricultural practices, to showcase and assess the contribution of well managed pollinators. As these are developed, it is essential to base the activities on existing local practices - for example, the protection of sacred groves in agricultural landscapes - that already conserve pollinator diversity in farming systems. It will be important to document such practices before they are lost through the wholesale adoption of conventional modern agricultural practices. It is also essential to survey all other land management practices - traditional, conventional and alternative - that can be applied to pollinator conservation and use. A means of evaluating for their effectiveness, usable by farmers, land managers and researchers, is needed. Experience in similar projects has shown that careful inventories of existing practices will identify a core of good practices that can be built upon and improved to achieve conservation objectives. However, initial assumptions of what are "beneficial" and "deleterious" practices are often not correct, and the impacts of some practices may often be unexpectedly good (or detrimental).

FAO has coordinated this initial survey of good practices to conserve and manage wild pollination services, in collaboration with the International Centre of Insect Physiology and Ecology (ICIPE) in Nairobi, Kenya. Profiles of nine pollinator-dependent cropping systems from around the world have been compiled. The profiles provide detailed information on the impacts of specific practices on pollination services and the research or traditional systems supporting these practices, their socio-economic aspects, environmental costs, benefits and replicability. People interested in learning how to manage pollination services will find these profiles informative, as they explain practical applications of good practices in on-the-ground settings.

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Initial Survey of Good Pollination Practices

PROFILES OF BEST PRACTICES FROM AROUND THE WORLD

Africa

Figure 2.1.A. Papaya trees with heavy fruit set surrounded by natural vegetation, Biretwo, Kerio Valley, Kenya.

2.1 PAPAYA ON SMALL-HOLDER FARMS IN THE KERIO VALLEY, KENYA: 'BOMAS', HEDGEROWS, NATIVE PLANTS AND CONSERVING MALE TREES

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Nature Kenya — the East Africa Natural History Society

2.1.1 THE PAPAYA (*CARICA PAPAYA*) FARMING SYSTEM OF KERIO VALLEY

The Kerio Valley of Kenya forms a large extension of the Great Rift Valley system. It runs from north to south with Lakes Baringo and Bogoria lying east of the valley. Altitude ranges from 900 metres in the Lake Baringo and Lake Kamnarok basins to over 2300 metres in the adjacent highlands. The mean annual temperature ranges from 14° C in the highlands to 24° C in the semi-arid lowlands.

The Nilotic people (including the Keiyo, Elgeyo, Pokot, Tugen and Marakwet peoples) inhabiting the valley, practice a mixture of pastoralism and small scale subsistence agriculture using irrigation. Population density in the valley is low (about 15 people per square kilometre) and dispersed, as people follow traditional patterns of livestock rearing in the lowlands of the valley. Most of the settled homesteads are close to water with large areas of uninhabited land in between.

Rainfall in the valley is highly variable and strongly linked to the altitudinal gradient, with steep highland areas receiving more rain than the arid bushland and acacia woodland that dominate the valley floor and lower slopes. Rainfall in the lower areas of the valley is rarely more than 400 mm annually and therefore long-term cultivation requires irrigation from permanent and semi-permanent streams originating in the highlands.

Settled farmers cultivate land on the valley floor close to the western wall of the valley. Their farms are typically small, rarely more than 4 acres in size and managed by one extended family with women doing most of the day-to-day cultivating and weeding and men tending livestock and preparing land before the rainy season begins. Crops grown include maize, beans and millet seasonally as well as small orchards of mango, citrus, banana and papaya, which are gathered locally, for sale and transport to towns and cities.

As cultivation is limited to areas adjacent to rivers where water for irrigation can be drawn, large areas of natural habitat remain around cultivation. *Acacia tortilis* forms extensive woodlands across the valley. Ground cover and shrubs are heavily overgrazed in many places (Thom and Martin 1983), but *Aloe lateritia, Salvadora persica* and *Balanites* sp. are common, as are grasses seasonally (*Tragus* sp., *Chloris roxburghiana*). Many subsistence farmers plant or build hedgerows of shrubs (*Euphorbia tirucallii, Acacia mellifera*) to keep livestock out of the farms and these are often covered by creepers from the Convolvulaceae family.

2.1.2 POLLINATION OF PAPAYA

Papaya trees in cultivation are generally considered to be 'male' or 'female', a fact also recognised by rural farmers. The papaya plant has separate male (pollen-bearing) and female (fruit-bearing) flowers, along with some flowers that are both male and female (hermaphroditic). The latter occur on what can be called separate male and female trees. The male flowers on 'male' trees are produced in larger numbers than female flowers. They are produced in small bunches on short panicles originating from the trunk in-between the leaf-bases. Female flowers are borne on short stalks from the tree-trunk, amongst the leaves. The fruit hangs down as it develops and ripe fruit are generally located below the leaves.

There are some characteristics of papaya pollination that are important to consider, in evaluating good pollination practices. The floral biology and fruit development of papaya is quite variable (Ronse Decraene and Smets 1999). In general, the female flowers account for the majority of saleable fruit while hermaphroditic flowers can

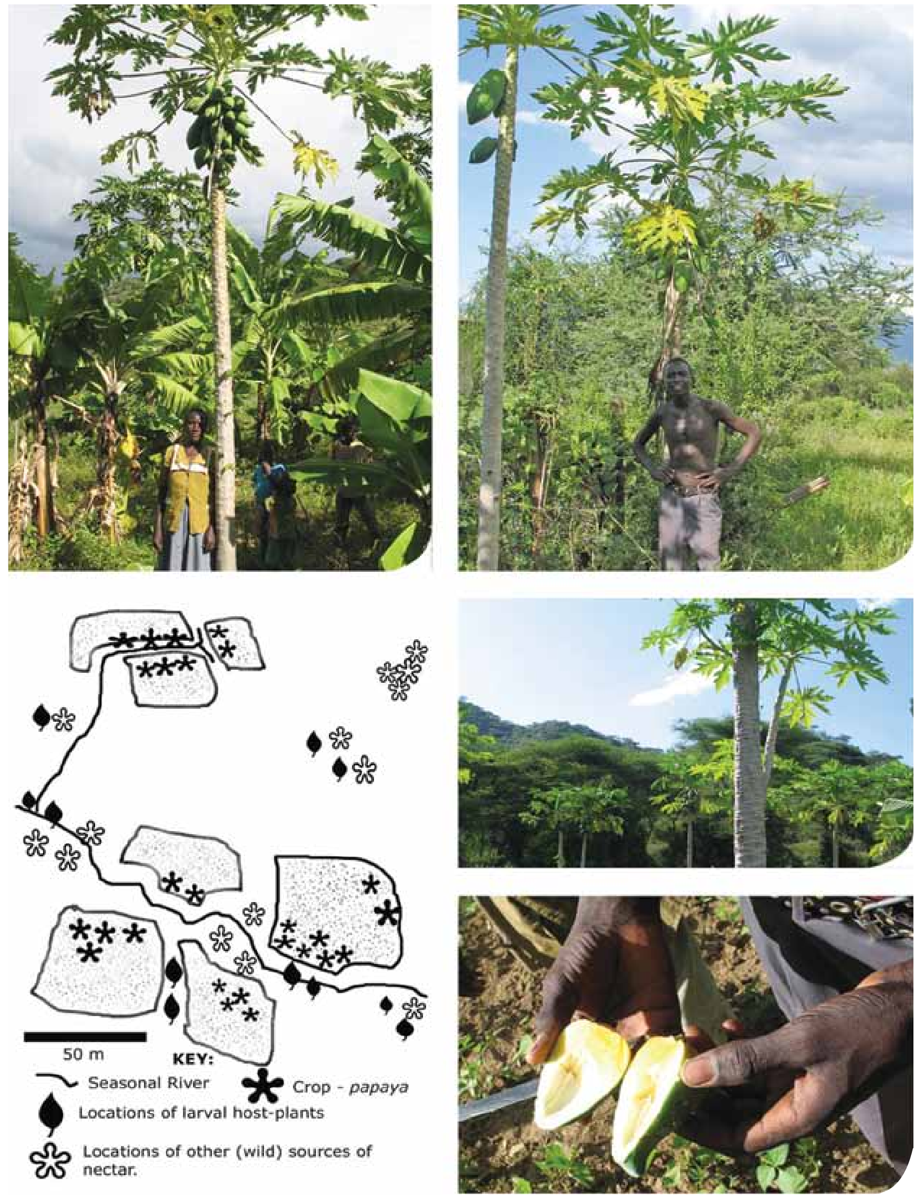

Figure 2.1.B. Clockwise from top left: Typical cultivation of papaya – note thick ground-cover of natural vegetation, papaya trees along a hedgerow of indigenous plants, papaya farm with larges areas of natural habitat in the backgroud – typical of most Kerio Valley sites. Young papaya fruit cut open, showing the kind of inferior fruit that develops without adequate pollination. Map of typical farming system in the region showing crop in relation to pollinator habitat and resources.

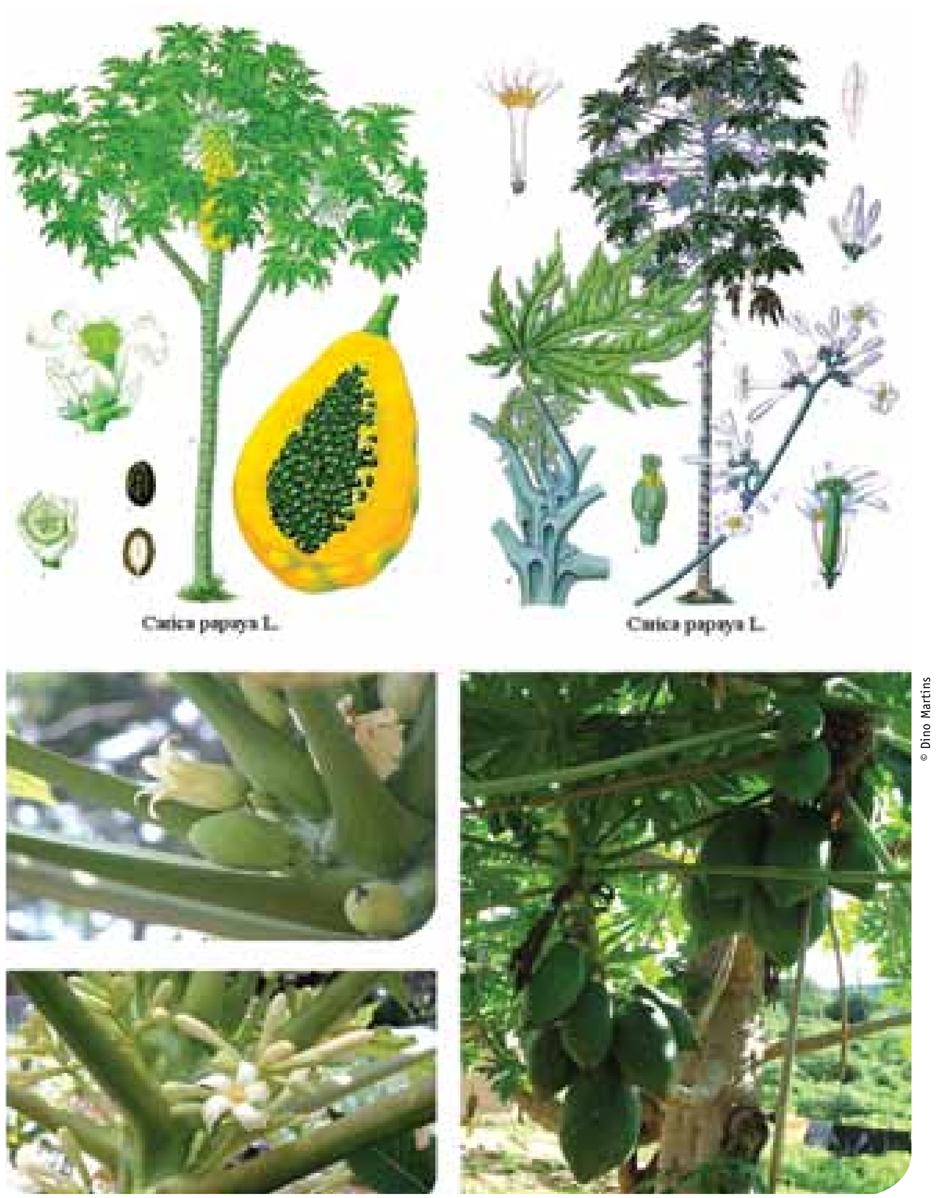

Figure 2.1.C. Clockwise from top left: detail of female tree and fruit, detail of male tree and staminate flowers (from Koehler's Medicinal-Plants 1887), heavy fruit set typical of well-pollinated female tree in the Kerio Valley, male panicle of flowers, female flower and developing (recently pollinated) young fruits.

self-pollinate to produce smaller fruits that ripen less readily, but can be cooked and eaten. Cross-pollination of these female flowers produces higher fruit set of better quality. Only male flowers, as a rule, actually offer nectar to pollinators in most of the Kenyan small-holder farm systems observed. Female flowers have no nectar, and pollinators only visit them because they are attracted to stands of papaya trees by the cues advertised to pollinators by male flowers.

This has two important implications: the first is that papaya requires cross pollination by animal pollinators to set good, saleable fruit. The second is that if farmers remove male trees, knowing they are not particularly productive, there will be a shortage of pollen to cross fertilise the female flowers, and the papaya trees will be less attractive to pollinators.

2.1.3 PAPAYA POLLINATORS

Papaya flowers produce a sweet fragrance after the sun sets in the evening. This fact, combined with the fact that the flowers are white and thus stand out in the dark, suggest that the flowers are attractive to moths that fly at night. Floral production of fragrance and floral visitor activity is highest between dusk and eight p.m. This floral behaviour is consistent with a moth-pollination syndrome.

Indeed, when a pilot assessment (by the African Pollinator Initiative – API) of the pollinators and insects visiting papaya flowers in the Kerio Valley was made in 2003 *(Crops, Browse and Pollinators in Africa: An Initial Stocktaking)*, the principal pollinators of papaya were the hawkmoths or sphinxmoths (Sphingidae) that visit flowers typically at dusk, dawn, or in the night. These are fast-flying, large and highly mobile insects. This makes them extremely efficient pollinators.

Preliminary observations on Kenyan farms show that different moth species are responsible for pollination across different sites. Papaya flowers are ready to be pollinated mostly for the hour or so just after dusk. This is a fairly narrow window and only the hawkmoths visit both male and female flowers at this time, and are able to cover the distances between trees and plantations quickly.

Insects OBSERVED VISITING PAPAYA

SPECIES OBSERVED	NOTES/OBSERVATIONS/SITES WHERE PRESENT
Bluebottle flies, Diptera: Calliphoridae.	Occasional diurnal visitors to female flowers. Not pollinating.
Fruit Flies Diptera: Tephritidae: *Didacus* sp.	Common diurnal visitor to female flowers. Not pollinating. May be laying eggs in young fruit.
Honeybees, Hymenoptera: Apidae: *Apis mellifera.*	Occasional visitor to male flowers. Not pollinating.
Skipper butterfly, Lepidoptera: Hesperiidae*: Ceoliades* sp.	Occasional diurnal visitor to both male and female flowers. Some pollen transport. Pollinator.
Hawkmoth, Lepidoptera: Sphingidae: *Hippotion celerio.*	Abundant floral visitor. Seen at both male and female trees. Hovers while feeding. Pollinator.
Hawkmoth, Lepidoptera: Sphingidae: *Herse convolvuli.*	Abundant floral visitor. Seen at both male and female trees. Hovers while feeding. Pollinator.
Hawkmoth, Lepidoptera: Sphingidae: *Macroglossum trochilus.*	Abundant floral visitor. Seen at both male and female trees. Hovers while feeding. Diurnal. Pollinator.
Hawkmoth, Lepidoptera: Sphingidae: *Daphnis nerii.*	Abundant floral visitor. Seen at both male and female trees. Hovers while feeding. Pollinator.
Hawkmoth, Lepidoptera: Sphingidae: *Nephele comma.*	Abundant floral visitor. Seen at both male and female trees. Hovers while feeding. Pollinator.
Moth, Lepidoptera: Noctuidae: *Sphingomorpha chlorea.*	Occasional floral visitor. Hovers and alights on flowers. Pollinator (?).

Hawkmoths (Sphingidae: Lepidoptera) are the most important pollinators for Papaya *(Carica papaya),* that visit papaya flowers to sip nectar. For them to persist as localized populations, and not migrate in search of greater resources, depends on the farming landscape being able to provide adequate floral resources across seasons. Sustaining a good fruit set on this widespread small-holder crop in Kenya ensures perennial fruit supply for food and as a small-scale cash crop. This provides both nutrition and incomes for rural farmers.

Based on the API stocktaking study conducted at two sites on small-holder farms in Kenya, two main aspects of landscape use were found to be related to hawkmoth availability and persistence, as wild insects capable of providing pollination services to papaya trees. These are: (1) maintenance of alternative nectar sources in the form of wildflowers and other flowering plants, occuring essentially year-round and abundant in the landscape, across a broad temporal and spatial scale and abundant in the landscape, across a broad temporal and spatial scale and (2) the availability of food-plants for the larvae of the hawkmoths, so that the female moth lays eggs on the local vegetation and thus ensures continuation of hawkmoth generations across seasons. These sites are also used as diurnal resting locations by the hawkmoths (Martins and Johnson 2007).

2.1.4 PROFILE OF BEST PRACTICES FOR PAPAYA POLLINATION MANAGEMENT

Farmers in the Kerio Valley show different levels of understanding of the pollination of papaya. Some farmers, who had been educated or participated in farmer-training sessions at a local farmer's development society linked to missionary institutions, were aware of the necessity of pollination. Other farmers were not aware of pollination as a process. However, on most farms, 'unproductive' male papaya trees are maintained. This is often done because the farmer has seen other farmers doing this – and since the larger farms with several male trees are more productive, this sets an example for smaller-scale farms.

The main practices being carried out at this site in relation to papaya pollination are:

- Maintenance of male trees on the farms
- Protection and encouragement of alternative nectar sources for pollinators
- Planting of larval food plants in hedgerows
- Protection of trees in surrounding bush and woodland areas

These practices make use of indigenous biodiversity: the native trees and plants, and hawkmoths. As the farms are all located along streams, the large trees associated with these are an important component of the agro-biodiversity on and around the farms. Large stands of acacia trees are also protected around the farms as these are seasonally used as a source of pods, which are fed to livestock and traded in centres further up in the adjacent highlands.

Traditionally the livestock enclosures and homesteads of the region, known as *bomas,* are encircled with a thorny fence or hedgerow to keep the livestock in and deter predators at night. These hedgerows are often overgrown and covered by creepers including several Morning glory species (*Ipomoea* spp.: Convolvulaceae),

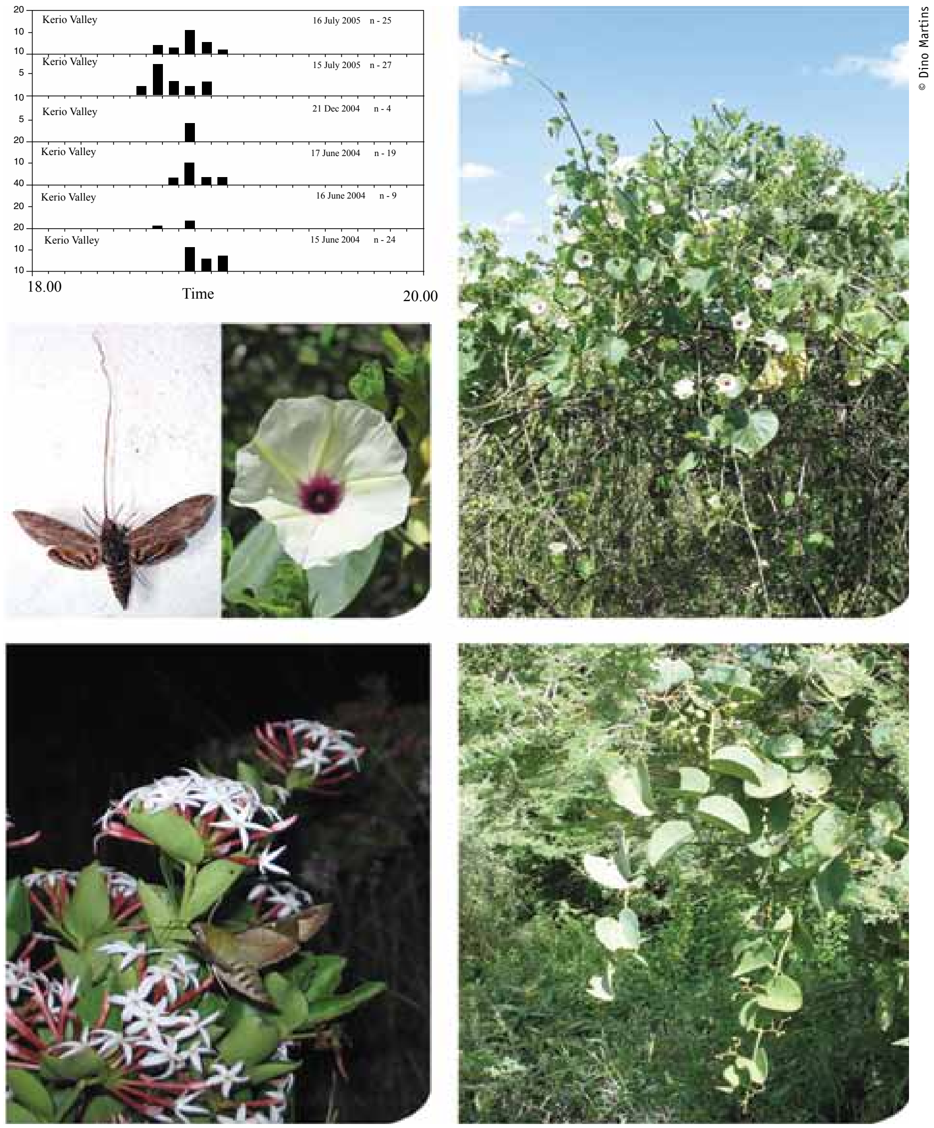

Figure 2.1.D. Clockwise from top left: graph showing temporally-restricted hawkmoth visitation to papaya, a Morning glory growing on a hedgerow, Veld grape growing on acacias alongside a boma, *a* hawkmoth foraging on a Carissa flower (*Carissa spinarum* – a nectar source for hawkmoth pollinators), A hawkmoth assoctated with Morning glories *(Agrius convolvuli)* – with tongue extended, detail of *a* Morning glorly flower, which is an important larval foodplant of hawkmoths as well as a source of nectar.

and Veld grape *(Cissus quadrangulari: Vitaceae*). The maintenance of the thorny hedgerow in the settled small-scale farms alongside large numbers of free-ranging livestock is one of the main practices contributing to persistence of hawkmoths around the farms. Both Morning glories and Veld grapes are larval host-plants for two of the more common hawkmoth pollinators of papaya.

The surrounding vegetation, which is primarily *Acacia tortilis* is dominated by woodland and bush with a variety of trees and shrubs, includes several species that are in flower at different times of the year and provide nectar resources to hawkmoths on the wing outside the farms. These are important as hawkmoth are fast-flying insects with high-energy needs for nectar on a regular basis.

2.1.5 KNOWLEDGE BASE OF BEST PRACTICES

As noted above, one of the most important practices to sustain papaya pollination services is to not cull the 'unproductive' male papaya trees. Many farmers observed this practice of conserving male trees, even without knowing their role in pollination. In many cases, farmers did so because it is a practice that the larger and more successful farmers follow.

The development of hedgerows using local species of plants is a traditional practice that is widespread among small-scale mixed farms in the lower-altitude irrigated and riverine sites of the Kerio Valley.

The practice is based on traditional enclosures for livestock which were made from thorny branches and then creepers and other plants grown into and onto this structure. A number of farmers also indicated that they used some of the indigenous plants growing along the hedgerows and farm boundaries as a source of traditional livestock and human medicine. These ethno-veterinary and ethno-botanical practices are still widespread in the region as access to clinics and livestock drugs or services is very limited due to the remoteness of most of the communities. Several of these are planted when a *boma* is first established.

There has been some planting of hedgerows of succulents and creepers as part of the routine extension work carried out by extension workers supported by local NGOs. This has, in recent years, also included a focus on planting aloes as these are seen as potentially valuable economically.

2.1.6 COSTS AND BENEFITS OF BEST PRACTICES

Costs and benefits associated with management of agro-biodiversity aspects related to pollination of papaya in the Kerio Valley are significant, but will be perceived through other more direct implications of land use management. This is important as farmers are unlikely to gain direct benefits of conserving and sustainably using pollination services; benefits will accrue, but they will be additional and supplemental to other benefits (and costs).

The greatest challenges to many of the households involved in papaya farming in the Kerio Valley are two-fold: one is a basic question of food-security in the face of unpredictable weather/climate patterns and another widespread moderate to severe land-degradation from soil erosion due to overgrazing. One of the main reasons for maintaining the dense hedgerows is to keep out the burgeoning numbers of livestock, primarily goats and fat-tailed sheep, from the cropping areas. Minor conflicts between farmers with enclosed plots and irrigated crops, and those who remain primarily pastoralists, are common when the hedgerows are breached by foraging livestock.

Another major emerging challenge is the access to a reliable source of water for irrigation. Without irrigation neither papaya nor any other perennial crops can be successfully cultivated in the valley lowlands. Due to widespread deforestation in the surrounding highlands and greater catchment area, most of the streams are currently much-reduced in volume and reliability. Several streams used to be permanent, but now only flow after heavy rains. Abstraction of water for domestic and agricultural use further upstream is also contributing to the reduced flow and unreliability.

Another growing area of concern is the emergence of large-scale charcoal burning as an industry in the dryland areas close to roads. This is currently being carried out by organised groups from nearby towns and most of the charcoal produced is transported to cities and towns for sale and re-sale. Charcoal production involves clearing of large areas of woodland and removal of large, old trees, primarily *Acacia* spp., which are the favoured species for production of high-quality charcoal.

Several farmers with stands of trees around their farms indicated that they had been approached by the charcoal burners, who often operate as independent groups working from lorries, to allow access to trees on or around their land. Clearing for charcoal exposes the soil to erosion and directly impacts the availability of nectar sources, larval host plants and diurnal resting sites for hawkmoths and other pollinators.

Given the complex interplay of dryland ecology and farming using irrigation in a semi-traditional land tenure system, a number of costs and benefits from the practices promoting hawkmoth pollination of papaya are evident. These are summarised in the following table:

PRACTICE	COSTS	BENEFITS
Maintenance of 'unproductive' male papaya trees on farms.	The space might be used to grow annual food crops.	Provides pollen for dispersal to many different fruit-bearing female trees, shade, mulch.
Protection of alternative nectar sources.	None identified.	Forage for livestock, source of traditional medicines, good ground cover against erosion.
Planting of thorny hedgerows.	Labour intensive to set-up initially, block access to stream frontage – may reduce livestock access to water.	When established with creepers these are used for medicine, mulch and fuel-wood, reducing the time women have to spend collecting these items.
Protection of stands of trees surrounding farms.	Trees may have short term highly lucrative value if processed into charcoal.	A ready source of fuel-wood, fodder for goats, reduces time spent, soil stabilisation, medicines, etc.

2.1.7 CHALLENGES AND OPPORTUNITIES FOR WIDER ADOPTION

The maintenance of biodiversity-rich hedgerows surrounding the *bomas* in the Kerio Valley and the scaling-up of this practice to other areas, or its re-introduction to farming systems where it has been abandoned, presents both a number of challenges and opportunities.

One of the main issues is an unclear land tenure management and ownership system. Very few of the individual farmer innovators in the region actually hold title to their land. The designation of ownership and boundary is still mitigated in a semi-traditional system. However, given the rapid population growth experienced by the area over the last few decades, this system is proving inadequate. This is leading to local minor conflict and also means that farmers are unwilling to make long-term investments in a particular piece of land due to the insecurity of their tenure.

The conflicting interests of pastoralists versus settled small-scale farmers also pose a major challenge to maintaining hedgerows. In times of drought, which is frequently the case, the goats and fat-tailed sheep forage from the hedgerows and can even trample them. Pastoralists in turn complain that their access to water and the amount of water available is reduced by the small-scale farms which, because they need to be irrigated, must be located near the water. This is not a new conflict and it has been traditionally mitigated through innovative communal action. For example, in a few areas, long culverts have been established to re-direct water to farms/households some distance from the streams. These are also available for use by livestock as they are open along their length between the source at a stream and the destination farm or homestead. Some of these mini-canals have been in use for many years.

Another issue is conflicting advice from extension workers and local agricultural development non-governmental organizations. Several farmers complained that they were not regularly visited by government extension workers, due to the remoteness of the area and the seasonal collapse of bridges or other infrastructure. Some development organisations promote agro-biodiversity friendly practices, such as hedgerows, mulching and planting indigenous trees while others encourage the clearing of undergrowth and bush as it is seen as 'untidy' or 'a place for pests to hide'.

The main lesson learned from this profile is that seemingly small practices, such as maintaining a hedgerow with indigenous plants, can have a very real impact on the persistence of a wild pollinator species. The creeper-covered structures that encircle the farms are also a refuge and nesting site for carpenter bees *(Xylocopa* spp.) in these semi-arid areas.

The needs of hawkmoth pollinators of papaya in drylands like the Kerio Valley can link to wider pollinator conservation strategies as most wild insects and other useful creatures have the same basic needs. Natural areas in these drylands adjacent to farms support not just hawkmoth pollinators or pollinators in general, but are also heavily used for communal grazing of livestock, keeping of honeybees and collection of firewood, traditional herbal medicines and occasionally, grasses for thatching roofs. These patterns suggest that activities centred on pollinator conservation need not conflict with existing landscape management practices.

To adequately conserve pollination services for papaya (and other crops) the pollinators need larval host/breeding sites, wild sources of nectar and protection from exposure to potentially lethal pesticides and other chemicals. Existing land-management strategies could be harnessed to incorporate pollinator conservation strategies. For example, fallow communal land is a widespread feature of subsistence-farming rural Kenya and these areas tend to be used by families who need to graze livestock, but do not have plots of adequate size to support a herd of goats or one or two cows.

This could take the form of both public education and awareness on the general importance of pollination and its direct relevance to yields of specific crops as well as coordinated efforts with other agro-ecological land-management structures and institutions. Extension officers who provide regular information to farmers need to be adequately informed about pollinators and their importance to agriculture. Other venues for sharing this information are demonstration farms and provincial or district-level agricultural shows.

Much work remains to be done in assessing the potential for conserving pollination services as part of a larger agrobiodiversity - conservation strategy. The papaya farms of the Kerio Valley, with their heavy fruit set, are a good example of the productivity that can be associated with healthy populations of wild pollinating insects and good agricultural practices.

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Figure 2.2.A. Pollination of pigeonpea in Western Tanzania by a carpenter bee Xylocopa inconstans.

2.2 PIGEONPEA (CAJANUS CAJAN) IN MWANZA, WESTERN TANZANIA

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2.2.1 OVERVIEW OF LANDSCAPE AND FARMING SYSTEM

Lake Victoria is shared by three countries: Kenya, Tanzania and Uganda. The immediate basin is home to some thirty-five million people, making it one of the most densely populated parts of Africa. Most of the people living in the Lake Victoria basin rely on subsistence farming for survival. The typical farm is a small plot where a family resides and is tilled by hand by members of the family.

The greater Mwanza area, in Tanzania, is inhabited by the Sukuma who practice a mixture of subsistence agriculture and keep a few head of livestock. Along the lakeshore a number of communities rely on fishing for a livelihood, but the vast majority of people are small-scale mixed subsistence farmers.

The climate is characterized by distinct wet and dry seasons, with peak rainfall from March to May and again in November. The proportion of arable land under cultivation varies from 22% in the majority of Mwanza district to 77% in the nearby (wetter) Ukerewe district. The most important food crops grown in Mwanza region are: maize, paddy rice, sorghum and millet, cassava, sweet potatoes, bananas, beans and pigeonpeas.

The majority of the population in Mwanza region depend largely on grains as their staple food. Cassava and sweet potatoes are also staple foods. Bananas and rice are less widely regarded as major food crops in regional diets. Amongst the majority of peasant farmers subsistence crops are also sold for cash; half of the pigeonpea crop in this region is estimated to be used for home consumption, and half for sale. Pigeonpea is thus both an important source of nutrition and income for small-scale farmers in Mwanza District.

Farms vary considerably in size, but are typically small-to-medium-sized, ranging from 1 to 10 acres. Farms are typically cultivated by a single family with both men and women working in the day-to-day cultivating and weeding. Farms near the lake or wetlands utilize irrigation trenches and foot-pumps to extend the growing season, primarily of horticultural crops and green leafy vegetables, year round.

Many farms have strips of natural vegetation or fallow land near or around them. There are a large number of kopjes (inselbergs) that are not cultivated and provide isolated patches of natural habitat. Farms farther inland from the lake have more natural habitat around them. This is because lower rainfall and distance from infrastructure does not encourage intensive cultivation. The native vegetation is tall-grass savannah with several Acacia trees (*Acacia polyacantha, A. tanganyikensis* and *A. seyal* var. *fistula*). Grasses are dominated by a mixture of elephant grass (*Pennisetum*), *Panicum* and *Hyparrhenia*. Homesteads sometimes have hedgerows of croton *(Euphorbia tirucalli*)and Kei-apple *(Dovyalis)*.

2.2.2 POLLINATION OF PIGEONPEA

The pigeonpea, *Cajanus cajan*, is a leguminous plant (Family: Fabaceae) that is indigenous to Africa and occurs widely across the continent both as a crop in traditional subsistence agriculture and as a native plant of bush-grassland and savannah areas. The genus *Cajanus* is very diverse in Africa and includes a number of cultivated and edible species.

Pigeonpea is an important food crop in the semi-arid tropics of Asia, Africa, southern Europe and Central and South America. A highly variable species, it occurs in many different landraces and varieties that have been selected and maintained by farmers in both Africa and parts of Asia. It is quite drought-tolerant and has nitrogen-fixing nodules on its roots that enable it to grow and thrive in otherwise nitrogen-poor soils. The normal method of cultivation is intercropping with maize, millet, sorghum, sugarcane, and cotton. Intercropping is a common feature of dryland agriculture throughout East Africa, and especially in drier regions of Kenya and Tanzania, where the pigeonpea is widely cultivated.

The pigeonpea plant bears flowers in loose panicles that range in colour from pale-yellow through to darker orange. Flowers open in the morning and are available

to pollinators from mid-morning through to the late-afternoon. On sunny days and cooler nights the flowers generally last about a day, rarely two, and open in succession from the lower part of the flowering branch progressing towards the tip. The plants themselves range widely in height depending on the local growing conditions, but average about 1m high when flowering. They are generally sown from seed and can persist for several seasons if growing conditions allow. The actual breeding mechanism remains unclear.

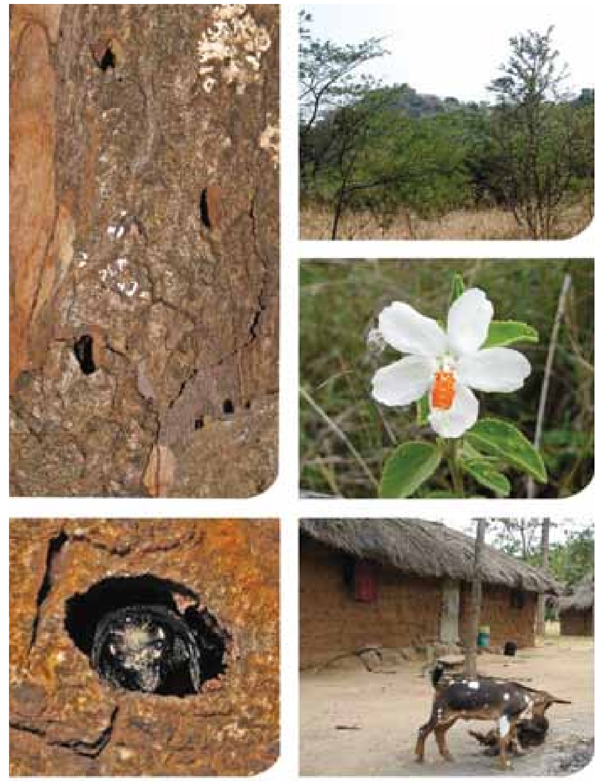

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Figure 2.2.B. Clockwise from top left: multiple nest-holes of native bee species in wooden part of structure on farm, typical fallow vegetation with kopje in background near pigeonpea plot, *Hibiscus* spp. one of the wildflowers in fallow land visited by pollinators, homestead showing earthen wall and wooden posts that serve as nest sites, *Gronocera sp.* **peering out of nest entrance.**

2.2.3 POLLINATORS OF PIGEONPEA

Pigeonpea is a crop that seems to have a component of selfing. However, the basic breeding biology of legumes — the bilateral symmetry of the flowers (a generalised feature of more complex pollination systems in flowering plants) and the abundant visitation by various species of bees (Apoidea) to the flowers, suggests that pollination by insects is an important aspect of the plant's reproductive biology. In other crops such as coffee where self-pollination occurs, and pollinators have traditionally been deemed unnecessary, such as coffee, several studies have demonstrated that visitation and bee diversity are closely tied to higher yields and better

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2.2.C. Clockwise from top left: Pigeonpea, Cajanus cajan, detail of flowering branch and flowers. Young pods alongside flowers. Mixed vegetable garden at edge of wetland – pigeonpeas grown on drier ground before this area. Typical pigeonpea cultivation in Mwanza, near Lake Victoria, Western Tanzania – note papyrus wetland in background and strip of fallow vegetation.

quality fruit set. Sorting out the contribution of pollinators to pigeonpea production may be well worth the effort.

Observations were made of insect visitors to the flowers over a number of days at the study site. Honeybees were seen visiting the flowers earlier in the morning, and struggling in some cases to access the partially open flowers. The main peak of bee activity is mid-morning. Several different native bee species were also seen visiting the flowers. Of these the large carpenter bees (*Xylocopa* spp.) and leaf-cutter bees (Megachilidae) were the most reliable and effective visitors. These bees landed on the flowers, moving constantly between different individual plants and between fields of the crop.

Carpenter and leaf-cutter bees manipulated the flower landing on the keel and grappling with it in the process of seeking nectar and pollen. Pollen loads on the bees were observed to be abundant and the ability of these bees to disperse swiftly across large areas suggests that they are able to cross-pollinate the pigeonpea flowers regularly and efficiently. Both kinds of bees were seen using areas of the farmstead and homestead to nest. Nests were found both in wooden structures and

earthen-walls. Many other wildflowers growing in the vicinity were also visited by the carpenter and leaf-cutter bees. Below is a table summarising the insect visitors observed to Pigeonpea flowers.

2.2.4 PROFILE OF BEST PRACTICES FOR CROP POLLINATION

INSECTS OBSERVED VISITING PIGEONPEAS

SPECIES OBSERVED	NOTES/OBSERVATIONS
Carpenter Bees – *Xylocopa* spp.	Frequent visitor, manipulate flowers correctly, move between individual plants and field – carry a lot of pollen.
Ants - Formicidae.	Very common visitors, don't move between plants, no pollen transport.
Leaf-cutter bees – *Gronocera* sp.	Frequent visitor, manipulate flowers correctly, move between individual plants and field – carry a lot of pollen.
Honeybees – *Apis mellifera.*	Frequent visitors in the early morning only (heat avoidance behaviour) and struggle with flowers. Carry large loads of pollen.

MANAGEMENT

Farmers at the site growing pigeonpea were well-informed and aware of the importance of pollinators for certain crops. Due to extension services from the Tanzanian government and interaction with local development projects, some information about the necessity of pollinators has been widely disseminated in the area near St. Augustine University. Bees, including native bees such as carpenter bees, were recognised and encouraged by the farmers.

The main practices being carried out at this site in relation to pigeonpea pollination are:

- Protection and encouragement of alternative nectar sources for pollinators
- Protection of trees in surrounding bush, kopjes, wetlands and woodland areas
- Provision, protection and encouragement of native bee nesting sites in wooden

structures and earthen walls of homestead and farm structures

- Recognition of pollinators and not using pesticides on these useful insects when they are seen visiting the crops

The surrounding vegetation is primarily Acacia–dominated woodland and bush with a variety of trees and shrubs that are in flower at different times of year and provide nectar resources to native bee species outside the farms. These are important as the bees that pollinate pigeonpea are widely-dispersed insects that have high-energy needs for nectar on a regular basis and require resources with which to provision their nests and larvae. Farmers also indicated that they used some of the indigenous plants growing along the hedgerows and farm boundaries as a source of traditional medicine.

2.2. D. **Clockwise from top left:** *Xylocopa inconstans* **pollinating pigeonpea, note heavy pollen baskets. Woman farmer in mixed subsistence farm – one of the farmers aware of pollination and conserving pollinators near Mwanza.** *Xylocopa inconstans* **on pigeonpea.** *Gronocera* **sp. approaching and pollinating pigeonpea flowers.**

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2.2.5 KNOWLEDGE BASE OF BEST PRACTICES

Farmers in Mwanza growing pigeonpea as part of mixed agricultural systems are aware of the needs of pollination and pollinators. Practices centred around this, including the recognition of pollination, are spread to farmers through semi-formal farmers' groups who meet periodically as part of the normal system of local government and rural empowerment (generally termed 'Ujamaa') that was developed as part of Tanzania's socialist policy.

Many farmers also indicated that they had copied practices from their peers who had been seen to have better yields through specific farming practices. Homesteads are also still traditionally organised and local materials are preferred in the building of certain kinds of farm structures. This also helps provide long-term pollinator nesting sites. The benefits of traditional building materials in providing nesting sites for pollinators is still not directly recognised by many farmers and represents a potential area where awareness-raising can contribute to pollinator management and protection.

2.2.6 COSTS AND BENEFITS OF BEST PRACTICES

Costs and benefits associated with management of agro-biodiversity related to pollination of pigeonpea in Mwanza are incurred primarily through indirect effects, as is the protection of the pollinators and pollination services.

The main issues raised by farmers were lack of access to adequate land, depletion of water resources, land degradation (soil erosion) and as a consequence of these, insecurity about their ability to produce enough food to support themselves and their families in the future. Some conflicts were seen between the use of water resources for large-scale irrigation (primarily cotton and rice paddies) and subsistence agricultural use. Deforestation in nearby hilly regions was also blamed for silting of streams and wetlands.

A number of farming areas are currently expanding into papyrus wetlands around Lake Victoria. This is in part facilitated by the drop in water levels that allows the papyrus beds to be burned and drained. While some farmers recognised that this was detrimental to water management, many were sympathetic to those clearing the wetlands, as land passes through a traditional inheritance system, forcing families to sub-divide the farms repeatedly. Most communities feel short of land for cultivating, and tend to increase the area and intensity of cultivation where possible. This leads indirectly to less native vegetation and fallow land available for pollinator alternate resources and nesting sites.

Despite the many challenges faced by small-scale farmers, most of the smallholder agriculturalists had a number of pollinator-friendly practices as part of their farming system. These are summarised in the table below.

PRACTICE	COSTS	BENEFITS
Awareness of the need for pollination and encouraging of pollinators.	None identified.	Recognition of pollinators and their protection ensures adequate pollination services for crops.
Protection of alternative nectar sources.	None identified.	Forage for livestock, source of traditional medicines, good ground cover against erosion.
Protection of trees and natural vegetation in strips near farm.	Space might be used for crops, shading not suitable for staples like maize and other cereals.	Ready source of fuel-wood, soil stabilisation, shading of crops that need protection, limits erosion by heavy storms.
Limited use of fire.	May increase tick and other parasite loads in fallow land.	Allows establishment of ground-cover which reduces erosion, keeps wildflower diversity adjacent high.
Not using pesticides.	May involve some loss of food crops to pests.	Allows natural enemies of pests to flourish, less risk of contamination of food.
Tolerating/protecting carpenter and leaf-cutter bee nests.	Slight damage to wooden structures in some cases.	Year-round availability of pollinators for crops.

2.2.7 CHALLENGES AND OPPORTUNITIES FOR WIDER ADOPTION

The maintenance of native bee pollination services to pigeonpea in the Mwanza area and the scaling-up of this practice to other areas, or its re-introduction to farming systems where it has collapsed due to poor land management, presents both a number of challenges and opportunities.

One of the main issues is an unclear land tenure management and ownership system in the light of rapid population growth experienced by the area over the last few decades. This is leading to local insecurity about the ability to continue subsistence farming, which also means that farmers are unwilling to make long-term investments in a particular piece of land and fear starvation in the long term. This was identified by a number of farmers as a potential reason to abandon farming and migrate to urban areas.

The main lesson learned from this profile is that seemingly small practices, such as maintaining a hedgerow with indigenous plants and tolerating and encouraging pollinator nesting sites, can have a very real impact on the persistence of a wild pollinator species. So too can the use of local materials for farm structures, which provide a refuge and nesting site for carpenter bees (*Xylocopa* spp.) in these semi-arid areas. None of the small-scale farmers growing pigeonpea were using chemical pesticides although a few used commercial fertilisers when they could obtain them.

The needs of native bee pollinators of pigeonpea in seasonal densely-farmed landscapes such as Mwanza, links to wider pollinator conservation strategies as most wild insects and other useful creatures have the same basic needs. Natural areas in the kopjes and fallow land adjacent to farms support not just native pollinators but are also heavily used for communal grazing of livestock, keeping of honeybees, collection of firewood, traditional herbal medicines and occasionally, grasses for thatching roofs. These patterns suggest that activities centred on pollinator conservation need not conflict with existing landscape management practices.

The recognition of the importance of pollinators is primarily by women farmers who had had some schooling and attended small-scale agricultural improvement meetings as members of their local women's group. This represents an ideal way to disseminate information on pollinators and encourage their conservation. If simple posters, brochures and/or hands-on demonstrations were developed for pollinator-friendly practices, the existing networks of farmer groups and women's groups could be tapped to distribute the information and provide feedback and further ideas on pollinator conservation strategies.

2.2.8 REFERENCES CITED

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2.3. A. Pollination of vanilla in Uganda, and elsewhere in Africa, is done by hand, primarily by women.

2.3 VANILLA - AN EMERGING CROP IN WESTERN UGANDA

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2.3.1 THE VANILLA CROPPING SYSTEM IN UGANDA

The main vanilla growing areas in Uganda are located in the southern and western regions of the country, which have a warm and wet climate with reliable seasonal rainfall patterns.

A large portion of Uganda lies in an elevated basin between the Eastern and Western branches of the Great Rift Valley. In Western Uganda, the 70 km long Rwenzori Mountains run north-south along the border with the Democratic Republic of Congo. Most of these regions of Uganda are well-watered and have an equatorial climate tempered by the altitude. The mean daily temperature ranges between 18º C and 27º C. The average annual rainfall is between 1000 and 2000 mm. Rainfall around the Rwenzoris and in the Lake Victoria basin is spread out over two rainy seasons from mid-September to November and from March to May, though it also rains at other times of year. The climate and fertile soils allow for perennial cultivation in most areas of this region.

This region of Western Uganda is inhabited by the Baganda, Toro and Ankole peoples. These are Bantu-speaking peoples practising a mixed agricultural subsistence farming system with intensive long-term cultivation of land being the norm. Livestock are kept in small numbers, with small herds being maintained primarily by the Ankole people who keep characteristic 'Ankole Cattle' with extra-long horns.

This region is one of the most densely populated regions of rural Africa; densities of over 200 people per km^2 are typical for most of the region. The high population density means that apart from a few commercial farms, most land under cultivation is typically a few acres in size and is generally farmed by a single household within the context of an extended family land-inheritance system.

Farmers in Western Uganda have typically been resident on their land for more than one generation and cultivate a mixture of crops including bananas (plantains), maize, groundnuts, potatoes, sorghum and millet as staples, and beans, pulses, kale, pumpkins and a number of traditional green leafy vegetables for household use. There is some cultivation of coffee and tea closer to the Rwenzori Mountains where local climatic conditions allow.

Cultivation is done by hand with several members of a family cooperating to maintain and plant small fields of mixed crops. Inter-cropping is common, usually with a staple such as maize or millet and fast-growing beans or leafy vegetables. Many trees are maintained on farms including several *Croton* spp., *Milicia*, *Ficus*, *Acacia*, introduced eucalypts and *Grevillea*. Hedgerows of the naturalised weedy species, *Tithonia diversifolia*, as well as indigenous species of creepers are also common. Most farms leave small strips of natural vegetation and fallow around the fields and all homesteads have at least one to two large perennial fruit trees (papaya, mango, avocado, guava).

2.3.2 POLLINATION OF VANILLA

Cultivated vanilla is an orchid, *Vanilla* sp., (Family: Orchidaceae). The genus Vanilla is widely distributed across the tropics with species in Central and South America and tropical Africa. Three species of Vanilla are of commercial importance: *V. planifolia*, *V. pompona* and *V. tahitensis*. *Vanilla planifolia* is by far the most important and is the species currently being cultivated in Western Uganda.

Vanilla is cultivated for its pods, which, under processing and curing, yields the flavouring known as vanilla extract. This flavour comes from the compound vanillin, which is present in the cured pods. The United States is the primary consumer of vanilla extract with the Coca Cola company being the biggest buyer of vanilla.

Vanilla is an evergreen and slightly fleshy vine that often climbs to the top of trees when growing in its natural habitat. It has thick, oblong, 6 to 9 inch, pale to dark-green leaves and forms roots opposite the leaves by which it clings to the tree.

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Figure 2.3.B. Hand pollination of vanilla clockwise from top left: opening of flower, removal of pollinia; pressing of pollinia into rostellum/stigma, woman farmer hand-pollinating vanilla; typical growth habit of vanilla in agro-forestry system; freshly pollinated flower.

The typical growth habit of most vanilla species is a straggling liana, with leaves arranged in an alternating fashion along the main stem. The plant produces aerial roots, like many orchids, but it is not a true epiphyte, and a portion of it is often rooted in the ground or leaf-litter.

The greenish-yellow vanilla flowers are 1.5 by 2.5 inches long. There may be as many as 100 flowers in a raceme, but usually there are about 20. Usually, only one flower in a raceme opens in a day, with the entire flowering period of the raceme lasting an average of 24 days.

Flowers are borne at the very tips of the growing axillary liana branches. They open successively, with lower individual flowers maturing first and progressing in a continuous order towards the tip of the bunch of buds. The flowers, unlike many orchids, do not last very long. Depending on local weather conditions, the individual flowers wilt within a 4 – 10 hour window of time after the bud opens.

Buds open in the early morning or before dawn and the petals and sepals curl back slightly. In most cultivated vanilla, the flowers open only partially, with the petals and sepals remaining half-open and forming a sleeve. Once the flower is open, it is available to pollination/pollinators. If pollination does not take place - by natural or artificial (hand) pollination - the flower wilts and will drop off the plant by the next day.

The central petal, as in most orchids, is modified into a 'lip' – this is where the reproductive parts of the flower are located. Within the lip is a central column comprised of the united stamen and pistil. These are the reproductive portions of the flower. The anther (male portion) is at the apex of the column and hangs over the stigma (female portion), but a flap or rostellum separates them. The anther bears a pair of *pollinia*. Pollinia are special fused sacs of pollen. Unlike many flowering plants, orchids do not produce granular pollen, but have the pollen fused into pollinia, also known as pollinaria, that are highly modified and adapted for specialised dispersal by pollinators.

2.3.3 VANILLA POLLINATORS

Vanilla requires pollination in order to set fruit. The flowers cannot self-pollinate, as the pollinia need to be physically detached from the column, then moved over to the stigma by-passing a barrier, called the rostellum that normally separates them in the flower. Therefore, even for an individual vanilla flower to be selfed, i.e. pollinated using its own pollinia, a pollinator is required to remove the pollinia and carry them to the sticky stigma that lies behind them on the column, which is a specialised structure, unique to orchids, housing the reproductive components of the flowers.

Most cultivated vanilla is pollinated by hand by people. This task in Western Uganda and in the other vanilla-growing regions of the area is primarily carried out by women. In some sites in Western Uganda, around the Kibale forest and towards the border of the Democratic Republic of Congo, no hand-pollination is carried out. However, the plants produce pods of harvestable quality. This suggests that they are being pollinated naturally by insects from the adjacent forests.

The genus of *Vanilla*, is a fairly large one and is found scattered throughout the tropics. However, none have been studied in any depth in the wild in terms of their pollination biology and needs. Yet wild pollination systems can often give us hints of what the effective pollinators of crops may be. There are about 100 species in the genus *Vanilla*, with fifteen species found in Africa and four in Eastern Africa. In Eastern Africa, most of the *Vanilla* spp. are localised and/or rare with only occasional records of plants flowering. However, two species *Vanilla roscheri* and *Vanilla imperialis,* occur in some numbers in certain locations and flower regularly.

Vanilla imperialis is a leafy, scrambling liana of forest areas in Western Kenya (where it is rare) and Uganda (locally common at some sites). It bears showy flowers with green petals and sepals and a prominent purple lip. Preliminary observations indicate that medium-to-large-sized carpenter bees (*Xylocopa* spp.) and leaf-cutter bees (*Gronocera* sp.) are the main pollinators of this indigenous African species of vanilla.

Vanilla roscheri is a terrestrial or scrambling liana with brownish stems and vestigial leaves. It grows along the coast of Kenya and Tanzania and can be found in the dense, dry bushland in the interior of the country. It can be locally common and has inflorescences that bear up to thirty-five flowers that open in succession. The flowers are white, with the inside of the orchid's lip being pink or yellow. Observations of this species around Mt Kasigau in the Tsavo ecosystem, in Kenya, suggest that hawkmoths (Sphingidae) are the primary pollinators.

Despite the long history of vanilla cultivation, exploration and its movement as a crop around the world, no studies are available on the pollination of *Vanilla planifolia,* and its close relatives in its native forest habitats of Central America. However, a few observations have been made on the insect visitors to the flowers. Given the structure and behaviour of the flower, i.e. colour, scent, brief period of opening and nectar rewards, the pollinators are thought to be stingless bees (Meliponini), which are relatively common insects throughout forests in Central America and beyond.

Following is a table summarising the insect visitors observed on *Vanilla planifolia* flowers in Uganda, and globally.

INSECTS SPECIES OBSERVED VISITING VANILLA

SPECIES OBSERVED	NOTES/OBSERVATIONS/REFERENCE
Ants (*Technomyrmex* sp.), (Formicidae, Hymenoptera).	Common visitors to the inflorescences in Western Uganda, feeding on extrafloral nectar and patrolling flowers.
Ants (*Messor* sp.) (Formicidae, Hymenoptera).	Common visitors to the inflorescences in Western Uganda, feeding on extrafloral nectar and patrolling flowers.
Stingless bee *Meliponula* sp. (Apidae, Hymenoptera).	Visiting flowers (only observed twice near Kibale Forest, western Uganda). Seen transporting pollinia.
'Bees' (Apidae, Hymenoptera).	Recorded on flowers of *Vanilla* sp. in India, thought to be main pollinator (Devarigny, 1894).
Stingless bees, *Melipona* spp. (Apidae, Hymenoptera).	Thought to be the main pollinators in Central America, but this remains to be verified (Irvine & Delfel, 1961).

Stingless bees (Tribe: Meliponini) are likely to be the primary pollinators of *Vanilla planifolia,* the species in cultivation, both in Central America and in other regions of the world where they occur simultaneously with vanilla cultivation. The preliminary observations made in Western Uganda and the few references in the literature suggest that these insects, which are common and generalist foragers in tropical forest ecosystems, are providing pollination services to vanilla. However, the majority of cultivated vanilla, even in areas within the range of stingless bees is still pollinated by hand. This suggests that stingless bees are not present on most of the farms or have been eliminated through a range of practices.

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Figure 2.3.C. Top left: stem of vanilla liana showing axillary inflorescences and leaves. Top right: typical method of vanilla cultivation in western Uganda on short tree in agro-forestry system. Bottom: Detail of hand-pollinated flower — vanilla flower opened for hand-pollination. Note the damaged lip and the pollinia, which have been pressed against the rostellum rather than the stigma (indicated by red arrow on right).

Stingless bees, like the honeybee *(Apis mellifera)*, also live in eusocial colonies and gather stores of honey, pollen and resins. These are generally smaller than typical honeybee colonies and located inside tree-hollows, crevasses in rocks or termite mounds. Stingless bees are widely exploited in Africa for their honey, which is used both medicinally and consumed as food. The typical exploitation of a wild stingless bee nest involves destruction of the colony as the nest is broken open and the bees driven out. In many places stingless bees have been locally extirpated due to repeated harvesting. However, as demonstrated by the small-holder farms adjacent to forest patches, they can provide pollination services as part of their normal routine, when foraging from their nests in the protected/undisturbed forest areas.

2.3.4 PROFILE OF BEST PRACTICES FOR CROP POLLINATION MANAGEMENT

Farmers in Western Uganda were in general puzzled by the question of pollination of vanilla. It is a recently introduced crop, with growing appeal due to the demand for high-quality organically-grown natural vanilla. There has been little time for extension workers and agricultural NGOs to engage in public education and awareness about vanilla growing. But, as this region has recently been certified as a 'Fair Trade' site for vanilla growing, there is growing interest in and awareness about the crop.


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Figure 2.3.D. Clockwise from top: typical landscape of Western Uganda – looking towards the Rwenzoris from Fort Portal; *Messor* sp. tending vanilla flower – ants are common at the flowers and may discourage other insects; view inside an artificial stingless bee nest; *Meliponula* sp., this stingless bee represents a potential wild pollinator of vanilla in East Africa; typical agro-forestry forest edge vegetation and undergrowth, Western Uganda.

Most of the knowledge about the crop is spread by word of mouth from farmer to farmer. Some of the larger farmers and buyers of vanilla have organised small demonstrations and discussions at buying venues that demonstrate the basics of cultivation. For example, the use of small trees as a means of supporting the vanilla liana has been presented. All farmers indicated that they had learned about hand-pollination from other farmers or from visits to larger commercial farms, are often the buyers for locally-produced vanilla from small-holder mixed-agriculture farms.

A number of farmers were not aware of the role of pollination in the production of vanilla pods. They expressed bewilderment at the fact that they had to hand pollinate the crop as none of the other species cultivated require such manipulation. One explanation given to them, is that the practice developed as a result of the vanilla plant being 'interfered with' or 'hybridised', before it was introduced to Uganda.

However, the most interesting and relevant examples of pollination-perception came from those farmers adjacent to forest fragments where native bee species provided pollination services and no hand-pollination was carried out. These farms were primarily agro-forestry subsistence systems and vanilla was grown only as a supplement to household income. These \sites were restricted to the forest fragment edges of the greater Kibale-area and in the Bundibugiyo region towards the border with the Democratic Republic of Congo.

The main practices being carried out at these sites in relation to stingless bee protection/vanilla pollination are:

- Maintenance of diverse flowering trees- both indigenous and exotic - on farms (nectar resources, potential nesting sites for stingless bees).
- Protection and encouragement of alternative nectar sources for pollinators in the form of hedgerows and fallow strips with natural vegetation.
- Not over-exploiting stingless bee nests in the surrounding areas.
- Limited use of fire and other potentially hazardous practices in the surrounding areas.
- Tolerance/protection of stingless bee nests within the homestead when they occasionally nest in wooden structures or earthen walls of traditional houses. These are typically allowed to thrive for harvesting at a future date. However, the harvesting methods still tend to destroy or displace the colony.
- No spraying of pesticides on crops, including both vanilla and other flowering cultivated species that stingless bees potentially visit such as beans, peas, maize.

The main practices that maintain stingless bees and potential natural pollination services of vanilla in this region, are protection and encouragement of indigenous flora. The farms are all either located along a matrix of forest-edge vegetation or are bounded by rows of trees. Several of them are true agro-forestry plots with large trees shading a mixture of crops. These are the exception though, as it is generally not possible to grow staples, such as maize and other cereals in a shaded situation.

The surrounding vegetation is heavily used as a source of traditional medicine for both humans and livestock. These ethno-veterinary and ethnobotanical practices are common throughout Western Uganda as the remoteness limits access to the clinics or livestock veterinary services. Most of the local infrastructure providing these services remains limited as it is still recovering from many years of instability and strife in the region.

Several species, such as the creeper *Cyphostemma adenocaule,* are widely encouraged or tolerated on farm boundaries. This creeper is used to treat athlete's foot and intestinal worms in both humans and livestock (Powys and Duckworth, 2006). The tiny cup-like nectariferous flowers are often visited by stingless bees in large numbers. The large fig trees, *Ficus glumosa,* also found in this region are used by stingless bees gathering resins for nest construction. They are typically protected locally as places to gather in the shade.

This is just one example of the on-farm and adjacent-forest biodiversity that is both useful to the farmers directly and simultaneously provides nectar resources to foraging stingless bees. This is especially important as crops are not perennially in flower and the stingless bees need to subsist through these periods. In addition, as vanilla flowers are only available for relatively short periods of time, it is necessary to have many other sources of nectar for the potential pollinators.

2.3.5 KNOWLEDGE BASE OF BEST PRACTICES

The default system of hand-pollination in Western Uganda is a learned practice that has been spread and developed in two ways. Limited extension work has been carried out by commercial buyers and large-scale farmers who buy vanilla from small-scale growers. This has taken the form of informal farmer-field days or demonstrations during bulk purchases.

On a more local level, several farmers indicated that they had learned about hand-pollination from their fellow-farmers. Those not hand-pollinating and living adjacent to forest were aware of the need to protect and encourage stingless bees, but more for the reason that this represented a potential future source of honey, rather than purely for pollination services.

2.3.6 COSTS AND BENEFITS OF BEST PRACTICES

Costs and benefits associated with agro-biodiversity and other aspects related to the pollination of vanilla in Western Uganda need to be considered on two separate levels given the atypical pollination system of this emerging crop.

On one level there are a limited number of clear-cut costs and benefits to the widespread practice of hand-pollination, which is generally carried out within one flower and thus results in self-pollination. The main challenge in this particular method of pollination is that it operates with little consideration for the biology of the flower. Selfing in orchids is widely known to produce pods with ovules (seeds) of inferior quality.

As most of the vanillin itself is a compound associated with the seeds and the surrounding tissues, selfing is not the best method of obtaining a large, healthy pod that can be cured to yield a strong vanilla flavour. Damaging the lip of the orchid during hand-pollination also allows for easier infection of the developing pod by fungi or bacteria as this exposes the developing tissues. This is also more likely to result in badly-developed or misshapen pods.

In terms of the farmers who allow natural pollination of the crop, the analysis of costs and benefits needs to take into account the fact that most of the benefits are currently derived from indirect effects associated with the wider agro-biodiversity practices in the region.

The costs and benefits associated with the practices promoting pollination of vanilla by hand-pollination vs. natural pollination are complex. It must be kept in mind that a lot more groundwork needs to be done before a real sense of the larger agro-biodiversity trends and practices relevant to the unique pollination system are considered.

The following table summarises some of the major costs and benefits evident from the preliminary observations made in Western Uganda:

On a broader scale, farmers in the region identified two main challenges to the

PRACTICE	COSTS	BENEFITS
Hand pollination of vanilla flowers.	Time consuming, labour-intensive, inefficient, takes women away from other productive tasks such as growing food.	Provides the major means of pollinating the flowers under the current cultivation system. No yield on this crop without pollination.
Protection of alternative nectar sources.	None identified.	Forage for livestock, source of traditional medicines, good ground cover against erosion.
Protection of large forest flowering trees.	Space might be used for crops, shading not suitable for staples like maize and other cereals	Ready source of fuel-wood, soil stabilisation, shading of crops that need protection, limits erosion by heavy storms.
Limited use of fire.	May increase tick and other parasite loads in fallow land.	Allows establishment of ground-cover which reduces erosion, keeps undergrowth diverse and intact on forest edges.
Not using pesticides.	May involve some loss of food crops to pests.	Allows natural enemies of pests to flourish, higher prices paid for organic and fair-trade produce.
Tolerating/protecting stingless bee nests.	None identified.	Source of honey for consumption, sale and medicinal use.

current intensive and agro-biodiverse system of farming. Firstly, the subdivision of land due to high population growth is an issue of great concern. Secondly, and more specifically to vanilla, it was widely felt that this was a crop with an uncertain future especially given the lack of adequate and relevant information on its cultivation and pollination needs.

2.3.7 CHALLENGES AND OPPORTUNITIES FOR WIDER ADOPTION

The unique pollination needs of vanilla in Western Uganda as an emerging crop present an unusual challenge and real opportunity to the conservation and promotion of wild pollinators as part of the useful services provided by agro-biodiversity. There is great potential in this system to save many thousands of rural farmers hours of painstaking labour through the establishment of a viable pollination system for the crop.

The indigenous species of vanilla are observed to set seed and receive pollinators. The insects known to be pollinating *Vanilla planifolia* elsewhere are present within this region, in the form of closely-related species. This illustrates that there is much potential here to link the conservation of biodiversity and forest

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Figure 2.3.E. Clockwise from top left: vanilla pods on plant ready for picking; typical curing area of vanilla, the drum is for heating the pods, the racks for drying them – a process taking about 2 months; stored vanilla pods at a large commercial farm/processing location undergoing curing; measuring and sorting of cured pods for packaging and sale.

fragments with good agricultural practices and agro-biodiversity, giving farmers an alternative to hand-pollination.

One of the main issues that remains to be resolved that was identified in this preliminary analysis is the lack of technical advice and resources in terms of information available to most rural farmers in the region. While communicating methods and best practices by word-of-mouth is a very useful system at the grassroots level, it is not that effective on a large scale. Farmers growing vanilla and other crops for sale need more specific systems and recommendations that complement the current best practices while maintaining subsistence food production. Extension workers and agricultural non-governmental organizations in the region need packages of information and training about pollination and the needs of pollinators.

The main lesson learned from this profile is that wild insects can provide effective pollination services in agro-biodiverse systems that include protected forest-fragments and other viable patches of micro-habitat. These serve to meet the resource needs of the pollinators in terms of nesting sites and materials for nest construction. In the case of nectar-dependent bees, forest patches provide additional forage over different seasons and when the crops are not in flower. The natural pollination of vanilla on small-holder farms near forest patches is a very promising outcome that needs to be further documented.

Intensive agriculture as practiced in Western Uganda and throughout most of the Lake Victoria basin is among some of the most productive farming systems in the region. There is great scope here to link best practices from traditional farmer innovations with a broader agro-biodiversity conservation strategy that includes pollinators such as stingless bees.

Stingless bees are widely recognised in Western Uganda and are currently being managed in hives by farmers in other parts of Eastern Africa. There is the potential to re-introduce these bees to vanilla farms through propagation of colonies in artificial hives that could be placed among the crop. This approach has been shown to work with strawberries, tomatoes and other crops that require an insect pollinator.

This system represents an opportunity to match the expansion of an emerging crop with sound agro-biodiversity management linking best practices with pollinator conservation as well as public education and awareness.

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Figure 2.4.A. Coffee growing in natural secondary forest, Jimma, Oromia, Ethiopia

2.4 COFFEE (COFFEA ARABICA) IN FOREST AND AGRO-FORESTRY CULTIVATION IN JIMMA, ETHIOPIA

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2.4.1 COFFEE CROPPING SYSTEMS IN ETHIOPIA

Coffee originates in the Kaffa region of Western Ethiopia where it still grows wild in the highland sub-tropical moist forests that cover large areas of the region. The name of the area 'Kaffa' is thought to be the base for the origin of the words 'coffee' and 'café'. There are a number of different strains and cultivars of coffee distributed across eastern and tropical Africa. Kaffa is where the 'arabica' variety of coffee originates. This is also thought to be where coffee was first harvested from the forests and also where it was first domesticated and cultivated.

The highlands of Western Ethiopia have been farmed and settled for a long time – upwards of several thousand years. This is one of the nine centres of early agricultural domestication worldwide. Coffee is thought to have become a widespread crop sometime during the 3rd and 10th centuries, based on local folklore. Kaffa region was ruled by various dynasties and was influenced by the Christian empires of the Ethiopian highlands, but fell outside their direct rule as it was so remote. The peoples of the region belong to the Ghibe ethno-linguistic group and speak their own languages as well as Amharigna (Amharic) and Oromifa, the regional language.

Farming is carried out in intensive mixed subsistence plots of varying size dependent on complex local politics and relationships. Farms consist of individual households with all members of the family tending the farm and assisting with

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Figure 2.4.B. Coffee growing in Jimma, Ethiopia: clockwise from top left: landscape of Jimma region looking out from forest coffee grove; path through forest coffee; coffee in agro-forestry with mix of indigenous and exotic tree spp.; coffee fruiting in farm on edge of forest.

tilling and harvesting. Some family members may specialize on aspects of tending coffee, such as weeding or picking berries, but there is no strict division of labour. The fertile soils and lush sub-tropical climate of this region allow for cultivation of a wide range of crops including the cereals tef and maize, pulses, beans, bananas and fruit trees such as oranges, guavas, mangoes, papaya and avocado. Small numbers of livestock and poultry, mainly fat-tailed sheep and chickens, but also cattle, donkeys and Ethiopian ponies are also kept.

Being isolated from the central highlands, the people of this region have been relatively self-sufficient in terms of food production for centuries. The farming landscapes are old and are closely tied to forest and agro-forestry systems. Virtually all farms are bordered by trees or small patches of forest, which are also heavily used for firewood, traditional medicines and grazing of livestock as well as harvesting of forest products (wild coffee, honey, edible fungi). There is extensive planting of trees, some indigenous, but mostly exotic *Eucalyptus, Grevillea* and cypress around farms.

Land is passed down through families, in traditional patrilineal inheritance systems, with some adjustment under the socialist period that

followed the end of the monarchy in Ethiopia. Having farms near to forests is considered highly desirable, given the quality of soil and access to forest products. Large areas of land are communal fallow areas often covered with bush and secondary forest. These are used for livestock and beekeeping.

2.4.2 POLLINATION ECOLOGY OF COFFEE

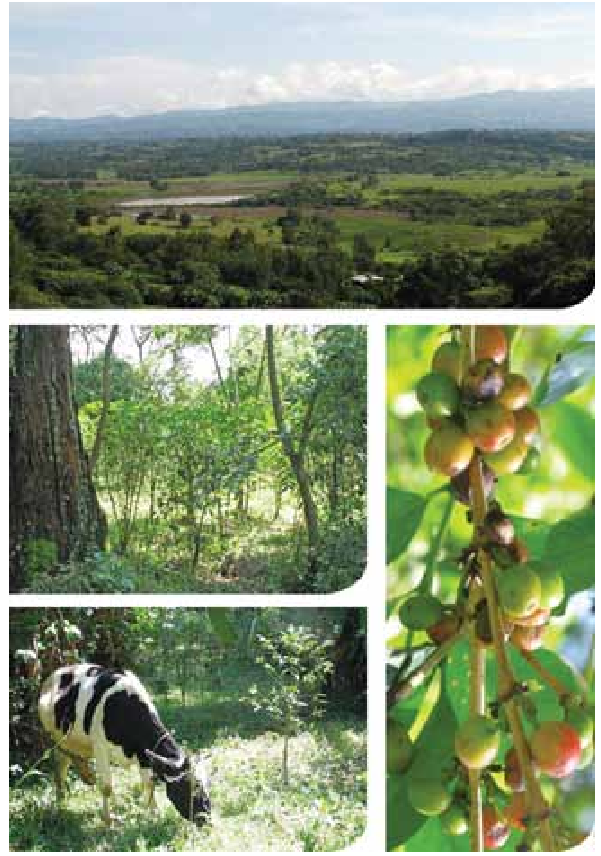

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Figure 2.4.C. Clockwise from top: landscape of Jimma, coffee-growing region of Western Ethiopia with Lake Boye, a wetland-fringed lake on the left; detail of Arabica coffee berries; dairy cow tethered in coffee forest grove – note Coffea arabica sapling on right; young coffee established in rows in secondary forest.

Coffee in the wild can be found as a shrub or small understorey tree. The species *Coffea arabica*, from which the exceptionally high-quality cultivated variety 'arabica' is derived, grows naturally dispersed in the forests of Southern and Western Ethiopia with relict populations on Mt. Marsabit in Northern Kenya.

A member of the Rubiaceae family, the coffee berries are borne on the branches developing from axillary flowers. The white flowers are generally produced synchronously at, or just after, the beginning of the rainy season after a dry spell. The white flowers are sweetly scented and attractive to a wide range of insects ranging from bees to hawkmoths, as well as nectar-loving birds like sunbirds. The flowers are considered self-fertile and coffee was widely thought to be largely self-pollinating until recent studies showed clearly that there is a link between pollinators (mainly bees: honeybees, stingless bees and solitary bee species) and the yields in terms of the numbers and quality of berries produced (Klein et al., 2003).

The flowers produce small quantities of nectar and open in the early morning at or shortly after dawn. By mid-morning on a sunny day, especially near a forest patch, hundreds of different insects can be seen visiting the coffee flowers, including flies, beetles, ants and wasps. However, only bees are considered the 'true' pollinators as their behaviour, physical manipulation of the flowers and frequency of visitation correlate with what would be expected to maximise pollen transfer and pollination. Intensive visits by bees, both honeybees and solitary bee species, can be readily observed on a sunny morning on flowering coffee in Eastern Africa.

2.4.4 PROFILE OF BEST PRACTICES FOR COFFEE POLLINATION MANAGEMENT

2.4.3 COFFEE POLLINATORS

INSECTS OBSERVED VISITING VANILLA

SPECIES OBSERVED	NOTES/OBSERVATIONS/SITES WHERE PRESENT
Honeybee, *Apis mellifera scutellata*.	Frequent visitor to flowers in the morning, carries pollen, visits in large numbers. Kenya highlands.
Honeybee, *Apis mellifera monticola*.	Frequent visitor to flowers from mid-morning to early afternoon, carries pollen, visits in large numbers. Highlands of western Ethiopia. From hives and wild colonies in forest.
Carpenter bees, *Xylocopa spp*.	Frequent visitor to flowers in early morning through to later in the day, even after many other bee species and most insects have stopped foraging. Kenya, Ethiopia.
Diurnal Hawkmoths, *Cephonodes hylas, Macroglossum sp*.	Infrequent visitors to flowers in mid-morning hours. Carry small amounts of pollen. Highlands of Kenya and Ethiopia.
Solitary native bee species.	Many different spp. of these bees are regular and reliable visitors to coffee. Some species carry large loads of coffee pollen and visit many flowers while dispersing between forest and cultivated plants. Kenya and Ethiopia.

The pollination of coffee on small farms and agro-forestry systems in the Jimma region, based on observations of fruit set and quality, seems to be more than adequate thanks to an abundance of both honeybees (mainly the 'highland' variety *Apis mellifera monticola)* and solitary bee species. Given that bees provide the major pollination services to *Coffea arabica*, the best practices documented were focused around the needs of these two groups of insects.

Figure 2.4.D. Clockwise from top: Detail of flowering coffee with forest canopy in background; *Ocimum* **sp. in agro-forestry coffee plot – used by bees; Orchid,** *Microcoelia* **sp. growing on coffee branch; Butterfly,** *Junonia terea*, **sunning in coffee glade; Clover growing in grazed coffee glade – heavily visited by bees that also visit coffee flowers.**

Farmers asked about the question of pollination showed some basic perception of the necessity of pollination for the production of fruit/yield. There has been some education of farmers' groups (less so in some of the more remote areas) on a range of good agricultural practices, but it was not evident that this included information on pollination.

All the small-scale farming, including that of coffee, is purely organic. A large portion of the coffee produced in this region is grown under shade-tree conditions, - in secondary forest, or in groves in older indigenous forest - with very little interference with the native vegetation other than pruning back to prevent the coffee being overgrown by other species. The best practices at these farms relate to all aspects of pollinator requirements ranging from protecting and encouraging a diverse suite of bees to the provision and protection of nesting sites.

The main practices being carried out at this site in relation to coffee pollination

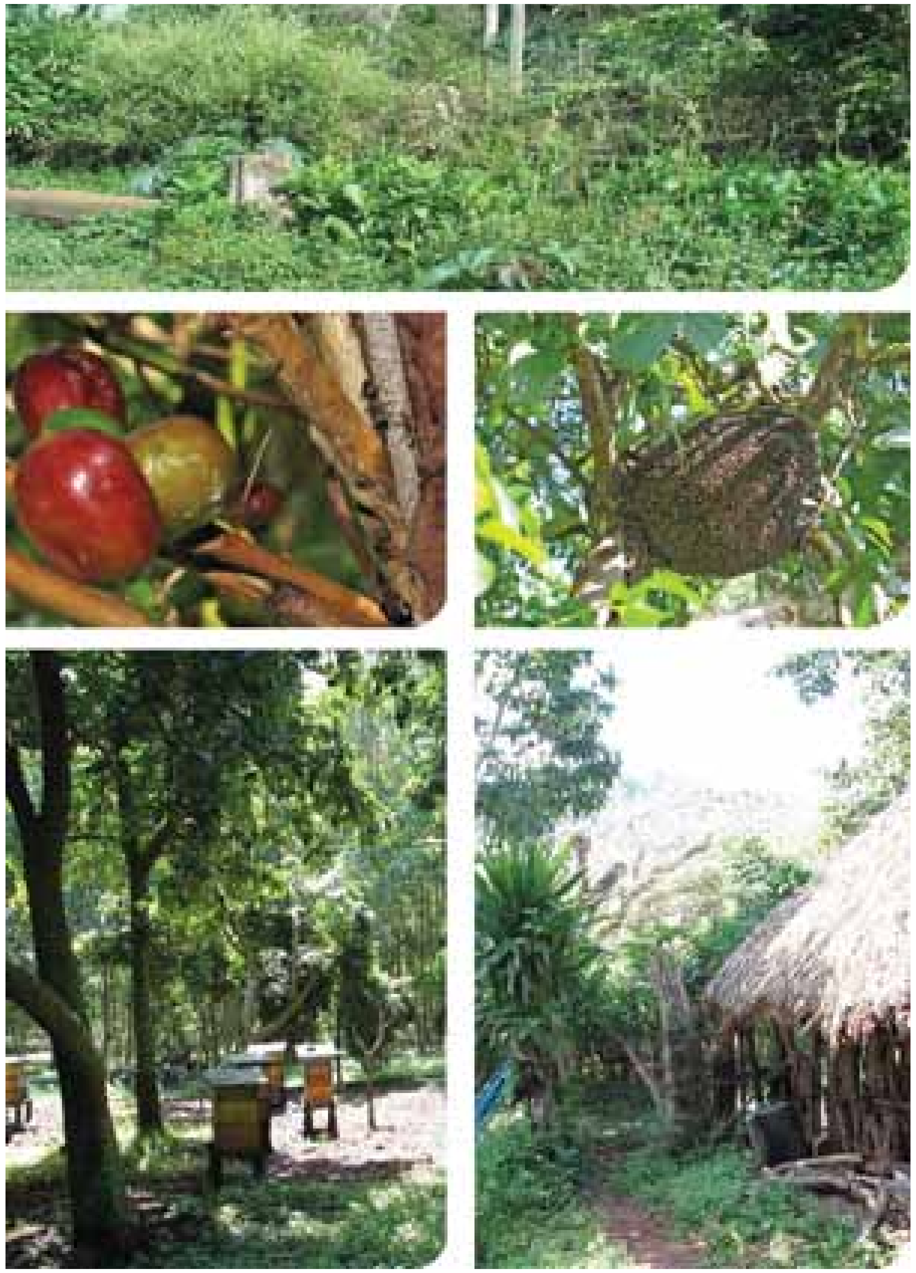

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Figure 2.4.E. Clockwise from top: dense hedgerow with flowers (cannas) on edge of more open coffee farm; *Crematogaster* carton-ants nest in guava tree in agro-forestry coffee; wooden and thatched structure with many *Xylocopa* and other bee spp. nesting; honeybee hives in agro-forestry grove; carton-ants patrolling on *Coffea arabica* twigs.

are:

- Protection and encouragement of alternative forage for both solitary bees and honeybees in the form of wildflowers on paths and forest edges.
- Protection of nesting sites of bees in farm structures.
- Placing of honeybee hives within forest groves with coffee.
- Protection of carton-ants' nests; natural pest control, possible bee nest sites.
- Strict protection of wild coffee in native forest (with limited harvesting of berries).
- Planting of species-rich hedgerows around coffee farms.

Farmers using the forest for coffee cultivation, be it in groves or more intensive agro-forestry settings, all were keenly aware of the need for forest conservation. This in itself is key to maintaining pollination services as many of the bees foraging in the coffee are linked to wider ecosystem processes. The secondary forest and forest grove coffee plots were observed to be exceptionally rich in biodiversity including birds, butterflies and epiphytic orchids – in some cases these are actually growing on the coffee bushes. Over forty butterfly species were observed over a few hours in one of the forest coffee groves alone!

Many different bees are constantly foraging in the coffee groves and agro-forestry coffee as the understory clearings, made to grow coffee, allow herbaceous wildflowers to thrive and the sunnier spots in themselves attract more insects. Livestock also are tethered within these settings and their grazing helps keep shrubbery down and promotes forest grasses and wildflowers, which in turn attract more bees.

2.4.5 KNOWLEDGE BASE OF BEST PRACTICES

The use of groves in forest and agro-forestry coffee growing in secondary forest is an extension of the traditional farming systems that have been practiced in the region for several centuries. Bee-keeping has been promoted recently with the introduction of rectangular hives with supers replacing traditional hives, which were made by weaving rushes and palm leaves around a cylindrical wooden frame. Several farmers indicated that they had started keeping bees after observing or hearing about their positive effects on yields from their fellow farmers.

There have been some efforts to document and advise on some of the land-tilling practices from the local Jimma Agricultural Research Centre, a state institution. There are some farmers' groups which hold periodic extension services between and among farmers. In some cases, these services have been supported by donors, such as the Japanese International Development Agency (JICA), as a component of participatory forest management programmes.

2.4.6 COSTS AND BENEFITS OF BEST PRACTICES

The costs and benefits associated with coffee pollination in this region are primarily related to the maintenance of biodiversity on and around coffee groves/farms and the issues related to intensive bee-keeping within coffee and agro-forestry settings.

2.4.7 CHALLENGES AND OPPORTUNITIES FOR WIDER ADOPTION

The pollination of *Coffea arabica* by bees in forest-dependent agriculture as practiced

PRACTICE	COSTS	BENEFITS
Protection of alternative nectar sources.	None identified.	Forage for livestock, source of traditional medicines, used in traditional ceremonies, good ground cover against erosion.
Planting of mixed species hedgerows.	Labour intensive to set-up initially.	Source of traditional medicines and materials for weaving, etc.
Protection of stands of trees surrounding farms.	None identified.	A ready source of fuel-wood, reduces time spent, soil stabilisation, medicines, etc.
Bee-keeping.	Space used for hives not accessible to livestock grazing or other activities (potential bee aggression).	Production of honey, beeswax and other useful products.
Protection of wild *Coffea arabica* trees in forest.	None identified.	Potential source of pollen for out-crossing with managed and cultivate coffee.
Protection of *Crematogaster* carton-ants nests.	Aggressive ants might interfere with harvest, may tend some scale insects.	Provide effective pest-control through constant patrolling of twigs, trunks and unripe berries.
Bee-nesting sites in farm structures.	None identified.	Structures also used by predatory wasps and spiders that feed on potential pests.

by some of the Jimma coffee farmers, is a productive and sustainable system. However, the practices centred around this are limited to areas of the more remote rural landscapes where large areas of forest cover still persist. This is not the case in many parts of rural Ethiopia or indeed Eastern Africa. The typical subsistence farmed small-holder landscape is a mosaic of fairly dense plots with little forest cover remaining in highland areas that were cleared of original forest.

The growing of coffee in proximity with its wild progenitor suggests a potential for constant enrichment of the crop through flow of pollen from the forest into the cultivated varieties. Some of the original wild forest coffee is harvested by forest-dwelling and forest-edge communities. This is being encouraged through participatory forest management programmes - an outstanding example of sustainable forest utilisation for the region. However, the unique social history of Ethiopia plays a major part in the success of these initiatives. In contrast, in most other regional countries, such as Kenya and Tanzania, where colonial structures of forestry practices still persist, such approaches are mostly viewed with suspicion by both government and communities.

Population density in Western Ethiopia's forested highlands is also not as high as some other regions and this means that pressure on the forests for settlement or agricultural expansion is not as pressing. In addition, farmers indicated that most fuel-wood needs are met from cultivated eucalyptus and other exotics, which are widely planted. Planting of these trees is very widespread and may have a potential long term effect on the agro-forestry coffee systems, if the exotics come to dominate. All the sites profiled here have fairly young eucalypts and *Grevillea,* alongside older *Albizzia, Croton, Ficus* and many other indigenous highland forest trees.

As with many other farming areas localized deforestation is compounded by two major issues: insecurity of land tenure and food security. The legal aspects of land ownership in Ethiopia are very complex and in a state of flux as the country now faces globalization and the opening up of its economy to the world market. Farmers identified land-ownership as an issue and in some specific sites are unsure as to whether they fall within forest reserves or in communal agricultural land.

Most farmers growing coffee in Jimma felt secure in their tenure and could therefore make long-term investment in systems like allowing secondary forest to regenerate around their carefully-tended coffee bushes. This is also related to the ability to produce enough food from other land or to purchase food from other sources from the income generated through the sale of coffee.

The most impressive practice that could be more widely adopted would be the planting of species-rich hedgerows surrounding the coffee plots. This is done both for aesthetic and practical reasons (barrier to livestock, source of fuel, fibre and medicine). With farmers learning from each other, a local campaign in other coffee-growing areas could easily supply two vital needs of bees visiting coffee: alternative forage and nest sites, through the development of simple hedgerows using a mixture of native and exotic species.

Forest farming - using the groves and allowing regeneration of secondary forest around the existing crop - is another practice that could be more widely adopted. This is especially important given the amount of land under coffee cultivation in Eastern Africa. The richness of birds and butterflies in the coffee groves and secondary forest plots could also readily contribute to eco-tourism for bird-watching and forest walking. This is further enhanced by the fact that this could also support community based conservation and sustainable agriculture. There is one coffee farm near Mizan Tefari that is currently hosting bird-watchers alongside coffee growing. Some of the communities harvesting wild coffee are also developing infrastructure to host eco-tourists.

Bee-keeping within coffee growing plots could also be practiced in other areas. This needs to be further investigated as honeybees may or may not be best for crop pollination. In Central America the ntroduction of honeybees have been shown to increase yields on coffee (Roubik, 2000).

Perhaps the most unique lesson from the practices centred on *Coffea arabica* that could be applied to other systems is the productivity associated with wild varieties or original stocks. Other species in the region, such as cowpeas, are also cultivated near with their wild relatives and this could form the basis of a pollinator conservation programme that demonstrates the importance of wild pollinating insects moving between wild species and cultivated varieties.

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2.5 LOCAL INNOVATION IN MANGO POLLINATION IN GHANA

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2.5.1 THE MANGO CROPPING SYSTEM IN GHANA AND ITS CHALLENGES

The main mango growing areas in Ghana are located in the south east of the country, with concentrations in the Dangme West and Somanya Districts. Country-wide, there are about 460 farmers specialising on mango with a total of 5,600 acres under mango plantations. Most mangoes are consumed on the local market, with exports estimated in 2004 at around 220 metric tonnes (less than 1% of imports to the EU). The main varieties of mangoes cultivated in Ghana are Kent, Keitt, Haden, Palmer and Springfield. Nationally the majority (85%) are of the Keitt variety, but the larger fruits of the Kent and Springfield varieties are attracting increasing attention because of their export potential. Major constraints on mango production in Ghana include weak producer organisations,

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Figure 2.5.A. Mango flowers in Dodowa, Ghana

low productivity resulting in high cost of production, inadequate control of insect pests and diseases, poor post-harvest management relating to handling, grading and packaging, transport and storage, among other problems.

This best practice profile comes from Dodowa in the Dangme West District, which has a total population of around 100,000 living in around 1400 square kilometres. Major crops include maize, cassava and a variety of vegetable and tree crops (mango and cassava). Mango cultivation is concentrated around Dodowa where the landscape is flat, abutting in the north to the hills of the Akwapim Range and leading to the Atlantic coast in the south. Soil wash from the Akwapim Hills produces deep, well drained loamy soils highly suitable for the production of mangoes. There is an extensive road network, with the Accra–Lome International Highway and feeder roads providing easy access to nearby major towns and export markets.

The farmer who developed the practices described here is the late Kwesi Owusu, who, until his untimely death in a car crash in November 2006, was the president of the Dangme West Mango Farmer's Association (DWMFA), representing 82 farmers. The DWMFA meets monthly and conducts three monthly audits on the farms of its members and prospective members. It promotes good practices and discourages bad practices like fire setting for bush clearance and hunting, misapplication of agrochemicals and not clearing infested mangoes. It also assists in obtaining credit from the local Village/Rural Banks and in facilitating exports.

Kwesi was an Akan, born to farming parents in the Eastern Region at Begaro in 1945. Kwesi trained as an accountant, working for the State Fishing Corporation as Principal Auditor before returning to farming in 1988. He then experimented with different crops and farming systems before settling on mangoes in 1991, in a 36 acre plot purchased on a 50 year lease, with a loan from the Agricultural Development Bank. In that year Kwesi planted 280 mango trees on eight acres in the plot, each eventually producing around 100 kilos. His best recorded harvest amounted to around 32 tonnes.

The markets for mangoes are strong. In 2006 Kwesi was exporting mangoes weighing over 500 grams directly to Beirut, others over 400 grams through Ghanaian middlemen to Britain, while the remainder that were below export quality were sold on the local market.

A USAID-funded project (Trade and International Program for a Competitive Export Economy), will be establishing a pack-house in Dodowa to assist with the export trade. Despite heavy repayment obligations and greatly increased interest rates, the returns from mango farming enabled Kwesi to expand his house, purchase a generator and employ as many as eight people during the harvesting season. In addition to harvesting mango fruits, he also sold mango seedlings, kept ducks, chickens, guinea fowl, rabbits, honeybees and planted cassava and maize, all mainly for subsistence purposes.

The biggest problems that Kwesi faced were bush fires, insect pests and fungal diseases. Bush fires are frequent in the dry season, mostly for bush clearance as poor farmers in the area cannot afford herbicides or the labour to do this by hand. The new invasive fruitfly, *Bactrocera invadens*, has been a problem since 2005 especially in the Somanya area, and is particularly serious for the local varieties of mangoes,

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Figure 2.5.B. Clockwise from top left: Close-up of a single mango flower; Mango flowers clustered on a panicle; Anthracnose – a problem for mango farmers; Mrs Owusu taking care of the mango seedlings that are an additional source of income.

causing losses of up to 50%. These mango varities mature early and are thus a source of infestation for the later maturing commercial varieties. Farmers are encouraged to scout for dropped fruits every week and to bury or burn them. Farmers are also advised to spray insecticide if they see more than 20-30 fruit flies around a tree. Stone weevils are also a problem and farmers are encouraged to spray unripe fruits with Dimethoate (an insecticide permited under Eurepgap regulations) when they reach the size of a small tomato and are vulnerable to this pest. Fungal disease (anthracnose) is a long standing problem, especially during heavy rains, and is controlled by the use of Shavit and Funguran fungicides. Other agrochemicals used include Impact fertiliser and potassium nitrate, the latter as a foliar spray to induce fruiting between July and September and December to February.

Additional management practices on Kwesi's farm, other than those described below for pollination, include pruning and the application of organic manure from chickens (three bags soaked in 250 lites of water). Pruning is done after harvest, and involves the removal of the central branches. This enables the sun to penetrate, helping to avoid fungal disease. It also avoids the production of too many small fruit and reduces labour and spraying costs.

2.5.2 POLLINATION OF MANGOES

Mangoes are monoecious, with tiny red-yellowish flowers, that have five sepals and three to nine (usually five) petals that are borne in large numbers, on long branched and clustered panicles, from 10 to 40 centimetres long. A single tree can have from 200 to 3,000 per tree with 500 to 10,000 flowers per panicle. Large numbers (30-80%) of flowers are imperfect or staminate (i.e. lacking a style and therefore incapable of being fertislised). Perfect flowers have a globular ovary and lateral style together with one to three functional stamens. As the style and stamens are of the same length, self-pollination by visiting insects is possible, and a high degree of self pollination has been reported. Only a tiny proportion of perfect flowers actually set fruit (zero to three per panicle).

The sweet smelling flowers open early in the morning and immediately produce nectar and are receptive to pollination. Pollen shedding is a little delayed, reaching a maximum between 8 a.m. and noon. The flowers attract large numbers of pollinators, including flies, wasps, wild and domesticated bees, butterflies, moths, beetles, ants and bugs. Despite such conspicuous visitation, early reports suggested that mangoes were wind pollinated. Some of the disagreements relate to differences between cultivars, but the great weight of evidence shows that insect pollinators in particular play a vital role. There is general agreement that dipteran flies top the lists of insect visitors to mango flowers (29 Diptera recorded in Ghana, 26 in Israel and 19 in India), followed by Hymenoptera (12 species in Israel and 3 in India) and Coleoptera (6 in Israel and 3 in India).

2.5.3 MANGO POLLINATORS

Figure 2.5.C. Clockwise from left: Mating tiger moths (*Euchromia*) on mango panicle; Stingless bee (*Dactylurina*) on mango flower; bluebottle fly on mango flower; Honeybee (*Apis mellifera*) on mango flower.

INSECTS OBSERVED VISITING MANGOES

SPECIES OBSERVED	NOTES/OBSERVATIONS/SITES WHERE PRESENT
Blowflies **Diptera:** Calliphoridae: *Chrysomya albiceps, C, megacephala, C. pinguis, Lucilia serata.*	Important pollinators in Israel and Ghana (this study) As effective as honey bees in Israel "Large flies" reported as effective in Australia. *Chrysomya* species recommended as pollinators.
Houseflies **Diptera: Muscidae:** *Musca domestica.*	Not as effective as honeybees or blowflies in Israel. Reported as siginificant pollinators in India.
Hoverflies **Diptera:** Sirphidae: *Episyrphus balfeatus, Melanostoma orientale.*	*M. orientale* one of the most effective pollinators in an Indian study but reported as not alighting on the flowers in Ghana.
Wasps **Hymenoptera:** Sphecidae: *Bembecinus tridens, Sceliphron spirifex.*	Wasps generally reported as regular visitors to mango flowers in most locations. *B. tridens* specifically mentioned in Israel and *S. spirifex* seen visiting mango flowers in Ghana.
Honeybees **Hymenoptera:** Apidae: *Apis mellifera, A cerana.*	Inconsistent reports in literature, but clearly important in some cases (e.g. for Keit varieties in Israel, and in Ghana). Recommended as pollinators despite low pollen loads.
Stingless bees **Hymenoptera:** Apidae: Meliponinae *Trigona, Dactylurina.*	Frequent reports. *Trigona* effective in Australia and *Dactylurina* seen on flowers in Ghana (this study). *Trigona* reported as important pollinator in India.
Sweat bees **Hymenoptera:** Halictididae: *Hailctus, Lasioglossumm.*	Recommended pollinators for mango. *Lassioglossum* bees full of pollen on hind femurs.
Ants **Hymenoptera:** Formicidae: *Anoplolepis longipes.*	Frequently reported on flowers. Large ants reported as significant in Australia.
Blister beetles **Coleoptera:** Cantharidae: C*antharis atropoveolatus.*	Reported in Israel as frequent visitors to mango flowers but not as effective as flies or honeybees. May be poor cross pollinators as do not tend to move between trees.
Flour beetles **Coleoptera:** Tenrebrionidae : *Omophlus syriacus.*	Reported in Israel as frequent visitors to mango flowers but not as effective as flies or honeybees. May be poor cross pollinators as do not tend to move between trees.
Butterflies and moths, **Lepidoptera:** E.g. Nymphalidae: *Hypolimnas misippu*; Arctiidae: *Euchromia* sp.	Butterflies are regularly reported as less abundant floral visitors. Pollinator efficacy not assessed. *H. misippus* and *Euchromia* seen on flowers in Ghana. Hawkmoths reported in Ghana.

2.5.4 PROFILE OF BEST PRACTICES FOR CROP POLLINATION MANAGEMENT

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Figure 2.5.D. Clockwise from top left: A conventional-well weeded plantation adjacent to Kwesi's farm; Kwesi in his weed-rich, pollinator friendly plantation; *Stachytarpheta* weeds between the mangoes; the six foot buffer zone of wild vegetation

When Kwesi went into mango farming, he knew nothing about management of mango trees, so he worked with the labourers on an existing plantation to learn the basic principles. These included the practice of keeping the plantation well weeded (either through labour or through the use of herbicides), regular spraying with insecticides to control stone weevils and fruit flies, post-harvest pruning, foliar mist-spraying with potassium nitrate to induce flowering, and the use of fungicides to control anthracnose. Kwesi's innovation was to restrict the weeding operations, reduce insecticide use to a bare minimum and to introduce other pollinators such as blowflies and bees.

In 1993, despite increased costs (350,000 cedis an acre for labour as opposed to 45,000 using chemicals), Kwesi switched to clearing the weeds manually instead of chemically. He had observed that herbicides killed them to their roots, whereas they were quick to regenerate with the rains when cut by machete. He saved labour costs by not clearing in the dry season when the weeds died back and by weeding only after the mango fruits had set. Weeds were allowed to flourish when the mangoes were in flower from July to September after the major rains and between October and February following the minor rains. Among the weedy species observed during a visit in September 2006 were *Sida acuta, Portulaca olearacea, Tridax procumbens, Aspelia africana, Mimosa, Stachytarpheta, and Occimum*. In addition to the weeds in the plantation, Kwesi maintained a six foot wide buffer zone of wild vegetation on the margins of his farm.

An increase in fruit yields was rapidly apparent and in 1994, Kwesi tried to further augment the pollinator populations by attracting blowflies. He distributed scraps of beef in the mango plantation. He quickly discovered that the meat was most attractive when it was boneless and bloody, and that by spacing boxes of meat a hundred yards apart, together with adjacent piles of sand, he could reap more benefits from subsequent generations of blowflies. The mature fly larvae crawled out of the meat and pupated in the sand, giving rise to adult flies after 10 to 14 days. In contrast to the bees that came only in the early morning from five to seven thirty, and then again after three in the afternoon, the blowflies worked the mango flowers throughout the day.

With these techniques Kwesi was able to increase his harvests from around 60-80 to 100 kilos from each tree, easily recouping expenses incurred from hiring labour and buying meat. He also benefited from minimal use of insecticides, applying Dimethoate in strictly timed and targeted doses to control stone weevils and careful scouting for fallen fruit to control fruit fly infestations.

There was however a predictably unpleasant side effect from the use of meat to attract blowflies. The odour became increasingly offensive, particularly since the mango plantation is immediately adjacent to his homestead, so in 2003, Kwesi switched to keeping bees. By September 2006 he had fifteen conventional hives and was beginning to experiment with stingless bees. *Dactylurina* species were frequent visitors to the mango flowers observed at this time. With the help of the bees, Kwesi was able to maintain his yields, despite the reduced presence of blowflies.

2.5.5 KNOWLEDGE BASE OF BEST PRACTICES

As a newcomer to mango farming, Kwesi was eager to learn from all established sources, but was also highly observant and keen to try new things. He was conscious of the low levels of mango fruit set and recalled the advice of his farming parents who made a practice of not killing insects because of their pollination services. Kwesi noticed that when the weeds flourished on adjacent uncultivated plots with the coming of the rains in May, their flowers were visited by large numbers of insect pollinators. This led him to restrict his weeding operations within the plantation. Through further enquiries and his own observations, he realised that blowflies were significant pollinators and started to encourage them with the meat scraps. His subsequent use of bees was through the encouragement of a friend and colleague (Kwame Aidoo), who has a bee products business near Winneba on the west coast.

2.5.6 COSTS AND BENEFITS OF BEST PRACTICES

Kwesi's innovations marked a departure from accepted practice and as a newcomer to mango farming, he experienced some initial scepticism from fellow farmers and extension staff, particularly those with links to the agro-chemical industry. Nonetheless, his results earned him respect, as shown by his presidency of the local mango growers association.

Other costs and benefits are outlined in the table on the following page. As is frequently the case with small holder innovations in agricultural practice, the lack of quantitative scientific validation is best seen as an opportunity for further research. In this instance, it would be particularly useful to know more about the trade-offs between increased pollination and the negative effects of weeds.

PRACTICE	COSTS	BENEFITS
Restricted weeding operations within plantation.	Unquantified but potential reduction in availability of soil nutrients for mango production as a result of their extraction to support weed growth. Increased fear of snakes.	Encourages pollinator presence contributing to reported overall 20-40% increase in yields. Nutrient losses mitigated by leaving cut weeds *in situ* following weeding after fruit set. Potential better water retention in soil, and reduced soil erosion.
Elimination of herbicide use.	Less effective weed control, as herbicide use restricts weed regeneration. Seven to eightfold increase in weed control costs per acre as a result of substituting labour.	Reduced use of herbicide encourages plant and insect biodiversity (including pollinators). Social benefits from providing employment for labourers to weed after fruit set.
Maintaining six-foot buffer of wild vegetation around plantation.	Less land available for cultivation.	Attracts and maintains pollinators on margins of plantation. Leaving land fallow stabilises and allows recovery of soils, reduces soil erosion and increases water retention.
Attracting blowflies with meat scraps.	Purchase cost of boneless meat (200,000 cedis per application). Unpleasant odour of rotting meat, especially in vicinity of homestead, made it undesirable to maintain this practice.	Blowflies are efficient mango pollinators. Attracts blowflies contributing to reported overall 20-40% increase in yields. Blowfly breeding on meat augments local populations.
Bee keeping.	Increased risk of bee stings, especially around homestead.	Bees contribute to reported overall 20-40% increase in yields. Source of honey for consumption, sale and medicinal use.
Reduced use of insecticides.	May increase pest damage and reduce marketability of blemished fruit.	Allows natural enemies of pests to flourish. Opens possibility of organic certification and fair trade marketing.

2.5.7 CHALLENGES AND OPPORTUNITIES FOR WIDER ADOPTION

Two generic lessons emerge from this case study:

1) Innovation with agricultural practices can originate from newcomers. Kwesi came into mango farming in his forties after a career in accounting. He had not been exposed to training or a formal education in agriculture, and therefore may have been more open to experimenting with new ideas based on his own observations and springing from the untutored experiences of his farming parents.
2) Because of the tight and highly personalised links between livelihood returns and agricultural practice, small holder farmers are quick to adopt technologies that work for them. They will do so in advance of the science that is needed to test such innovations. In this particular best practice, there are clear opportunities for research into the trade-offs involved.

Kwesi's experience suggests that there are substantial benefits for mango farmers if they modify their standard practice and allow more room for weeds. Yet this runs counter to conventional advice and may therefore be a hard idea to promulgate, particularly in the face of pressures from the industry to use ever greater quantities of agro-chemicals. A significant, but entirely surmountable challenge to its wider adoption, is the current lack of scientific validation for this best practice.

Initial Survey of Good Pollination Practices

PROFILES OF BEST PRACTICES FROM AROUND THE WORLD

ASIA

Figure 2.6.A. ***Apis dorsata*** **visiting a cardamom flower**

2.6 CARDAMOM IN THE WESTERN GHATS: BLOOM SEQUENCES KEEP POLLINATORS IN FIELDS

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2.6.1 THE CARDAMOM FARMING SYSTEM IN THE WESTERN GHATS

The fruits and seeds of Cardamom, *Elettaria cardamomum*, the Queen of Spices, are used in many parts of the world, but most frequently in Indian and Scandanavian cuisine. Cardamom is the world's second most expensive spice, second only to saffron. It is currently priced between US$14,000 and $16,000 per ton. In recent years cardamom production has moved out of its native range in India to other regions of the world suitable for its production, including Sri Lanka, Guatemala, Indo-China and Tanzania. Guatemala is currently the spice's major producer. Cardamom is, however, still a major crop in the Indian states of Kerala, Karnataka and Tamil Nadu. It is the production of cardamom in these Indian states that is focused on in this profile. In 2006-2007, 8545 MT of cardamom was produced from plantations covering 41,362 hectares in Kerala, with Karnataka following with 1725 MT from 26,611 hectares and 965 MT from 5255 hectares of production in Tamil Nadu (Spice Board of India estimates).

In Kerala, Karnataka and Tamil Nadu, cardamom is grown between 600 – 1200m above sea level in areas with annual rainfall levels of 1500 – 4000 mm

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Figure 2.6.B. Understory conditions in a cardamom plantation

and temperatures ranging from 10-35°C. Consistent rainfall between February and April is essential for good flower production. Cardamom grows best on soils with high organic content and good drainage. The crop is very sensitive to moisture stress and excessive or insufficient light. Cardamom grows best in partial shade, with 50-60% filtered sunlight. In recent years there has been increasing variability in rainfall levels during the summer months, causing many farmers to resort to irrigating their crops, starting in December.

Indian cardamom is commonly grown in semi-cleared forest understory, in artificially shaded plantations or in the understory of planted tree plantations. Plantations range in size from less than one to over 100 hectares, although most cardamom plantations are small. Many small growers cultivate cardamom as a mixed crop with areca nut and coffee. In most parts of the Hills of Karnataka (part of the Western Ghats), where coffee is the major crop, coffee is grown on the slopes of the hills and cardamom is cultivated in the cooler valleys.

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Figure 2.6.C. A monocultural cardamom plantation with interspersed shade trees.

Canopy trees play an important role in maximizing cardamom production. They provide the shade needed by cardamom plants and the leaves that fall from them are used as mulch. In November and December leaves fallen from shade trees are clustered around the base of plants to prevent the soil from drying during the summer dry season. Shade trees also provide nesting sites for pollinating bees and floral resources for pollinators at times of the year when cardamom is not blooming.

New plantations of cardamom are started by planting seedlings or suckers. Seeds are sown in raised beds in nurseries and grown for two years. Usually, two-year-old seedlings are then transplanted into the main field. When suckers are used, new suckers from old plants are separated along with the rhizome and directly planted. In the main field, planting is done at a spacing of 8 x 8 feet (in Karnataka) or 10 x 10 feet (in Kerala). The number of plants per hectare ranges between 2500 and 3000. Most small and marginal farmers (those with less than 5 acres) seldom apply any fertilizers. The majority of farmers with large plantations apply fertilizers and take up a variety of plant protection practices. Hardly any farmers use herbicides, but regularly employ manual labours who hand weed the fields. Fertilizers are applied in split doses and the quantity varies greatly. A fertilizer dose of 75 kg Nitrogen, 75 kg Phosphorus and 150 kg Potash per ha is recommended under irrigated conditions, for plantations yielding 100kg/ha and above. A dose of 30:60:30 kg/ha is recommended for plantations under rain-fed conditions. Organic manures like compost or cattle manure may also be applied at a rate of 5 kg per plant. Neem oilcakes are also applied at 1 kg per plant. Usually chemical fertilizers are given in two applications. In Kerala where cardamom cultivation is more intensive, fertilizers are applied at far higher rates (sometimes more than three to four times the recommended dosage) in six to eight applications. Major pests of cardamom include thrips, shoot and capsule borers, aphids, and nematodes. Most pests are controlled with the use of pesticides.

2.6.2 POLLINATION OF CARDAMOM

Elettaria cardamomum is a perennial species in the Zingiberaceae or ginger family. It is native to the rainforests of the Western Ghats of southwest India, which form the border between the Indian states of Kerala, Karnataka, and Tamil Nadu. Each plant generally grows to two or three meters tall and is composed of a cluster of sheathed stems (pseudostems). Flowers are borne on panicles emerging from the base of the plant. Each panicle can produce up to 45 flowers. Three types of cardamom are

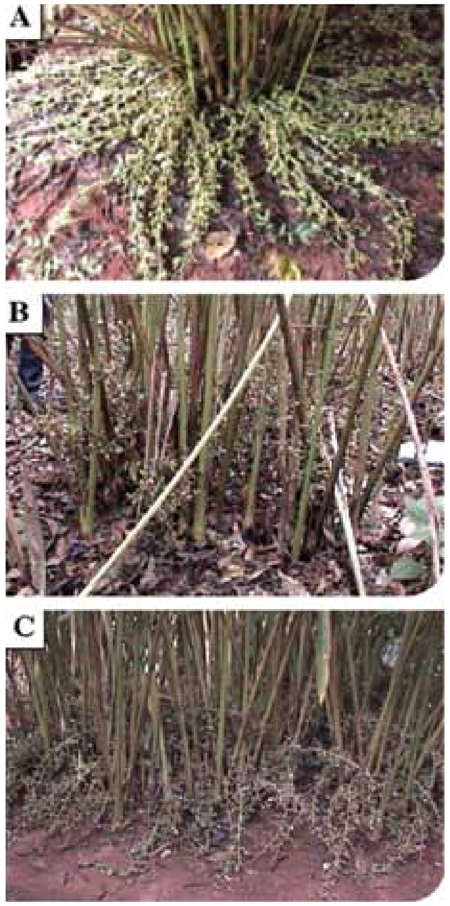

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Figure 2.6.D Lower portions of cardamom plants, showing pseudostems and panicles. A) Malabar type cardamom with prostrate panicles, B) Mysore type cardamom with erect panicles, and C) Vazukka type cardamom with semierect panicles.

cultivated in India – the Malabar type with prostrated panicles, the Mysore type with erect panicles and the Vazukka type with semi erect panicles. The main flowering season in southwestern India is between May and October.

Cardamom plants flower continuously from the last week of April, or first week of May until the second week of October. The bilaterally symmetrical white flowers have pink or purple "pollen guides" on the lower petal; these guides are thought to help pollinators find the nectaries. This lower petal, called the labellum, is a modified stamen that forms a landing platform for pollinators. Each flower has a solitary functional anther that releases pollen as the flower opens.

Each cardamom flower lasts a single day. Flowers open in the early morning hours between 4 and 5 am and the anthers start to release pollen around 7:30 am. Though all the pollen grains are not released at once, they have all been released (and can be picked up by pollinators) by 10:30 am.

Insect pollinators are required for any valuable fruit production. Since the anther is located very close to the labellum, a pollinator that has landed must squeeze through below the anther to reach the nectar in the corolla tube. In the process, its head and upper thorax come in contact with the stigma dislodging pollen onto the stigma. The pollinator while retrieving its tongue and itself from the corolla

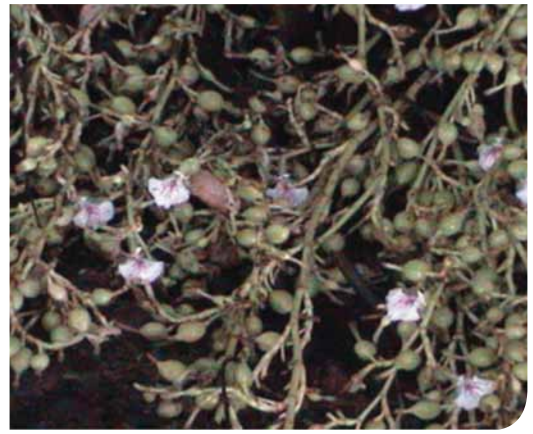

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Figure 2.6.E. Cardamom panicles with flowers and ripening capsules.

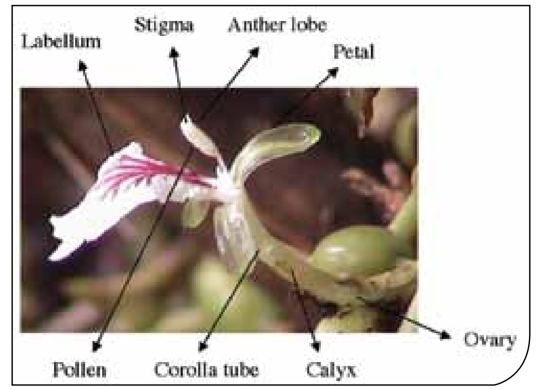

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Figure 2.6.F. Cardamom flower with labeled parts.

tube, again rubs its thorax and the upper part of its head on the anther, taking pollen grains.

The ovary of any flower will have anywhere between 18 to 27 ovules and for each ovule to become fertilized, the flower requires as many pollen grains. A single flower receives as many as 130 visits from pollinators on a sunny day to just over 20 visits on a rainy day (Belavadi et al. 2005). If pollinated, each cardamom flower produces a single capsule containing about 10 seeds. If the flowers are bagged to prevent pollinators from visiting, only around 13% of flowers bagged to prevent insect visitation set any fruit and these will have low seed numbers/ capsule (on average, only one). In comparison, there is 69% fruit set with an average of 10 seeds/ capsule for self-pollinated flowers and 61% fruit set (again with an average of 10 seeds per capsule) in cross-pollinated fruit (Sinu and Shivanna 2007). These results also indicate that the crop is self-compatible and does not require out-crossed pollen for fruit production; however, pollinator visits are critical for effectively and efficiently moving pollen from the anthers to the stigma.

Thus, within the one day that a cardamom flower is open, it is essential that it is visited by insect pollinators depositing an optimal quantity (at least 18 pollen grains) per flower.

Figure 2.6.G. *Apis cerana* **forager collecting nectar and pollinating a cardamom flower.**

2.6.3 MAJOR POLLINATORS AND THEIR POLLINATOR PREFERENCES

A recent study of cardamom's pollination ecology in the Western Ghats found a diversity of bees, flies, butterflies and bird species visiting cardamom flowers. Few visitors, however, were found to be true pollinators. Of the observed 18 flower visitor species, only 3: the Eastern honeybee *Apis cerana, Trigona iridipennis* and *Ceratina hieroglyphica,* actually collected pollen on their bodies (Sinu and Shivanna 2007). All of these are bees, and all evidence indicates that bees are the dominant pollinators of cardamom in southwestern India, although the dominant bee visitors vary by plantation and region (Sinu & Shivanna 2007 and Belavadi et al. 1997).

The most common bee pollinator of cardamom in southwestern India is *Apis cerana,* a honeybee species native to India. Other bees are also known to be effective pollinators of cardamom including *Apis dorsata, Trigona* sp., *Amegilla* sp. and *Ceratina hieroglyphica* (Belavadi et al. 1997, Sinu & Shivanna 2007). *Apis cerana* has been observed depositing from 3-23 grains of pollen per visit to a single cardamom flower and *Apis dorsata* has been observed depositing an average of 28 pollen grains per single visit (Mayfield, unpublished data).

Some of the smaller and less conspicuous bees may be even more effective. Sinu and Shivanna (2007) found that the small stingless bee *Trigona iridipennis* successfully pollinated between 83.3 and 95.5% of the flowers they visited (depending on the season). This is a significantly higher rate than that of the more common visitor, the Eastern honeybee, which only successfully pollinate 46.5% of the flowers they visit. The little bees also added to the services provided by *A. cerana,* that is, flowers that are visited first by *A. cerana* followed by *T. iridipennis* produced fruit 100% of the time, although the reverse visitation order did not result in higher pollination rates than single visits by *T. iridipennis* (Sinu and Shivanna 2007).

Several species of fast-flying long-tongued *Amegilla* bees also visit cardamom flowers (Belavadi et al. 2003, Parvathi 2006, Parvathi & Ramachandra 2006). *Amegilla* with its long tongue (~15mm) is capable of exhausting all the nectar available in the corolla of cardamom flowers and may actually be the original pollinators of wild cardamom. *Amegilla* is very active in the beginning and during the end of the flowering season, when the flower density is low, and then is replaced by the native honeybees in midseason when flower density is high. Despite the potential importance of *Amegilla* evolutionarily and historically, currently *A. cerana* and *A. dorsata* bees are the most important pollinators in the production of cultivated cardamom.

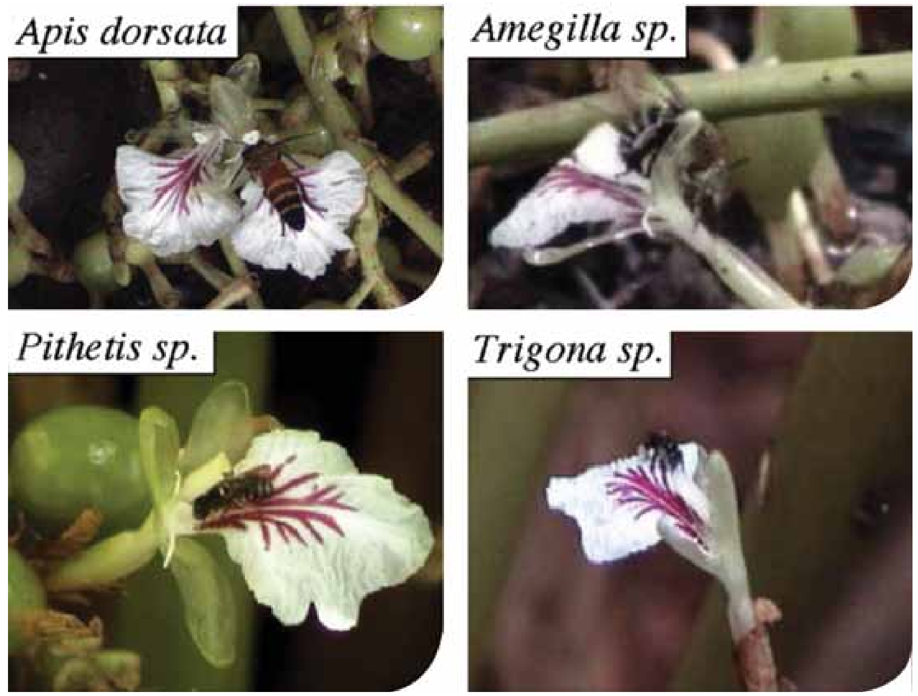

Figure 2.6.H. Common bee visitors to cardamom flowers in the Kerala and Karnataka

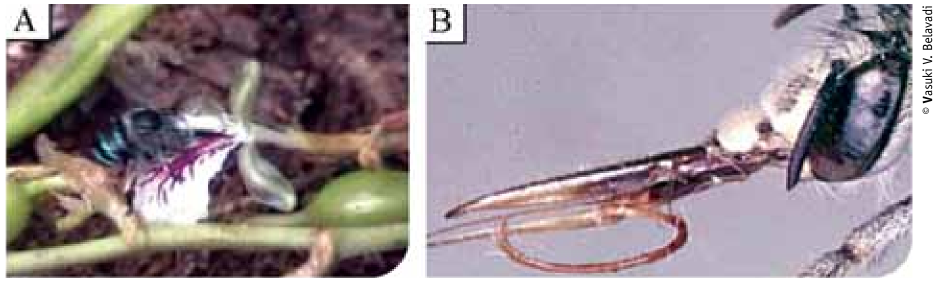

Figure 2.6.I. (A) *Amegilla* sp. landing on a cardamom species, (B) Close up of *Amegilla* mouthparts.

2.6.4 PROFILE OF BEST PRACTICES FOR CARDAMOM POLLINATION

Despite the diversity of pollinating bee species found visiting cardamom in southwestern India, pollination is a concern for cardamom farmers. As cardamom requires pollinators for fruit production it is crucial to ensure that large numbers of pollinators are available during the blooming season. One of the major hurdles to ensuring cardamom pollination is maintaining pollinator populations in plantations between years. Most pollinators of cardamom are wild and thus move freely through the landscape. As cardamom does not bloom year round, pollinators may leave cardamom plantations once blooming finishes and they do not necessarily return the following season. *A. cerana* is the only major cardamom pollinator that is kept in managed hives, but many cardamom farmers cannot afford to rent them and many lack the knowledge to maintain them themselves. The other major cardamom pollinator in southwestern India is *Apis dorsata.* These bees are highly migratory and move their nests in response to resources. The presence of a single *A. dorsata* hive in a small plantation can provide for the majority of the necessary pollination services. *A. dorsata* has never been successfully domesticated and is the target of traditional honey collectors who in recent years have devastated *A. dorsata* populations in southwestern India. The expense associated with farmed *A. cerana* and the increasing rarity of *A. dorsata* has increased interest in maintaining a diversity of wild bees in cardamom plantations for pollination services.

An additional factor behind the developing interest in wild bees is the presence in this region of a second crop that is similarly reliant on bees for pollination: coffee. Coffee has an even shorter blooming season, flowering for only a few days at a time in March/April. Although not as reliant on bees for fruit production as cardamom, it is known to need bees for maximized fruit production (Ricketts et al 2004; Belavadi et al 2005). Conveniently, many of the same pollinators visit both cardamom and coffee flowers, and coffee can tolerate the same levels of shade as cardamom requires. Often farmers have holdings of both on their land.

The innovative solution that is gaining popularity for ensuring quality pollination services to cardamom and coffee in southwest India, is the use of managed forestry to create "sequential blooms" in mixed coffee and cardamom plantations. Farmers of cardamom and coffee plantations often plant economically valuable timber trees or betel nut trees (a crop of domestic value) to provide shade while maximizing the economic value of their plantations. As concern about declining pollination services has increased, however, a new approach to shade trees is emerging.

Instead of monocultures of timber trees, many farmers are now planting a diversity of flowering tree species that in combination provide floral resources in plantations year round. This flower scheduling provides reliable pollen and nectar resources for native bees at times of the year when neither cardamom nor coffee is blooming. One well-documented example is the use of two species of *Schefflera (S. venulosa* and *S. wallachiana)*. Both of these tree species have flowers attractive to bees. Both flower almost immediately after coffee finishes blooming in the region and just before cardamom begins (Belavadi et al. 2004), thus greatly reducing the number of bees that leave plantations during the off-season. By providing year round floral resources, farmers are ensuring that there will be enough bees around to pollinate cardamom and coffee flowers during the appropriate seasons.

Figure 2.6.J. Mixed coffee and cardamom plantation, Karnataka, India (coffee on the left, cardamom on the right, diverse shade trees interspersed).

Additional benefits in the use of diverse bloom sequences,

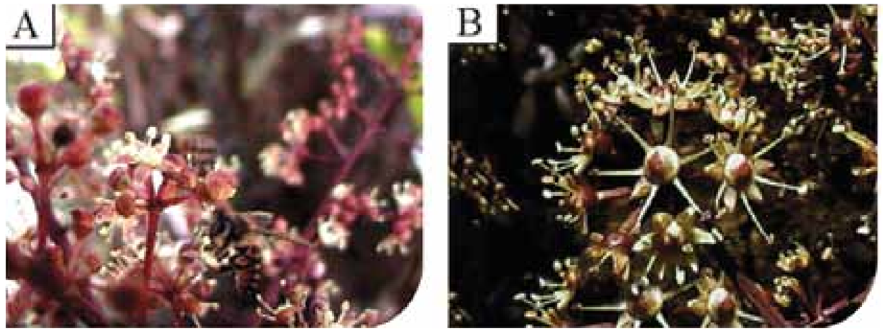

Figure 2.6.K. Flowers for *Schefflera venulosa* (A) and *Schefflera wallachiana* (B).

Figure 2.6.L. A cardamom plantation with black pepper being grown on interspersed shade trees.

is that the trees provide nesting sites for many bee species; can be used to support a third crop in mixed cropped plantations -most commonly black pepper and some of the trees can also be selectively logged for timber production (Kuruvilla et al. 1995).

2.6.5 KNOWLEDGE BASE OF BEST PRACTICES

At the Zonal Agricultural Research Station in Mudigere, India, cardamom and coffee planters are trained to understand the importance of pollinators and how to maintain bee colonies. Between 2000 and 2005 twenty training programmes were run by the Station, each serving approximately 30 farmers. Some of these programmes were conducted in villages rather than at the research station to ensure that the information provided in the programmes reached poor farmers. The training included information on how to locate bee colonies, "hiving"and maintaining colonies. In every programme the importance of honey bees *(A. cerana and A. dorsata)* as pollinators of cardamom and coffee was given more emphasis than the use of these species for honey production. These training programmes were supported by the Indian Council of Agricultural Research, New Delhi, and the Ministry of Rural Development of the State. During the five years approximately 600 farmers were trained and a recent survey has shown that at least 20% of them are now keeping bee colonies on their plantations. The Cardamom Board of India also has started to conduct similar training programmes. More training is needed to encourage the use of bloom sequences, but the level of governmental sponsored programmes to educate cardamom farmers throughout southwest India is already extensive and continues to grow.

2.6.6 COSTS AND BENEFITS OF BEST PRACTICES

More and more evidence is pointing at the overwhelming benefits of using floral calendars in cardamom plantations in India. The table following indicates costs and benefits of using floral calendars as well as related practices associated with this and other cardamom pollination-oriented practices. This list is generated based on cardamom production in India, but very similar considerations are likely to exist in other cardamom growing regions of the world.

PRACTICE	COSTS	BENEFITS
Shade trees selected for flowering schedule (planting a floral calendar).	Does not allow regulation of shade during each growing season (except when timber trees are also grown) Potential decrease in yields due to over shading. Potential increase in pests and diseases.	Ensures supply of pollinators and associated increased yields. Provides extra income from selective logging. Provides extra income from growing a third crop – black pepper.
Replanting shade trees to use calendar species in preexisting plantations.	Expensive to remove trees, buy seedlings, plant seedlings. Reduced or no income from cardamom while calendar trees grow.	Increases long-term value of plantation and future fields.
Planting calendar trees in new plantation.	Similar cost to planting a monoculture of timber trees with no floral value.	Increased pollinator numbers in fields and associated increases in yields and income from cardamom and coffee production.
Tolerating/protecting *Apis cerana* bee nests	No cost..	Additional income from honey collection Free pollination services for cardamom and coffee.
Keeping *A. cerana* domestic hives.	Must purchase hive boxes and other bee keeping equipment. Costs associated with learning how to maintain bees.	Without a floral calendar, likely be necessary to maximize cardamom yields.
Tolerating/protecting *Apis dorsata* bee nests.	If maintained, little income from honey (honey collection destroys hives).	Free pollination services for cardamom and coffee.
Tolerating/protecting other pollinating bees (*Amegilla* sp, *Trigona* sp, etc.)	No cost.	Free pollination services for cardamom and coffee.
Limited pesticide use. Timing of pesticide applications and using bee safe pesticides.	Increased risk of pest outbreaks.	Reduced input costs. Reduced risk of declining yields due to low pollinator numbers, and low numbers of beneficial insects.
Maintaining multiple crops.	Requires knowledge of multiple crops and more skilled labor for harvest.	Diversified income from land. Ensuring income each year. Maximizing yields on small land holdings.

2.6.7 CHALLENGES AND OPPORTUNITIES FOR WIDER ADOPTION

One of the major challenges to increasing the use of floral calendars in cardamom and coffee producing regions of the southwest India is the prevalence of other strategies for providing shade in plantations. Despite evidence showing the value of using multiple species of shade trees with appropriately timed flowering, the practice of planting a single shade tree species, specifically "silver oak", is still widespread. Although there are no studies documenting the differences between these practices, the "silver oak" approach is widely considered by agricultural scientists in the area to have strong negative effects on bee populations in coffee and cardamom plantations. In fact, in the last decade, there has been a notable decline in coffee and cardamom yields throughout the Western Ghats, which is generally attributed to the low bee numbers found in monocultural plantations. To increase the number of cardamom farmers utilizing bloom sequences, it is essential to increase research showing the value associated with them and the problems with using a monoculture of shade trees. A priority for increasing the prevalence of managed bloom sequences is to improve our knowledge of the flowering phenology of shade trees in existing plantations throughout the Western Ghats. While some trees such as the *Schefflera sp*. are well studied and are known to have phenologies conducive to use in floral calendars in southwestern India, trees are long-lived and phenologies change regionally. Much more extensive lists of tree species are needed for each sub region of Kerala, Karnataka and Tamil Nadul. These will be locally useful for providing floral resources between the cardamom and coffee flowering seasons, but will not compete for bees during these crop's blooming season. An additional hurdle is the time it takes for trees to reach reproductive maturity. Thus, it may be better to encourage farmers to implement this practice in their new fields, rather than in those already in operation. There is real promise in encouraging the use of bloom sequences in new plantations, but without convincing farmers to convert their current plantations, progress will continue to be slow.

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Initial Survey of Good Pollination Practices

PROFILES OF BEST PRACTICES FROM AROUND THE WORLD

NORTH AMERICA

Figure 2.7.A. Blueberries in bloom.

2.7 WILD BLUEBERRIES, WILD POLLINATORS IN MAINE, USA

Hannah Nadel
United States Department of Agriculture

2.7.1 BLUEBERRY CULTIVATION

Blueberries have traditionally been cultivated under more or less "wild" conditions, as they are difficult to transplant and were rarely planted until recent advances in propagation. Blueberry fields are started by clearing trees around wild blueberry bushes, promoting their spread and fruiting. Once the area around the plants is cleared, the plants send up new shoots from rhizomes and eventually spread naturally toward adjacent plants. These clonal individuals are commonly referred to simply as 'clones'. They are often distinguishable by subtle color and growth-form characteristics that give the fields the look of a vast patchwork tapestry. Propagated cuttings and seeds of selected varieties are now commercially available.

Shade greatly limits flower formation. Weedy trees, shrubs and herbs must be kept down within the blueberry field to prevent shading and competition for resources. Native Americans traditionally burned forests to encourage blueberry production. Commercial producers (including Native American-owned companies) continue with many practices that have been developed over centuries of blueberry cultivation.

Maine is the largest producer of wild blueberries in the world. Commercial blueberry fields in Maine consist exclusively of wild lowbush blueberry. The most abundant species managed in the state is the low sweet blueberry, *Vaccinium angustifolium,* which grows from 4 to 15 inches high. The next most common species is the sour top blueberry, *V. myrtilloides,* which reaches a height of 6 to 24 inches and tends to be more prevalent in mountains and hilly areas. The highbush blueberry, *V. corymbosum,* grows along lakes and ponds near managed wild blueberry fields and occasionally crosses with the lowbush plants to produce intermediate hybrids. Cultivated highbush varieties are grown in home gardens and small plantings, but are not part of the commercial wild blueberry industry in Maine.

Blueberry acreage in Maine has shrunk to about one-third its size in the mid-1800s. It currently consists of about 60,000 acres. But the fruit, and whole plant, is gaining in popularity. Both the fruit and leaves have extremely high amounts of antioxidants called anthocyanins. The United States Department of Agriculture (USDA) recently found that the berries rank highest in antioxidant activity compared with forty other fruits and vegetables tested. As the leaves are also high in anthocyanins, one of the interviewed growers is planning to harvest them for a herbal tea company.

The yearly cycle of wild blueberry farming activities in Maine consists of the following: in the fall or spring, one-half of the acreage is pruned by burning or mowing. Burning is done with oil burners (oil-fueled flame throwers) or by the traditional method of lighting straw spread over the plants. Straw is put on in the fall, and remains on the plants over the winter before being burned in the spring after sunny weather dries it out. Mowing is done mechanically with flail mowers. Repeated burning of fields results in yield reduction associated with destruction of the organic pad and exposure of the rhizomes. Mechanical mowing has the advantage that it is less costly and produces equivalent yields without depleting the organic pad. Burning, however, reduces certain insect pests and diseases that reside in the leaf litter.

The pruned acreage grows vegetatively for the year and forms reproductive shoot buds by fall. If done in spring, the pruning is usually completed by May; if done in the fall, it is done in October or November. Fertilizers are applied, but they encourage weeds. Quite often, sulfur is applied to the fallow half anytime during the growing season to lower soil pH and thereby help control weeds (especially grasses) and promote healthy blueberry plants. This practice can create a heavy metal problem in the soil, but blueberries tolerate it. Organic farms use fish-based fertilizer.

The unpruned half of the field blooms and sets fruit in April-May. After fruit set, fungal diseases such as botrytis and mummy-berry, and pests such as blueberry maggot are monitored and treated, if necessary. Weeding within the blueberry field is a constant chore throughout the growing season, and is accomplished either by hand-clipping of weedy trees, hand-pulling, or with herbicides. The blueberries are harvested over a four-week period from late July or early August to early September. If leaves are picked for tea, they are picked in the fall, around October or November.

Figure 2.7.B. Pruned and unprunned blueberry fields, Maine, USA

Large-scale mechanized blueberry farms often are capable of manipulating the farm environment more than small farmers. They generally remove rocks and smooth out the land ('leveling') by filling in depressions, facilitating movement of the farm machinery such as mowers and harvesters, and use irrigation to increase berry weight.

Large blueberry companies manage many of the large and small farms and buy up a considerable portion of the crop. They collectively own half to two-thirds of the 60,000 blueberry acres in the state. The remaining farmers have small acreage, and mostly sell to the larger growers. Some are sold as fresh pack, some roadside, but most is frozen and processed for cereals, juices, muffins, etc. Ironically, during harvest in Washington County, the blueberry capital of the world, tourists often can't find fresh berries for sale. The only place where bulk blueberries can be bought by the public is at Blueberry Land (housed in a building shaped like a gigantic blueberry), which also sells pies, jams, etc. There is also a Blueberry Festival around mid-August that brings in a lot of tourists and promotes the sale of locally grown berries.

2.7.2 POLLINATION OF BLUEBERRIES

The corolla of the blueberry flower is bell-shaped; the style is encircled by 10 shorter stamens. Nectar is secreted at the base of the style, requiring an insect to push its tongue between the filaments of the anthers to reach it. While collecting nectar, an insect may jar the anthers and dislodge pollen, which falls onto its body. It

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Figure 2.7.C. Commercial outlet for sale of blueberries to the public.

may then brush against the receptive part of the stigma, pollinating it with pollen collected from a flower previously visited. There are a diversity of blueberry species, and the corolla length may differ considerably between them. For example, the corolla tube length of *V. boreale* (one species of lowbush blueberry) is 3 mm compared to 5 -7 mm for *V. angustifolium* (another lowbush blueberry). This may affect the ability of different insects to handle the flowers and collect nectar (Free 1993).

There may be wide variation amongst different blueberry clones in their pollination requirements, but yield increases due to pollinator visits have been documented for all blueberry species. As blueberries are often grown near bogs, woodland, or abandoned farmland, the population of wild pollinators is often relatively large and sufficient to pollinate small fields adequately, but not big ones. In areas where blueberry plantations are concentrated, there may be too few wild bees, and in such areas inadequate pollination has been demonstrated.

Blueberry flowers have from 60 to 150 ovules. One pollen grain can result in one seed, but the more viable seeds in a fruit, the bigger the fruit, all else being equal. Thus, it is safe to say that the more pollen deposited on a blueberry flower, the better; with no pollination, fruit does not set. Without honeybees, fruit set is 40-60%, but growers would like to see 80-90% fruit set.

2.7.3 BLUEBERRY POLLINATORS

Most flower visitors probably visit blueberries for nectar, as the pollen is not actively collected. Honeybees and bumblebees are usually the most abundant flower visitors, but solitary bees and flies also visit blueberry flowers. Bumblebees visit more flowers per minute than other pollinators, and have no difficulty extracting nectar from blueberry flowers with their long tongues. Honeybees, however, seem to have more difficulty handling blueberry flowers, or effecting pollination. Honeybees

must visit many times to transfer sufficient amounts of pollen to initiate fruit set, whereas bumblebees seem to be quite effective in transfering large quantities of pollen with single visits, being able to sonicate the flower. Honeybee hives have 30,000 to 50,000 bees, while the bumblebee “boxes”(known as quads) have only 250 to 300 bees. A rule of thumb used by farmers for monitoring whether pollination is going well is to count about two honeybees per minute per square metre, and one bumblebee per ten minutes.

Currently many growers rent honeybees to increase fruit set and seed number, which improves yield. The cost of renting a honeybee hive was US$25 about 30 years ago, but now is about US$44/hive for large growers that rent hundreds of hives, and US$70/hive for small growers. The price has increased since the honeybee industry in North America was devastated by varoa and tracheal mites (and can be expected to increase more with Colony Collapse Disorder). Two to four hives have been recommended per acre, depending on field size and location. Honeybees do not overwinter well in Maine, due to diseases and mites, so most hives are rented from Florida beekeepers.

As mentioned, bumblebees are good pollinators of blueberries, being more efficient than the honeybee. A species native to eastern North America, *Bombus impatiens*, is commercially bred and sold (but not leased) in quads. Each quad contains four nests with a queen and workers, and costs about US$250. A disadvantage of buying these quads is that they can be used during only one season. However, if overwintering habitat, such as bales of straw, is provided near the quad, the young queens may survive the winter and build a nest in the soil the following year. Bumblebees tend to pollinate better in small, isolated fields where forage is restricted to that field.

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Figure 2.7.D. Blueberry flowers and fruit

When forage is abundant over a large area, bumblebees will disperse, and may not sufficiently concentrate on the blueberry crop.

Honeybee hives and bumblebee quads are protected from bears with electric fences. However, ambitious bears will pass even these barriers!

Other species of wild bees are known to visit and pollinate blueberries. Wild bees add stability to honeybee pollination, especially when the weather is erratic.

2.7.4 PROFILE OF BEST PRACTICES FOR CROP POLLINATION MANAGEMENT

Blueberries in Maine are grown in the high "barrens" of Maine , which have become a vast monoculture of blueberry fields, dotted with clumps of trees and shrubs and a few rows of windbreaks. The rows of trees, which act as windbreaks in the blueberry barrens, slow the wind and prevent frost/cold damage in winter. There are large differences in the practices between small farmers, and the larger commercial growers. The small independent blueberry growers in Maine usually encourage wild flowers as alternative forage, leave or maintain woodland on their properties, and reduce or eliminate pesticide use. The large-scale growers, one of which is a Native American company, rely heavily on honeybee rental for the blueberry crop and do not promote wild pollinators. This is due largely to the absence of bee nesting habitat inside the fields and reluctance of wild bees to forage far from the periphery or cover large acreage. The large scale farms produce higher blueberry yields than small farms.

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Figure 2.7.E Windbreak in blueberry barrens, Maine, USA

Research by the University of Maine, on blueberry Integrated Pest Management and pollinator needs and behavior, has improved the prospects of wild pollinator conservation and sustainable use, in Maine. However, the small independent blueberry farms are often struggling to survive and are being bought up by a handful of large companies. The fate of the wild pollinators and conservation of pollination services in the long term may be determined by the management practices of the large companies.

A tephritid fruit fly - the blueberry maggot *(Rhagoletis mendax)*, is the primary pest of blueberries in the region, and has traditionally been treated with the insecticides Malathion, Spintor and Imidan. New organic options are being evaluted, and a suite of cultural control options are available to farmers.

The pest can be controlled better if berries are not winnowed in the field, and if the berries are not left lying on the ground after harvest. If the field is isolated a possible control measure is not to split it into bearing and fallow halves so that it remains completely berry-free for a year. The flies are poor dispersers, so most will die out without reproducing during the fallow year. Organic growers can employ a delayed-harvest technique, where harvest is delayed until 2-3 weeks after the last flies emerged, to allow maggots to drop before the harvest (this doesn't control the fly, but avoids maggots in harvested berries). Another way to avoid maggots is to harvest only towards the center of the field, away from the edges where infestation is higher. A good monitoring system for the adult flies has been developed by the University of Maine.

Other pests include Flea beetle, blueberry spanworms and the red-striped fire worm. They are conventionally controlled with pesticides. If certain pesticides are applied to larvae early in the spring, it may not harm bees once it dries. Burning helps to control pests. Biological agents — the fungus *Bouveria bassiana,* seems safe for bees and flea bettle, and *Bacillus thuringiensis* is applied for spanworm. Spanworm populations often crash due to a natural virus. Fungal diseases such as botrytis can be treated with organically certified products, although they are very expensive. Conventional fungicides may kill bees. Turkeys can be pests in blueberry fields, as they like the ripe berries.

The organic farmers are very willing to implement practices to promote wild pollinators. The larger companies on the barrens probably would be challenged to do so, due to field size; and with no nesting habitat within the field, only the margins are visited by native pollinators.

Amongst the large producers, with considerable effort put into implementing good practices, is the Dawn-Passamaquoddy tribe. The tribe has 1,500 acres of blueberries and owns a blueberry processing company called Northeastern, which provides a substantial income to the tribe that is expected to increase in the future. About 700 tribe members help with the harvest, with around 60 working on weeding throughout the growing season. Pruning of their blueberries is done both by burning and flay-mowing, and a comparative study is being made of the two techniques and the impacts on disease. Diseases and pests are monitored by all who work in the fields, with one person in charge of regulating the pesticides. The tribe leases honeybees from Florida for blueberry pollination and also breeds its own bumblebees, *Bombus impatiens*.

A common theme amongst large and small producers is the high labor costs of blueberry production. Small independent growers generally manage their farm operations themselves, if they can afford the machinery. They also use family members and may hire people from the community to help harvest and process. There is a trend for large commercial growers to buy up the small independent blueberry farms because the small farms aren't profitable.

2.7.5 KNOWLEDGE BASE OF BEST PRACTICES

The Blueberry School at Machias teaches farmers about good farming practices for blueberry production, including managing for pests and pollinators. Participants get a book that is updated as new information becomes available.

Researchers at University of Maine have been carrying out an integrated research agenda to understand sustainable blueberry cultivation. They have worked to identify the pollination requirements of blueberries, and to understand variability in production by clones, and to work out how bee foraging patterns can be encouraged for maximum pollination and yields.

At the University's Blueberry Hill Research Station, researchers are working to define what densities of bumblebee colonies are needed per unit area. They are also working to identify a cash crop that can be interplanted and provide floral resources for the bees. This would be an incentive for both large and small growers to provide bee habitat.

Extension meetings are held at the station and participants are given points towards their pesticide-applicator licenses as an incentive to participate. They are exposed to information on bees and pollinators.

2.7.6 COSTS AND BENEFITS OF BEST PRACTICES

PRACTICE	COSTS	BENEFITS
Encouraging wild flowers on farm; uncut wildflower meadows; wild and escaped garden flowers bordering blueberry fields.	Shade from weedy trees, shrubs and herbs greatly limit flower formation.	Provides as alternative forage, particularly more desirable pollen, to pollinators. Rows of trees on farm act as windbreaks in the barrens, slowing the wind and preventing frost/cold damage in winter.
Leaving woodland habitat patches on farm, or leaving dead trees/down wood as habitat for wild bee nests.	Land not in production.	Good wild bee habitat.
Putting up drilled blocks of wood as nesting sites for leaf cutter bees.	Minimal.	Good diversity of bees, including leaf cutter bees.
Providing overwintering habitat for bumblebees.	Inexpensive; bales of straw may suffice.	Bumblebee hives nornally must be purchased each year at $250 for quads of four hives. If habitat is provided, young queens may survive the winter a build a nest in the soil the next year.
Small field sizes.	Some land not in production; may poses difficulties for mechanized cultivation and harvesting.	Bumblebees pollinate better; where fields are large they tend to disperse from the field.
Reduction of pesticide use; use of less toxic pesticides.	Costs of organic insecticides, burning, cultural controls.	Greater abundance of beneficial insects.
Spraying of pesticides spray at night.	Not possible for large growers, since they cannot complete a single spray in a night.	Avoids immediate contact with pollinators.
More selective forms of weed control/ weeding by hand.	Hand weeding is labour and time intensive.	Greater floral resources can be left for pollinators.

Figure 2.7.E Wildflowers providing additional resrouces to blueberry pollinators

2.7.7 CHALLENGES AND OPPORTUNITIES FOR WIDER ADOPTION

Most of the practices that are pollinator-friendly are ones that small farmers can adopt, but the big commercial growers cannot. For example, methods to avoid harming pollinators are easier for small growers, e.g. they can spray at night, whereas the large growers cannot finish a single spray in one night. Large commercial growers almost always have large fields, with no habitat that brings wild pollinators into the center of the field, causing them to rely almost entirely on rented honeybees. But the small independent blueberry farms are often struggling to survive and are being bought up by these large companies.

2.7.8 REFERENCES

Interviews with six organic or reduced-input blueberry growers; two large mechanized blueberry grower groups in Washington and Hancock Counties, Maine; researchers at University of Maine; the farm manager of the University of Maine, Blueberry Hill Research Station, May 2006.

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Figure 2.8.A. Almond trees in Capay Valley, Yolo County, CA USA

2.8 FRUIT AND NUT CROPS BENEFIT FROM HABITAT CORRIDORS AND EXPLICIT MANAGEMENT PRACTICES, YOLO COUNTY, CALIFORNIA, USA

Barbara Gemmill-Herren,
Food and Agriculture Organization of United Nations

2.8.1 OVERVIEW OF LANDSCAPE AND FARMING SYSTEM

Yolo County, in the Central Valley of California, has long been known for its commodity crops like processing tomatoes, alfalfa, and seed crops. More recently, organic fruits and vegetables, almonds and walnuts are among the top crops grown by family farmers who settled on the land several generations ago. Thousands of Community-Supported Agriculture boxes of food that are prepared each week by local farmers are sold in locations as far as San Francisco, in addition to sales at farmers' markets. Due to this, Yolo County is currently ranked first in the United States in the volume of direct sales from farmers to consumers.

Bound on the west by the Coast Range and its foothills, the county then flattens out into a rich alluvial plain that reaches to the Sacramento River. Along the foothills are many oak woodlands, almond orchards, olive groves, vineyards, free-range cattle operations and the Capay Valley, home to many organic farmers. On the valley floor to the east of the foothills, large farms of tomatoes, walnut trees, grain, rice, and alfalfa fill the landscape. Farming systems vary between conventional and organic. Most organic farms grow multiple crops in small, adjacent fields, use drip or spray irrigation, and tend to let weeds grow around field borders. Conventional farms grow large areas of single crops, practice bare-ground tillage and flood irrigation, and apply pesticides.

2.8.2 POLLINATION OF HORTICULTURAL CROPS: WATERMELON AND SUNFLOWER

Many of the horticultural and nut crops grown in Yolo County - watermelon, melon, heirloom and cherry tomatoes, almonds, sunflower - depend on pollinators for optimal production. Here the specific needs of watermelon and sunflower are considered.

Watermelon *Citrullus lanatus* (Thunb.) Matsum. and Nakai, is one of the species of the family Cucurbitaceae Juss., which is thought to have its origin in Africa. Studies in other regions (Corbet et al. 1997) have shown that flowers are almost exclusively insect pollinated, and that pollinator visitation contributes positively to productivity. Kremen et al. (2002, 2004), working in Yolo County, found that watermelon clearly requires multiple bee visits and deposition of 500 –1000 pollen grains for production of a marketable fruit.

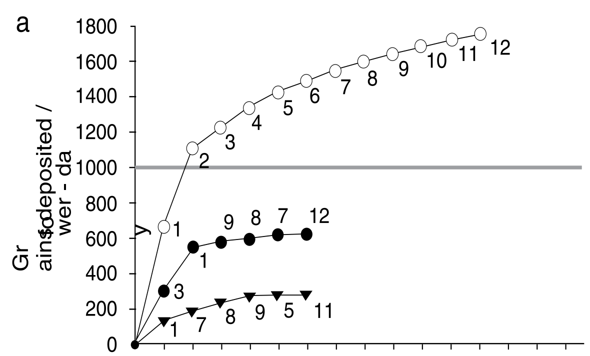
Most cultivars of sunflower *Helianthus annuus* L., are self-incompatible in which case the pollen must come from another plant. When selfing (within the head) occurs, seed setting is usually low (McGregor 1976), the seeds are undersized and the oil content and germination are reduced. Selfed seed also sprout more slowly, and production from them is lower than from plants derived from crossed seed. Thus insect pollination is strongly beneficial to yields and quality of sunflower production. Hybrid sunflower seed production - an economically important industry that supports other agricultural sectors, such as sunflower oil production and confection markets - requires male-fertile cultivars and male-sterile cultivars to be planted next to each other. Animal-mediated pollination is essential for transferring pollen from male to female parents (Free 1993, Schmierer et al. 2004).

2.8.3 POLLINATORS OF HORTICULTURAL CROPS: WATERMELON AND SUNFLOWER

Watermelon: Studies of the pollinators of horticultural crops in Yolo, Solano and Sacramento Counties from 2002-2004 (Kremen et al. 2002 and 2004), recorded the effective pollinators, including looking at the number of pollen grains deposited per visit for watermelon pollinators (Table 1). Comparing pollen deposition to the known crop pollen deposition threshold for watermelon fruit set allows this information to show where the pollination service is sufficient for good crop production. Honey bees were not included in the watermelon analysis since the objective was to evaluate whether wild pollinators could provide sufficient service in the face of threats of pests and diseases to managed honey bee colonies.

TABLE 1: POLLEN GRAINS DEPOSITED PER VISIT (WATERMELON POLLINATORS)

SPECIES OBSERVED	NOTES/OBSERVATIONS
Halictus tripartitus (1).	
Bombus californicus (2).	
Peponapis pruinosa (3).	
Bombus vosnesenskii (4).	
Melissodes lupina, robustior, stearnsi, or *tepida* timberlakei sp. (5).	
Halictus farinosus (6).	
Lasioglossum (Evylaeus) spp. (7)	
Lassioglossum (Dialictus) spp. (8)	
Halictus ligatus (9).	
Lassioglossum mellipes or *titusi (10).*	
Hylaeus rudebeckiae, stevensi, or *conspicuus; (11).*	
Agapostemon texanus (12).	



Note re graph: Cumulative estimated mean pollen deposition per flower for open circles, filled circles, and filled inverted triangles in 2001 on watermelon farms in Yolo, Solano and Sacramento counties, California. The gray line indicates pollen deposition threshold.

The levels of pollination service varied depending upon where farms were situated and how they were managed. For native bees, mean pollen deposition per flower was significantly related to proportion of riparian or upland habitat within 1-2.5 km of the farm site (a spatial scale that accords well with bee foraging distances), and to whether the farm wwas managed organically or conventionally (Figure 2.8.B shows the location and type of management of study locations in the vicinity of Yolo County in the watermelon study).

The study found that the native bee community alone could provide sufficient pollination for watermelon crops. This ability, however, depended on the diversity and abundance of bees in the community. When diversity and abundance declined, as they did with increasing agricultural intensification, the native bee community could no longer provide the needed pollination services without the addition of honey bee colonies. The majority of organically-managed farms that were near to natural habitat obtained sufficient pollination from the native bee community, but far from natural habitat, a much smaller percentage of organically-managed and no conventionally-managed farms received sufficient pollination from natives. These latter farms relied on honey bees for pollination. The estimated levels of pollination services at different distances from natural habitat and under different types of farm management were consistent over years, despite significant changes in the abundances of some species among years. This consistency suggests that in the aggregate, pollination function is more stable than the populations of individual bee species.

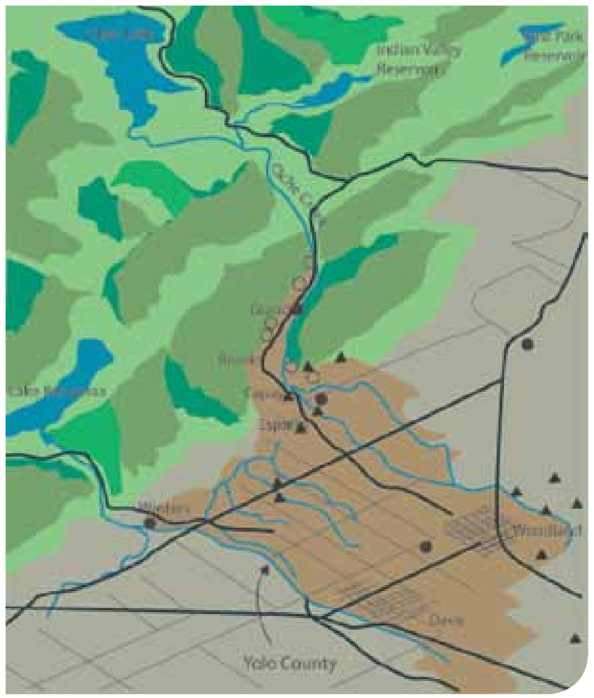


Figure 2.8.B. Organic farms near to wild habitat (open circles), Organic farms far from wild habitat (filled circles), and Conventional farms far from wild habitat (filled inverted triangles) watermelon farms in Yolo, Solano and Sacramento counties, California, included in Kremen study 2002.

Sunflower: Greenleaf and Kremen 2006 determined mean seed set after a single visit of a pollinator to sunflower blossoms in Yolo County (Table 2).

TABLE 2. SUNFLOWER WILD BEE POLLINATORS, YOLO COUNTY

SPECIES OBSERVED	NOTES/OBSERVATIONS
Svastra obliqua **expurgata, females.**	19.1*
Anthophora urbana, Diadasia **spp.,** ***Melissodes*** **spp, females.**	14.5
Melissodes **spp., males.**	5.8
Bombus vosnesenskii**, female.**	2.0
Dialictus **spp. female.**	2.0
Halictus ligatus **and** ***Halictus tripartitus*****, female.**	2.0
Peponapis pruinosa**, male.**	1.3
Halictus ligatus **and** ***Halictus tripartitus*****, male.**	0.5
	*Mean seed set after a single bee visit to a previously unvisited flower head. F, female; M, male.

They also found that behavioral interactions between wild and honey bees increase the pollination efficiency of honey bees on hybrid sunflower up to 5-fold, effectively doubling honey bee pollination services on the average field. These indirect contributions caused by interspecific interactions between wild and honey bees were more than five times more important than the contributions wild bees make to sunflower pollination directly. Both proximity to natural habitat and crop planting practices were significantly correlated with pollination services provided directly and indirectly by wild bees. These results, similarly to those with the watermelon studies, suggested that conserving wild habitat at the landscape scale and altering selected farm management techniques could increase hybrid sunflower production. These findings also demonstrate the economic importance of interspecific interactions for ecosystem services and suggest that protecting wild bee populations can help buffer the human food supply from honey bee shortages.


Sarah Greenleaf

Figure 2.8.C Sunflowers close to wild habitat, Yolo County, CA USA

2.8.4 PROFILE OF BEST PRACTICES FOR CROP POLLINATION MANAGEMENT

Two family farms and farmers in Yolo County were profiled for their exemplary farming practices with respect to pollination. The first of these was Judith Redmond, one of the owners of Full Belly Farm — a large organic farm in Capay Valley that was one of the pioneers of both heirloom tomato production and organic production for farmers' markets in California. The second was the Rominger Brothers farm.

Amongst the beneficial practices of both farms are:

- Judicious application of pest control products, only organic in the case of Full Belly Farm
- No-till or as little tillage as possible, with use of cover crops
- Maintenance of alternative forage within a cropped area
- Management (or rather, no management) of uncultivated land that affects forage and nest site availability — leaving wild and untouched
- Use of hedgerows

And particularly in Full Belly Farm, with heirloom tomatoes and other varieties:

- Crop genetic diversity — although not explicitly used for extending the season for pollinators; the practice was a response to market demands.

Full Belly Farm

Full Belly Farm grows two hectares of almonds for which - unlike most other commercial growers in California - they have always relied on natural pollinators rather than importing honeybee hives. They grow ten hectares of cucurbits, including cucumbers, melons and watermelon, and ten hectares of tomatoes. They are aware of how important pollination is for the watermelon and cucumbers, but have not seen pollination as something they need to manage in the tomatoes. They have promoted pollination services primarily by eliminating toxic chemicals through organic cultivation, and by providing habitat on farm: leaving patches of natural areas undisturbed, and planting hedgerows.

As organic farmers, they utilise only organic compounds to control pests such as garlic or powdered milk. They avoid some of the organic pesticides which nonetheless may be highly toxic to beneficial insects, such as pyrethrum.

Twelve years ago, they undertook to plant hedgerows on their farm. They were encouraged and assisted to do so by a non-governmental organization, California Alliance of Family Farmers (CAFF), working together with a University of California Agricultural Extension project, BIOS (Biologically Integrated Orchard Systems). Together with advisors from CAFF, Full Belly Farm put considerable energy and thought into planning and planting 2000 linear feet of hedgerows so that there would be flowers blooming all year round. The initial objective of the choice of planting material was to provide resources to natural enemies, so as to encourage natural pest control in the farm fields. Additional benefits of providing wind control and shade for people working in the field or taking lunch breaks, were not anticipated but have been highly appreciated. Appreciation of the role of hedgerows in providing resources and habitat for pollinators came much later, but in fact may be one of their greatest benefits.

Hedgerows were initially planted on the borders of the farm only. More recently, Full Belly Farm decided to introduce a hedgerow through the center of the farm, to bring more habitat into the fields. Border hedgerows pose some challenges since room is needed on the edge of fields for farm machinery to turn aorund. Hedgerows running through the center of the field are parallel to rows that tractors are driven along, so that they do not take away space for the tractors.

The role of CAFF was critical to their initial establishment of a hedgerow. CAFF produced a very useful manual on establishing and maintaining hedgerows, and made the necessary connections with native plant nurseries. They worked from a list of plants that had been shown by research to attract and hold natural enemies in farm fields - primarily *Ceanothus* and *Toyon*, both of which grow naturally in the nearby upland habitat - but with many other diverse plants included as well. Without the contacts and advice from CAFF, Fully Belly Farms doubts that many farmers would have been able to understand the benefits of hedgerows, find the planting material and take the initiative to establish them.

After Full Belly Farm served as one of the study sites for the pollination work of Kremen et al., the farmers have come to realise how doubly important all the measures they introduced for natural pest control and other purposes are; they actually contribute substantially to the yields of their horticultural crops through enhancing pollination services.

Rominger Brothers

The Rominger Brothers farm 1,400 hectares on the western edge of Yolo County, California, growing wheat, corn and safflower, sunflowers, rice and grapes as well as tomatoes for processing. The brothers have been local and regional innovators through implementation of a mix of no-till and minimum-till cropping systems, cover cropping, and organic crop production, along with conventional systems. At every opportunity and in any unused field space they install native plant hedgerows, sediment traps and ponds, native grass field borders, and vegetated waterways that benefit their farming operation or the landscape in some way, and also provide habitat for wildlife, including pollinators.

For over four years, they lent their fields and insight to pollination conservation research carried out by Claire Kremen and colleagues on crop pollination. The Romingers quickly understood and appreciated the role of wild native pollination services to their tomato and sunflower fields, and the recommendations from this research to provide pollinator habitat on the farm. These recommendations focused on increasing the diversity of native flowering plants used by crop-pollinating native bees. The Romingers adopted practices to grow these plants on the marginal areas of their farm. As a family, they already appreciated the value of native habitat on field edges and around farm ponds, but with data from the research of Dr. Kremen and others, fine-tuning this habitat for pollinators became an interest.

Figure 2.8.D. Nesting block for wild bees, Yolo County, CA USA

Managing for pollinators fit well into the Rominger Brothers' farming philosophy, based on an appreciation for the natural processes occurring both above-ground and below ground. The Romingers have been pioneers in Yolo County in introducing the new regime of farming operation called conservation tillage; they reduced tractor passages to prevent soils from compacting and to maintain soil biodiversity at optimal levels. Conservation tillage includes the sowing of nitrogen fixing cover crops, which are also good forage plants for bees. Not disturbing the soil has multiple other environmental benefits, as the brothers have understood: a reduction in the amount of carbon released to the atmosphere and the conservation of soil-nesting pollinators. As Dr. Kremen and others working on watermelon pollinators have found, small halictid bees pollinating watermelon often move into fields and nest in the soil adjacent to the crop; not "working" the soil means that these pollinators can complete their generations in place, in a farmer's field - to mutual benefit.

Most recently, the Romingers helped in the creation of a two-mile long pollinator hedgerow on farm land that they lease. The hedgerow is planted with carefully chosen species, based on the native bee research conducted on the Rominger Brothers farm, and includes nest blocks for tunnel-nesting bees, large areas of stable untilled soil for ground-nesting bees, and areas of dense grass plantings for potential nesting by bumble bee colonies. This pollinator project is part of collaboration with the Xerces

Society, Audubon California, UC Berkeley, and the Natural Resource Conservation Service (NRCS) to restore and monitor pollinator habitats on conventional farmland in Yolo County, California.

The Romingers are also generous spokesmen for pollinator conservation, and have been willing to share their knowledge and perspective on pollinator conservation with a wide range of media outlets, from National Geographic to local public television programs. Charlie Rominger provided the Xerces Society with a quote for use in a brochure promoting pollinator conservation in agricultural landscapes that has now been distributed to NRCS offices across all U.S. states and territories. In his own words:

> *"I was surprised to learn how native pollinators can make honey bees much more effective at pollinating our sunflowers. As we continue working to increase biodiversity on our farm, we'll be adding features to help the wild bees."*
> -- Charlie Rominger

2.8.5 KNOWLEDGE BASE OF BEST PRACTICES

Judith Redmond of Full Belly Farm came originally from the United Kingdom, and was aware of the traditional practices of maintaining hedgerows in the English countryside, when farming was less intensive. That knowledge, combined with research coming from University of California on the role of hedgerows in natural pest control, gave the farm sufficient information to convince them to introduce hedgerows. The farmers in Capay Valley benefit considerably from research, which they follow closely through such publications as "California Agriculture". Extension agents, by contrast, are overextended and often not well acquainted with the diverse problems faced by small scale organic and horticultural farmers, and are less a source of information than agricultural researchers.

The Romingers have long been active in supporting agricultural research and agricultural innovation throughout the State of California, and the United States. All the brothers studied agriculture or agricultural engineering at the University of California, and stay well informed of new developments in agricultural research and extension. Charlie Rominger was particularly interested in applying the concepts of Allan Savory and Holistic Resource Management to their farm management.

2.8.6 COSTS AND BENEFITS OF BEST PRACTICES

Full Belly Farm spent around US$1000 twelve years ago to buy planting material and establish hedgerows. In addition, there have been considerable maintenance costs to establish the hedgerows. For the first three years, it was necessary to carry out considerable irrigation and weeding to ensure that the hedgerows were well established; these investments have slowly tapered off over time. Full Belly Farm is convinced that introducing this new element of diversity on-farm has had multiple benefits, both for pollination and for pest control. Full Belly Farm is also convinced that their hedgerows also contribute substantially to reduce soil erosion. In the future, this may have direct economic benefits: new regulations require that all Californian farmers pay into a fund for the testing of water quality sediment levels. While this is presently only at a testing phase, the intention is that fines may be levied on landowners with runoff contributing above certain levels to sediment loads.

PRACTICE	COSTS	BENEFITS
Judicious application of pest control products.	May involve some loss of food crops to pests; organic products are often more costly.	Allows natural enemies of pests to flourish, less risk of contamination of food; price premiums for organic produce.
Conservation tillage or reduced tillage.	Costs of cover crops.	Allows establishment of ground-cover which reduces erosion and enriches the soil, keeps high density of pollinator forage plants in fields.
Maintenance of alternative forage within a cropped area.	Space might be used for crops.	Keeps high density of pollinator forage plants in fields.
Conservation of uncultivated land that affects forage and nest site availability- leaving wild and untouched.	None.	Provides resources to pollinators.
Use of hedgerows.	Space might be used for crops.	Allows natural enemies of pests to flourish, provids resources to pollinators, curbs soil erosion.
Crop genetic diversity	Different harvest times, input needs need to be tailored to diverse varieties.	Longer season of resources for pollinators, diversity in varieties for sale, premium prices for heirloom varieties.

2.8.7 CHALLENGES AND OPPORTUNITIES FOR WIDER ADOPTION

The two featured farms show that it is possible to incorporate conservation-based land management practices into successful organic and large-scale farming operations. As such they have inspired many other growers in their area to plant hedgerows, use conservation agriculture and plant marginal areas with native plants. Both farms have readily shared their knowledge, working with the media and giving presentations.

The support and participation of both farms for research into the native pollinators that work their fields has also had a wide-ranging impact. This research demonstrated that native bees play a very beneficial role in the pollination of tomatoes, sunflowers and other crops, when the habitat needs of these pollinators are met close to fields. As a result, the Xerces Society was able to build upon this research in collaboration with Dr. Kremen, Audubon California, the Center for Land-Based Learning, and the Natural Resource Conservation Service to implement a growing agricultural pollinator conservation program in the Yolo County area and beyond. The NRCS has funded a large project to implement pollinator conservation measures, based on this research.

The habitat restoration project recognises that the valleys near existing upland areas currently enjoy the benefits of the pollination services that upland habitats provide, while farms in the Central Valley, in contrast, are almost universally far from natural habitat. Here active restoration with native plants on and off farms, such as hedgerow plantings, or larger-scale restoration, may be required to enhance the level and stability of services provided by native bee populations. The agricultural landscape, even in the flat areas of the valley far from hills, offers two elements that the restoration projects are seeking to use to better link natural habitats: rural roads and irrigation channels. Hedgerow Farms, near Winters in Yolo County, has been working with the county to promote management of natural vegetation on rural roadsides, promoting habitat for birds and insects such as pollinators. These same restoration efforts are now being applied to the banks along sloughs and irrigation canals. Revegetation along these two landscape elements could effectively extend natural habitat into a mesh throughout the county, securing effective levels of pollination services throughout the county.

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Figure 2.8.AE. Newly established hedgerow in intensively cultivated area, Yolo County, CA USA

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Figure 2.9.A. A wild bee (Eulaema) visiting a lulo flower

Initial Survey of Good Pollination Practices

PROFILES OF BEST PRACTICES FROM AROUND THE WORLD

SOUTH AMERICA


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2.9 MANAGEMENT AND CONSERVATION OF WILD BEES FOR POLLINATION OF LULO AND OTHER CROPS BY A COMMUNITY IN THE COLOMBIAN ANDES

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2.9.1 THE CROPPING SYSTEM, LOCATION

The location Bellavista of El Dovio municipality is situated at the northwest of the Cauca Valley Province in Colombia (4°31'N-76° 10'W). It is located at 1750m altitude on the west slope of the Western range of the Colombian Andes. The climate is influenced by the slope facing the Pacific Ocean resulting in high relative humidity (85%) and an average temperature of 18°C. The area has a rainfall of over 1400 mm distributed in a bimodal pattern.

The landscape is characterised by forest remnants, protected areas, and areas modified by human activity. The community is engaged in farming and livestock production in small farms with an average size of 4.7ha (0.15 to 12ha). The farms have small forest remnants, fodder banks, pastures and diversified crops.

The inhabitants of Bellavista, like the majority of the population in the northern part of the Cauca Valley Province, are basically immigrants from the coffee-growing zone, with influence from immigrants from other regions - for instance, families displaced by the civil war in the mid 20th century. Currently 30 families live in the settlement, many of them related.

Human activity has led to changes in the landscape. In the 1950s a large extent of the forest was cut down to make land available for pastures and for production of coffee and crops for home consumption. In the 1970s the landscape was dominated by monocultures of tree tomato and sun coffee, both cash crops, grown with the technology promoted by the green revolution. These produced an initial income boom for the community, but in the long term affected the stability of the ecosystem, threatening natural resources, and economic, social, and food security. Changes in the landscape were reflected in changes in the microclimate, reduction of rainfall and the volume of water in rivers, and in erosion. This was aggravated by water contamination due to agricultural activities. At the beginning of the 1980s anthracnose wiped out tree tomato production. These drawbacks, in particular the water shortage, forced some growers to a change of strategy in the management of natural resources. Shade coffee and a diversity of crops for home consumption (garden crops) were taken up again; the area for livestock was expanded with the introduction of improved pastures.

In the late 1980s, Tiberio Giraldo took the lead to change his production system to a more sustainable form of agriculture on his farm "El Cipres". With support of institutions promoting sustainable agriculture, such as the Center for Research on Sustainable Systems of Agricultural Production (CIPAV in Spanish), the farm went through a process of conversion to sustainable farming. A programme of production diversification and agroforestry was started. This included growing fodder plants and multipurpose trees for the livestock, which allowed the reduction of the area under pasture, facilitating crop and livestock diversification. Animal wastes were used for production of biofertilisers (with assistance of earthworms) and renewable energy, such as biogas. Wastewater was recycled using a biological decontamination system with aquatic plants.


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Figure 2.9. B View of the landscape in Bellavista (left) and the farm "El Vergel" (right)

The farm "El Cipres" is nowadays a private natural reserve affiliated to the Private Reserves Network, which supports the management of a grouping of reserves owned and managed by the people for their own benefit and that of the environment. The network supports and encourages forest reserves on private land, not only to protect important ecosystems, but also to form corridors to link and complement Colombia's existing national parks. "El Cipres" has a learning centre and receives 1500 visitors every year.

Over time, other families of the community have followed this approach and have taken up some of the technologies. The community is actively engaged in activities related to production, education, culture and conservation of natural resources. Groups have been formed, notably the farmers association CAMPAB ("Corporacion No-Nacional Ambiental, Pecuaria y Agricola"), the women group "Amigas del buen sabor" and "Herederos del Planeta" (Inheritors of the Planet). The latter is a children and youth group, which is part of a larger organization set up by the network of private natural reserves. These young environmental activists motivate and train young people to become environmentally conscious.

Amongst the issues faced by the community has been the need to enhance the capacity of the land to serve as a watershed. The community addressed the water shortage by promoting the recovery of the watersheds. Biological corridors to protect water springs and the watershed of the mountain stream "Los Sainos", which provides the water for the community, were re-established through planting of native trees and allowing natural reforestation. Thus, in 1993 a reforestation process was started. For this purpose the community purchased open grassland. The community members shared the workload of planting and taking care of the plants. To date 14 ha have been reforested. During the water crisis, the water was not enough to supply 19 families. Now enough water is available for 42 families in two settlements. Currently half of the 30 families living in Bellavista are participating in the programme.

Some farms have been practicing organic farming since 1993 and others are in the process of conversion to organic production. However, the community is facing constraints such as the high costs of certification and the lack of price incentives for organic produce. For this profile, two community members who are actively conserving and using wild pollinators in their farm production systems were interviewed.

The first case was farm "El Vergel", a 5 ha farm, which has two hectares in pasture and the remaining in use for the production of green fodder in an agroforestry system of two cash crops: "arracacha" *(Arracacia xanthorrhiza)* and coffee. Sugar cane and fodder trees such as *Trichantera gigantea, Nocacia macrorhiza, Tithonia diversifolia,* and *Bohemeria nivea,* among others, are grown to feed livestock. Shade coffee (3500 plants) is kept mainly as a traditional crop. The coffee plants have been intercropped with pineapple, bananas, other crops and canopy trees such as *Cordia alliodora*, and *Montanoa quadrangularis* (locally known as arboloco). The farm has 10 heads of cattle and 15 pigs. Due to the small size of the farm the animals are kept in stables and fed with a mixture of fodder plants, produced on the farm, and concentrate (50%-50%). Animal waste is used for production of biogas and for production of compost with help of earthworms (lombricompost). The wastewater is decontaminated in canals and ponds with plants such as salvinia (water fern) and water hyacinth.

A neighbouring farm "El Oasis" is 8.5 ha in size, and has been farmed by the current owner for 20 years. Initially the land was farmed in the conventional way, using synthetic pesticides. According to the farmer twelve years ago production problems led to a change in the system of management. As the community and individuals started to be more conscious about the environment, the farm began the process of conversion to organic farming. The owner, Gilberto Giraldo Sanchez, has been participating in communal programmes on crop management, organic production, forest conservation, and fauna reestablishment. The farmer grows strawberries, beans, maize, "arracacha" and "lulo" *(Solanum quitoense)*. He keeps trees and other native plants among crops, and along the borders to provide a biological corridor. At the time of our visit he had one hectare in lulo (1400 plants) in different growth stages. "Lulo", also known as "naranjilla", is among the most popular fruits in the Northern Andes. The fruit is rich in vitamins, proteins and minerals. It is used to make juices, ice cream, jellies, jams and other preserves. It is an important market crop for small-scale producers.

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Figure 2.9. C Plant of "lulo" or "naranjilla"

2.9.2 POLLINATION OF CROP

Lulo *(Solanum quitoense)* is a perennial, herbaceous shrub 1-1.5 m high, with stout, spreading, brittle stems and large leaves. The pale-lilac flowers, borne in clusters, are covered with a thick "felt" of light purple hairs. The fruit is spherical, is 3-8 cm in diameter and when ripe yellow-orange in colour. It has a leathery skin densely covered with fine, brittle and easily removable white to brown hairs. The flesh is translucent yellow / green in colour with an acidic flavour.

The dependence of lulo on pollinators for fruit set is not clear. However, the structure of its reproductive system strongly suggests the necessity of a pollinator to transport pollen within flowers. In addition, it has been demonstrated that pollination by bumblebees increases fruit formation significantly. Lulo needs specialized pollinators with buzzing behaviour that are able to shake the flower so that pollen is released by vibration from anthers through pores. Pollinators of lulo identified in Bellavista include a number of wild bee groups, in table 2.9.3.

2.9.3 CROP POLLINATORS

INSECTS OBSERVED VISITING CROPS

SPECIES OBSERVED	NOTES/OBSERVATIONS/SITES WHERE PRESENT
Bees, *Hymenoptera.*	
Honeybee, *Apis mellifera.*	Compete with effective pollinators of coffee and lulo, in Bellavista.
Stingless bee, *Paratrigona.*	Pollinator of coffee in Bellavista.
Stingless bee, *Plebeia.*	Pollinator of coffee in Bellavista.
Stingless bee, *Partamona.*	Pollinator of coffee in Bellavista.
Orchid bee, *Eulaema sp.*	Pollinator of lulo in Bellavista.
Carpenter bee, *Xylocopa sp.*	Pollinator of lulo in Bellavista.
Eucerine bee, *Thygater sp.*	Pollinator of lulo in Bellavista.
Halictid bee, *Augorcholoropsis sp.*	Pollinator of lulo in Bellavista.
Bumble bee, *Bombus sp.*	Recognised pollinator of lulo in research carried out at Universidad Nueva Granada in Bogotá (Colombia).

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Figure 2. 9. D Gilberto Giraldo in his farm “El Oasis”.

2.9.4 PROFILE OF BEST PRACTICES FOR CROP POLLINATION MANAGEMENT

The owner of the farm “El Oasis”, Gilberto Giraldo Sanchez, is aware of the importance of keeping trees and other plants around and between crops and about the importance of keeping biological corridors for the native fauna and flora, to protect the watersheds and for providing nesting sites and alternative food to pollinators. He is also aware of the importance of pollinators. In his lulo field, he has left the trellises that supported the previous crop (granadilla) between the lulo plants. The old trellises serve as nesting sites for wild bee pollinators of lulo such as *Eulaema*.

Gilberto Giraldo practices sound crop management. His rotation system includes strawberries, beans (twice), maize, “arracacha” and “lulo”. Pests and diseases are managed through regular monitoring and use of biological pesticides or mechanical methods. Thus, he uses biological pesticides such as *Bacillus thuringiensis* for control of fruit borers, *Metharizium* for control of white grubs, and *Trichoderma* for control of Anthracnose and Fusarium. Foliage beetles are controlled manually with the help of a tin. Garlic, red onions and chillies are used for general pest control management: He uses preventive treatments with Bordeaux mixture and “Caldo Visosa” for management of diseases.

Wild bees nest in cliff overhangs, in the soil, on balks, on beams, and other structures around the house, and in trellises in the field. Bees nesting in the cliffs and in the soil are protected during cultivation. A 14 year old colony of *Partamona gr. testacea* has been nesting in a cavity on an overhang of a cliff bordering the lulo field.

Activities directed at conserving pollinators are not restricted to a farm or to a crop, but they are part of the agricultural practices in the community. Thus, Julian Giraldo

- the 25 year old son of the owners of the farm “El Vergel”, the farm neighbouring “El Oasis” - is actively involved in managing and conserving pollinators. He is very knowledgeable about the importance of pollinators and in particular about stingless wild bees. He is able to identify five species of social stingless bees and several solitary species, and is familiar with their nesting and foraging habits. He keeps

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Figure 2. 9. E Nests of solitary bees in roof beams and structures provided for nesting.

Figure 2. 9. F Lulo field in “El Oasis”. Note trellises and surrounding vegetation.

Figure 2. 9. G Nest of wild bee *Eulaema* in a trellis in a lulo field.

and monitors colonies of wild stingless bees (e.g. *Paratrigona rinconi, Plebeia sp, Scaptotrigona)* in the farm and its surroundings. Some are in their natural nests (on trees) and some in man-made nesting boxes. Some of the colonies were rescued by Julian when the plants/ trees in which they were nesting were burned or cut down.

Julian keeps flowering plants as a source of food for the bees, and there are numerous nesting sites for wild bees and wasps around the farm's house – in the roofs or in hollow logs on the farm. Julian is aware of the importance of plant diversification (cultivated and wild plants) as sources of refuge and food to bees. He says this is particularly important for coffee, since the sources of food provided by the crop are limited to the short flowering period. Thus, he cites "Arboloco" as being good for reforestation, a good source of timber, as well as being very good for bees. Coffee is pollinated by *Apis mellifera,* but several species of

Figure 2. 9. H Julian Giraldo and colonies of the wild bees *Plebeia* sp. in his farm "El Vergel"

Figure 2. 9. I Colonies of *Paratrigona rinconi,* rescued from coffee.

Figure 2.9.J Colony of *Scaptotrigona* rescued from a "guamo" tree (*Inga* sp.) before it was burned.

Figure 2. 9. K Shade coffee in a mixed cropping system in "El Vergel".

wild bees have been recorded visiting coffee in Bellavista (e.g. *Paratrigona, Plebeia, Partamona* - the first two being the same stingless bees that Julian keeps). Julian keeps these stingless bees for his own benefit and for the benefit of neighbouring farms. This is particularly important due to the small size of the farms and to the mobile behaviour of the pollinators. He has also occasionally sold wild bee colonies to farmers growing sweet granadilla *(Passiflora ligularis)*.

In summary, the following activities in the community contribute to wild bees conservation:

- Activities directed to conservation of pollinators:
- Rescue of colonies nesting on plants / trees which have been felled or burned, and transfer to hives on the farms.
- Avoiding interference with nests of bees on the farms and in the forest.
- Provision of nesting sites around the fields, such as sticks, stems and structures around houses.
- Conservation of nesting sites within cropped areas: for instance conservation of trellises in the lulo plantation and avoiding disturbance of soil nesting bees during cultivation.
- Provision of food sources through conservation and planting of plants and trees.
- Management of wild bees. Honey of wild bees is said to be very good for curing ailments and many colonies are destroyed in the process of honey collection.

Rationalising their management helps in their conservation.

- Activities and practices that although not targeting pollinator conservation have an important role on their conservation:
- Creating/conserving a diverse cropping pattern in the farms. For instance mixed cropping, kitchen gardens and agroforestry systems.
- Keeping biological corridors.
- Organic agriculture; minimising use of toxic agrochemicals.
- Conservation of hedgerows and of trees around and in the fields.
- Rehabilitation of landscapes; for instance the reforestation of the area to protect the watershed of the stream "Los Sainos".
- Conversion of livestock production from a traditional pasture-based system to a confined / semi-confined system allowing the conversion of areas for cattle grazing to fodder banks. This has helped to avoid / revert erosion, and has contributed to an increase in plant diversity and in diversity and number of livestock.
- Conservation of forest remnants.

2.9.5 KNOWLEDGE BASE OF BEST PRACTICES

The concept of sustainable use of natural resources and the necessary technologies were developed by the community with support of several institutions working in sustainable agriculture and management of natural resources. Members of the farmers group (CAMPAB) and of the youth group "Herederos del Planeta" have participated in programmes of crop and livestock diversification, conservation and rehabilitation of watersheds through reforestation and forest conservation. Some of them are associated researchers in these institutions.

Creating community awareness about pollinators was one of the outcomes of a study conducted in Bellavista from May to August 2002. The study was carried out by Juan Manuel Rosso, as thesis work for a degree in Animal Sciences at the "Universidad Nacional de Colombia".

The study sought to identify pollinators, in particular wild pollinators, in a diversity of agro-ecosystems (with varying levels of disturbance), and to study their biology, diversity, habitats, abundance and their importance. This was done through work with community groups (children and adults). Two members of the youth group "Herederos del Planeta" participated as co-researchers throughout the study. Workshops, participatory activities such as puppet shows, etc. were organised to create awareness about the importance of conservation and the use of wild bees not only for honey production but because of their role in pollination of wild and cultivated plants. Techniques for managing stingless bees (meliponiculture) were introduced.

At the time of these activities, the community had an existing appreciation of the importance of wild bees as pollinators; for example, some members of the community maintained stingless bees for their appeal or for honey production. With the study community members were made aware of the role of the components of the agro-ecosystems and their interaction on the conservation of bees. Aspects covered included the importance of wild and cultivated plants as sources of nesting sites, shelter and food for bees, and the dependence of pollinator conservation on the cultural practices and management of the different agro-ecosystems. They came to understand that plants outside of the crop may be important as sources of food and nesting for pollinators. The importance of knowing the bee-plant relationships was evident in instances where some bees visiting crops were not always pollinators. Some are opportunistic and in some cases their effect undesirable since they competed with the real pollinators for access to the flowers. Such was the case of the stingless bee *Paratrigona* in lulo and *Apis mellifera* in granadilla. However, these bees are important for honey production or as pollinators of other crops. Some wild bees can be harmful to crops, for instance *Trigona amalthea* that destroys the flowers of granadilla. The community learned that *Apis mellifera* is not the only bee that can be economically exploited and that this bee is not necessarily the best pollinator for all crops.

2.9.6 COSTS AND BENEFITS OF BEST PRACTICES

Farmers in the community have not received direct compensation for the sustainable use of natural resources (as has been popularised by the concept of "payments for ecosystem services"). The technologies adopted are often labour intensive, so the benefits must exceed the time and cost of their efforts. Indeed, community members acknowledge that their economy has improved due to diversification in production and increased productivity.

Production diversification of crops and livestock gives a number of economic and social benefits to the community; it:

- reduces risk by avoiding dependence on a single crop or economic activity, giving the community flexibility to react to market fluctuations,
- contributes to job security throughout the year, since in the coffee growing areas farmers are usually forced to look for other jobs during the no-harvesting period, and
- improves the nutrition of the community.

Agroforestry and crop diversification also provide environmental benefits, and make use of biodiversity components that provide services such as pollinators, natural enemies, and soil organisms. The conservation of forests and conservation/creation of biological corridors and of natural reserves reduces land available for farming, but is very important for conservation of watersheds. The adoption of confined or semi-confined livestock production systems, although labour intensive, reduces the need to clear forest and allows the conversion of areas under pastures to biologically diverse yet commercially profitable lands used for production of fodder, increasing the number and diversity of livestock.

The community had to buy land for reforestation of degraded land and invest money, time and labour, but this was compensated by reliable water supply as a result of the protection of the watersheds.

Organic farming reduces the effects of agrochemicals on the environment and biodiversity that provide services such as natural enemies and pollinators. However, it is labour intensive and in Bellavista there is no economic compensation or price incentives for organic products. Thus, Gilberto Giraldo said that while he had no problems with conservation of pollinators by conserving nesting sites and plants as source of shelter and food, he experienced no market incentive. His organically produced crops reaped the same price as conventional produce, and did not benefit from any preferential market links. The farmer sells his organic produce himself house to house, to consumers who are not aware or do not care about the benefits of buying organic produce. Due to these constraints he is giving up strawberries, but he will continue with lulo and other crops. Another constraint is the high cost of certification.

Managing stingless bees has required that farmers provide or conserve sources of shelter and food. Proactively, some farmers rescue colonies nesting on plants or trees which have been felled and transfer the colonies to hives on the farms. This

brings environmental and economic benefits by the pollination services and honey provided by the bees.

2.9.7 CHALLENGES AND OPPORTUNITIES FOR WIDER ADOPTION

The conservation of pollinators and pollination services was initially an indirect

PRACTICE	COSTS	BENEFITS
Rescue of threatened wild bee colonies.	Time spent could be used for other farming activities.	Rescued colonies may provide honey and contribute to plant pollination.
Avoiding interference with nests of bees in the farms and in the forest.	None identified.	Contribution of bees to pollination.
Provision of nesting sites in and around the fields.	Structures in field (e.g. trellises) may hamper cultivation. Nests may cause some damage to house structures.	Ensure presence of pollinators and some other beneficials like predatory wasps near the crops.
Provision/conservation of food sources and nesting sites through conservation and planting of plants and trees, keeping corridors of vegetation, mantaining forest remnants, reforestation.	Less land available for cultivation.	Promotes connectivity and allows movement of pollinators and other organisms to reach nectar and pollen sources. Avoids soil erosion, protects watersheds.
Creating/conserving a diverse cropping pattern in the farms. For instance mixed cropping, kitchen gardens and agroforestry systems.	Requires knowledge of multiple crops.	Diversified income from land.
Rationalising management of wild bee colonies (avoiding destruction of colonies in the process of honey collection).	Time spent on training, and construction and maintenance of hives.	Colonies are not destroyed, and bees continue providing services such as honey and pollination.
Organic agriculture. Minimise use of toxic agrochemicals.	More time needed for monitoring pests and diseases, pesticides allowed in organic farming may be more expensive than conventional pesticides, Compete with conventional produce, which are easier to produce.	Less risks of contamination, less exposure to toxic pesticides, allows natural enemies to thrive, makes use of services provided by natural enemies and pollinators.
Conversion of livestock production from a traditional pasture-based system to a confined / semi-confined system.	More labour intensive.	Allowes the conversion of areas for cattle grazing to fodder banks, contributing to landscape diversification; helps to avoid / revert erosion, and contributes to an increase in plant diversity and in diversity and number of livestock.

result of practices and approaches developed to address problems derived from injudicious use of natural resources. Good examples are the water shortage as a result of conversion of forest to open land for farming, and the unsustainable management of crops grown as monocultures with high use of external inputs. These challenges led to the creation of an environmental conscience in the community, which made them a much sought-after partner for institutions promoting rational use of natural resources, eco-agriculture and sustainable production systems using local agrobiodiversity. Members of the community have also been active partners in the implementation of a number of research projects on sustainable systems for agriculture and livestock production, biology and ecology, and in the adaptation and adoption of results. This has generated a wealth of knowledge and has brought about social, economic and environmental benefits for the community. This exposure and the experiences gained facilitated the knowledge-uptake by the community on the importance of wild bees not only as a source of honey, but also as pollinators, and the need to conserve them.

The active participation of the community and the integration of youth into research were crucial for the adoption of the concepts on the importance of wild bees and the need to conserve wild pollinators. It gave them ownership.

Four years after the study on pollinators was conducted members of the community interviewed were aware of the importance of wild bees as pollinators. Thanks to the youth initiative conservation and use of wild bees has been incorporated in the management of family farms. Some of the youths are actively conserving wild bees, even in cases where the crops they are cultivating in their farms do not depend on wild pollinators. This is particularly important due to the small size of the farms.

Teamwork also allowed building on indigenous knowledge. According to Juan Manuel Rosso, community participation in the study on pollinators was very important for the accomplishment of the study. They contributed with their knowledge based on their experiences (vernacular names, nesting sites, plants visited, foraging behaviour). In turn the community appreciated the value of wild bees not only as a source of honey, but also as service providers through pollination, and as important components of agro-ecosystems.

Young people play a key role in the development of their communities. Children and youth possess great capacity to assimilate technologies and are open to try new things. Their direct participation in research and implementation gives them confidence, since they see that the results of their work are important for their communities.

The study on pollinators was a first step in assessing the potential for conserving pollination services as part of a strategy for use and conservation of agrobiodiversity. Looking into the diversity and abundance of wild bees in diverse agro-ecosystems (with varying levels of habitat disturbance), and the study on wild bee/ plant relationship and crop associated pollinators contributed to the assessment of the status of pollinator diversity and to identifying the appropriate management of cropping system to support effective pollination. However, to get an insight into the trends of pollinators more long term studies/observations are needed. In this context, continuous observations by members of the community while working with wild bees are likely to make valuable contributions to assess the status and trends of pollinators. Any programme/project directed to assess these issues should take into account members of the community. This is happening in other fields. Thus, some youth of Bellavista are working or have worked as associated researchers in different projects.

The active participation of the community contributed to the creation of awareness and to strengthening their capacity to manage agrobiodiversity, including pollinators. The participation of youths as co-researchers built capacity in pollinator management conservation.

This profile also shows how adaptive research allowed the community to react to challenges resulting from irrational use of natural resources. Rational use of land and other natural resources e.g. environment friendly management practices in agricultural production, crop diversification, retention of natural areas, wastewater management and rehabilitation of degraded land using local trees and plants, brought the community social, environmental and economic benefits. Although not directly targeting pollinators these practices are likely to have contributed to the conservation of biodiversity components that provide services to the ecosystem such as natural enemies and pollinators. The high diversity of wild bees identified in Bellavista during the short period of the study on pollinators is an indication of this.

LESSONS LEARNED

Dissemination and recognition of the work carried out by the community and the benefits to the environment and the society is important to encourage continuity and adoption of this approach. Some of the farms in Bellavista have been awarded prizes as recognition for their ecological work. The study on pollinators by Juan Manuel Rosso received an award in recognition for the work he has done with the community to create awareness on pollinators. This was published in a popular newspaper in Colombia.

The existence of a training centre in the community has facilitated the dissemination of knowledge on sustainable management of natural resources. The community is regularly visited by farmers, indigenous communities, technical staff, and professionals from other parts of the country and abroad. The importance of pollinators is one of the topics presented by the group "Herederos del Planeta" to visitors. Some members of the community have had the opportunity to see their experiences with sustainable management of natural resources adopted by other farmers when visiting other regions.

The adoption of some practices benefiting pollinators could be jeopardised by the lack of support. For instance, farmers growing organic products face serious constraints such as a lack of market linkages, no price incentives, and high certification costs. In addition, many consumers are not aware about the benefits of buying organic crops. This makes it difficult for them to compete with conventional producers. Thus, one of the farmers has given up granadilla and is not going to continue growing strawberries.

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Farm evaluation of jujube pollination in Lao

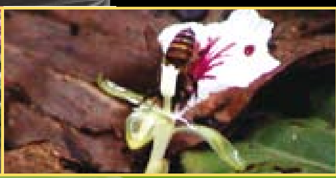
3. CONCLUSION

The profiles included in this initial survey demonstrate the broad range of measures that farmers and communities can and are using that are beneficial to pollinators. The profiles also highlight areas needing more attention. In many case studies, there exists some - in individual cases even detailed - knowledge about the biology and ecology of crops and their related pollinators, although this knowledge is not always available to the farmers. In a few cases the awareness about the value of pollinators was a result of the initative, and observations, of the farmers, whereas in others the community has been explosed to training on sustainable use of resources, or the role of pollinators in particular. The translation of awareness to specific policy measures that can scale up the practices is another area needing further attention.

This initial compilation of profiles is a first step in a process. Partners in the Global Pollination Project will continue to document good practices through additional profiles, and submissions from others involved in managing pollination services are encouraged.

Beyond the value of sharing experiences, these profiles can help to develop a means of evaluating practices for their impacts on pollinators, and their relative costs and benefits to farmers. The value of these practices must withstand the test of providing sufficient benefits in terms of income and food security - for the time, effort and costs of implementing them - to farmers and land managers. An analysis of the practices, indicator values and outcomes compiled through the survey and case study contributions will be forthcoming to identify sound indicators for evaluation of pollinator-friendly practices.

FAO has coordinated this initial survey of good practices to conserve and manage wild pollination services, in collaboration with the International Centre of Insect Physiology and Ecology (ICIPE) in Nairobi, Kenya. Profiles of nine pollinator-dependent cropping systems from around the world have been compiled. The profiles provide detailed information on the impacts of specific practices on pollination services and the research or traditional systems supporting these practices, their socio-economic aspects, environmental costs, benefits and replicability. People interested in learning how to manage pollination services will find these profiles informative, as they explain practical applications of good practices in on-the-ground settings.


GLOBAL ACTION ON **POLLINATION SERVICES**
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