POLLINATION SERVICES FOR SUSTAINABLE AGRICULTURE

- EXTENSION OF KNOWLEDGE BASE
- ADAPTIVE MANAGEMENT
- CAPACITY BUILDING
- MAINSTREAMING

RAPID ASSESSMENT OF POLLINATORS' STATUS

A CONTRIBUTION TO THE INTERNATIONAL INITIATIVE FOR THE CONSERVATION AND SUSTAINABLE USE OF POLLINATORS

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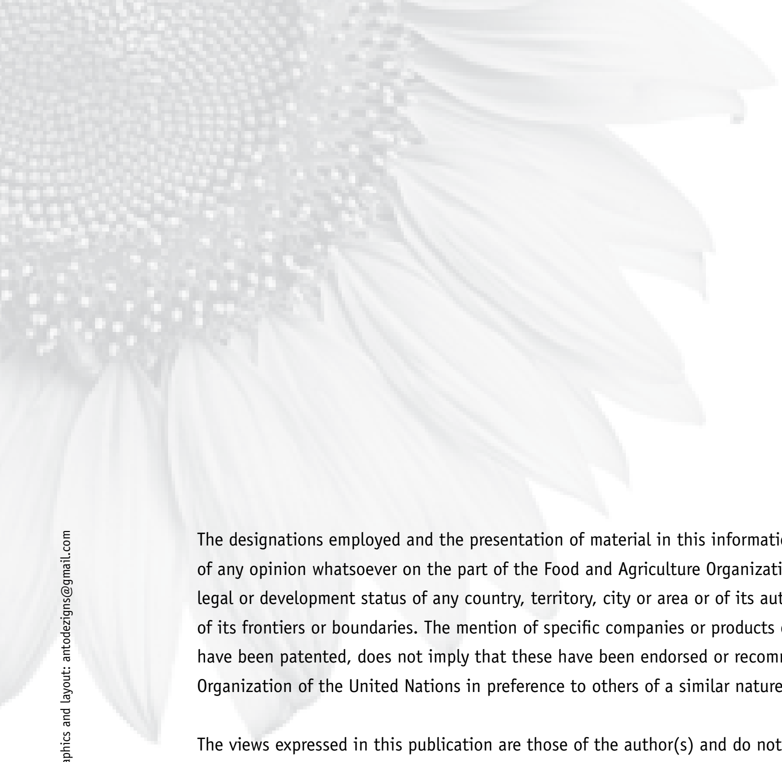
GLOBAL ACTION ON POLLINATION SERVICES
FOR SUSTAINABLE AGRICULTURE



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EXECUTIVE SUMMARY

Every continent has reports of pollinator declines in at least one region/ country. The losses of pollination services have been well documented in many specific instances; what remains lacking are global assessments of changes in the distribution and levels of pollination services. As the recognized drivers of pollinator losses (changing land-use patterns, pesticide use, diseases, invasive species and climate change) are themselves changing in intensity, the global community is justified in taking note and determining the actions that will conserve pollinators. The insidious nature of the loss of ecosystem services- by slow erosion rather than cataclysmic events- demands careful monitoring.

Pollinators provide essential services to humans. In several instances, impressive documentation of the market and non-market values derived from pollination services has been made. Despite this, the economic valuation of pollination services has a number of challenges to overcome, many stemming from the gaps in understanding of the actual contribution of pollination to crop production.

Developing sound management plans for pollinators will hinge on good taxonomic support. Linked to the taxonomic information about species is other information on biological characteristics (including floral relationships and ecological linkages) that are important for adaptive management. New approaches to managing pollinator information should help to overcome the taxonomic impediment, although the focus at present has been on bees, and not on other key pollinator groups.

The ecology of pollination services reinforces the need for an ecosystem approach. Pollinator communities have an inherent robustness in that many species often serve as pollinators to specific plants, each with somewhat different effectiveness or responses to environmental change. However, the loss of particular pollinator species then reduces the resilience of the ecosystem to change. The conservation and, where appropriate, restoration of interactions and processes such as pollination is of greater significance for the long-term maintenance of biological diversity than simply protection of species.

Indigenous knowledge of pollination is quite variable; knowledge often resides with particular individuals with strong or innate understanding of natural history. The understanding of pollinator behaviour needs are reinforced when pollinators live in close proximity to people. Indigenous knowledge of honey-producing bees has a long and rich tradition.

The role of pollination as an agricultural input- along with other inputs such as water, nutrients and pest control - is gaining in recognition. Increases in yields are being documented even in crops where pollination was previously not considered important, such as coffee. Some practices that promote pollination services include conservation of patches of wild habitat- such as forests or structurally diverse grasslands- in agricultural landscapes. Often, pollinator-friendly practices will lead farmers and land managers to think (and then to manage) on a landscape scale, as pollinators can range over several kilometers. Pro-pollinator practices that seek to reduce and rationalize the use of agricultural chemicals can build on existing good practices for plant protection, and may contribute to win-win solutions for farmers and consumers. Good pollination practices have an important role to play in maintaining genetic diversity. All of these need greater examination and documentation in a large diversity of farming systems.

There is a paucity of attention to pollination services at all levels of formal and informal education. Nonetheless, a number of initiatives have developed innovative approaches and curriculum materials, which can be used as a basis for scaling-up the building of capacity to manage pollination services.

Mainstreaming pollinator conservation and sustainable use into public policy requires the efforts of a diverse set of actors, from government agencies, intergovernmental organizations and civil society. Initiatives and efforts have been initiated on several levels. However, concrete and explicit policy approaches to conserve and better manage pollination services have not been well articulated in most countries or regions. Approaches at the local level in developing pro-pollinator policy are also needed, since this is the level at which most actions need to take place.

PREFACE

Pollination is a keystone process in both human-managed and natural terrestrial ecosystems. It is critical for food production and human livelihoods, and directly links wild ecosystems with agricultural production systems. The vast majority of flowering plant species only produce seeds if animal pollinators move pollen from the anthers to the stigmas of their flowers. Without this service, many interconnected species and processes functioning within an ecosystem would collapse. With well over 200,000 flowering plant species dependent on pollination from over 100,000 other species, pollination is critical to the overall maintenance of biodiversity in many senses. Animal pollinators allow many kinds of flowering plants to coexist in an ecosystem, rather than restricting it to the lower-diversity stands of wind-pollinated plants that dominated before the flowering plants evolved. Pollination services thus shape plant communities and determine fruit and seed availability, providing tremendously important food and habitat resources for other animals.

Every continent, except for Antarctica, has reports of pollinator declines in at least one region/country. The losses of pollination services have been well documented in many specific instances. As managed pollinators such as honeybees face a suite of debilitating threats, the services provided by wild pollinators become even more essential. Concerns about the loss of pollinators - wild as well as managed - and the services they provide have continued to mount over the last decades. On a global level, the international community has identified the importance of pollinators with the establishment of the International Initiative for the Conservation and Sustainable Use of Pollinators (also known as the International Pollinators Initiative-IPI) in 2000 by the Convention on Biological Diversity. When the Fifth Conference of the Parties (COP) to the Convention Biological Diversity established the IPI, FAO was invited to facilitate and co-ordinate the Initiative in close co-operation with other relevant organizations.

A Plan of Action for the IPI was adopted at COP 6 (decision VI/5), providing an overall structure to the initiative, with four elements: assessment, adaptive management, capacity building and mainstreaming. The plan of action recognizes the need to take action, while still collecting evidence and expanding the knowledge base. This first assessment of the status of pollinators serves to address progress in each of these four components.

The present document was compiled and prepared by FAO as a contribution to the implementation of the IPI. This report, based on case studies and other technical inputs, was coordinated by FAO in collaboration with the Environment Liaison Centre International in Nairobi, Kenya. The chapters have been peer reviewed by twenty-six case study authors. Support from the Government of Norway has permitted its production and dissemination. We thank the many contributors of case studies which enriched this assessment, the peer reviewers for each chapter, and Carmen Loughlin for final editing.

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CHAPTER ONE: MONITORING THE STATUS AND TRENDS OF POLLINATORS

1.1 POLLINATORS AND POLLINATION SERVICES

The efforts in many parts of the world to conserve and better manage pollinators are proposing innovative concepts in the conservation of biodiversity. Thinking beyond the confines of species conservation and a focus on rare and endangered species, the conservation of pollination is concerned with relationships between species. It is the loss of this that was noted years ago by an eminent ecologist: "What escapes the eye is the most insidious kind of extinction – the extinction of interactions." [1] Pollination, of course, is a key interaction with implications for both wild ecosystems and human livelihoods. It enables both plant reproduction, and food production for humans and animals of fruits and seeds, including many crops essential to food security and sound nutrition.

Pollinators such as bees, birds and bats affect 35 percent of the world's crop production. Animal pollinators increase the outputs of 87 of the leading food crops worldwide[2]. In the continents of Latin America, Africa and Asia, an average of 40% of the land area of crops is planted to crops with some dependence on animal pollinators. These are low estimates, as they do not include secondary crops, medicinal plants or wild-harvested crops, but they do provide an indication of the extent to which pollinators are essential for many "diversities": diversity in diet, biological diversity including its agricultural dimension and the maintenance of a diverse and resilient natural resource base.

With focused efforts to conserve and manage pollination services, biodiversity conservation enters a new and innovative phase. Ecosystem services, including climate regulation, soil production, water purification, pest control and pollination, are critical to human survival. Nonetheless, few natural areas are managed or valued for the services they provide, although many are managed to produce ecosystem goods such as wood, wildlife, or fish. Pollination services, supplying direct production inputs to agriculture from wild biodiversity, provides one of the strongest cases for valuing and managing natural habitats and resources for the services they provide to livelihoods. No other natural phenomenon illustrates more vividly the principle that conservation measures must be directed at ecological processes, and not just individual species.

One of the most potent indicators of the health of pollinator interactions may be the incidence of plants suffering pollen limitation: receiving insufficient quantities of pollen to produce seed or fruit at what would be considered optimal levels. Recent research has shown pollen-limited fecundity is widespread amongst natural populations; in natural communities up to 62% of plants may be experiencing pollen deficits[3]. Pollen limitations are more severe in areas of high plant diversity, and may be due to a shortage of pollinators[4].

1.2 GLOBAL STATUS OF POLLINATORS

Worldwide, the number of flower-visiting species is estimated to be around 150,000[5]. Bees account for 25,000 to 30,000 species and together with flies, butterflies, moths, wasps, beetles and some other insect orders encompass the majority of pollinating species[6]. Vertebrate pollinators include bats, non-flying mammals (several species of monkey, lemur, rodents, tree squirrel, coati, olingo and kinkajou) and birds (hummingbirds, sunbirds, honeycreepers and some parrot species).

Though pollinators are known to provide essential services to critical ecosystem functions, changes in the distributions of most pollinator groups remain poorly described. The challenges of identifying declines in pollinators are considerable given the high rarity found in some taxonomic groups (e.g. bees), the lack of baseline data collected and high spatial and temporal variation in pollinator populations[7]. While there is a need for more data, there are however two sources of information available: (1) direct evidence in the form of case studies recording declines of specific

BOX 1-A PRECIPITOUS DECLINE IN THE STATUS OF HIMALAYAN CLIFF BEES

As they have for generations, Nepalese men gather at the base of cliffs twice a year and carry out a semi-annual harvest of honey from the world's largest honeybee, *Apis laboriosa*, the Himalayan cliff bee - with prayers and a sacrifice of flowers, fruit and rice. Descending the cliff by a rope ladder, honey hunters use smoke to subdue bees before cutting chunks of honey from the combs. For hundreds of years, the skills required to perform this treacherous task have been passed down through the generations. But recent surveys show that over the last 20 years, the number of bee nests and bee cliffs substantially decreased. The cliff bee is extraordinarily well-adapted to the harsh, oxygen-poor conditions of the high Himalayan altitudes, and serve as the prime pollinator for the eco-region. Its decline is thought to have devastating consequences for the native, high-altitude plants that rely on the honeybee for their reproduction.

A key threat to the cliff bees and traditional Nepalese honey hunters may be the growing recognition of the honey's value for use in Japanese, Chinese, and Korean traditional medicines. In the past few decades, demand for *A. laboriosa* honey, which is produced during the spring when the rhododendrons bloom, has soared. A kilogram (2.2 pounds) fetches upwards of US$15 on the open market. Traditional honey hunting techniques and rituals that ensured a sustainable harvest and maintained bee populations have given way to non-traditional techniques that denude cliffs of nests in an effort by contractors to maximize profits. Forest destruction and habitat loss also impact *A. laboriosa* populations with dwindling forage resources, as pristine forests are cleared and replanted with non-native commercial crops or fast-growing plantation trees that are of no use to the bees.

from Ahmad et al. (2003)

© Farooq Ahmad

Himalayan cliff bee nest in Bhutan

taxa in a particular region; and (2) indirect evidence from studies focusing on the distribution of known drivers of pollinator loss as a surrogate for declines.

1.3 DIRECT EVIDENCE FOR POLLINATOR DECLINES

Pollinator declines have been noted in many regions of the world. Every continent, except for Antarctica, has reports of pollinator declines in at least one region or country. Evidence is generally in the form of case studies and fragmented in nature, making it difficult to identify general trends across taxa and across regions. However, a recent large-scale assessment and analysis of long-term data in the Netherlands and the United Kingdom has shown parallel declines in pollinating species and the plants they pollinate[8].

Honeybee (*Apis mellifera*) colonies, both managed and wild, have undergone marked declines in the US and some European countries. The number of managed honeybee colonies in the US dropped from 5.9 million in the 1940's to 1.9 million in 1996, and most feral colonies have also been lost.[9,10] Numbers of honeybee colonies are reported to have declined from 15 to 30% between 1985 and 2005 from locations in Italy, Austria, France, Germany, Netherlands, Sweden and Hungary.[11] The related Himalayan cliff bee (*Apis laboriosa*) has experienced significant declines (see Box 1-A). In a regional study, all but one censused cliff showed declines in number of colonies or total loss across a 15 year period[12].

Studies have described marked declines of bumblebees (*Bombus* spp.) in Britain, Belgium and eastern Germany and native solitary bee species in Germany and in Britain[13]. Changes have been attributed to habitat loss resulting from agricultural intensification.

Beekeepers of the stingless bee *Melipona beecheii*, traditionally kept in log hives in the Maya zone in Quintana Roo state, southeastern Mexico, testify to a sharp drop during the last twelve years in the already declining managed bee populations. Important reasons for that decline include deforestation, competition from introduced feral African *Apis mellifera*, hurricane damage, a lack of economic incentives for traditional stingless beekeeping, and the failure to properly instruct new stingless beekeepers. Since 1980, the numbers of bee hives have decreased by over 90%. For the tropics, this scenario, sampled from 20% of the largest traditional beekeeping group in the Americas, shows how pollinators are threatened both by environmental events and inappropriate conservation efforts[14].

BOX 1-B: ENDANGERED MUTUALISMS

The beautiful black and white ruffed lemurs are found in the eastern rain forest of Madagascar where both habitat destruction and hunting for food has resulted in this species being classified as Endangered on the IUCN Red List. These striking primates primarily eat fruit, but also feed on nectar, leaves and seed, as well as occasional small birds and rodents. Black and white ruffed lemurs are associated with the traveller's palm, a familiar Madagascan plant that has large flowers, up to 25 cm long. Black and white lemurs have been seen using the stems of leaves and flower bracts as ladders to help them reach up into the flowers for nectar. The pollen is then transferred as they move from one bloom to another. This makes them one of the largest, and most unique of all pollinators.

© Steve Hart

Black and white ruffed lemur

Traveller's Palm

from Kress et al. (1994).

Population characteristics of bees may show changes before actual declines may be detected: bees that appear common may in fact be in jeopardy. For genetic reasons alone, bees are more extinction prone than other taxa as single locus sex determination makes them particularly sensitive to the effects of small population size through the production of sterile diploid males[15]. An example of this is the most abundant orchid bee in lowland forest in Panama, *Euglossa imperialis*, which frequently has high levels of sterile males resulting in low effective population sizes subject to extinction[16].

The widespread declines of invertebrate pollinators in North America highlighted in the "Forgotten Pollinators" campaign have been critically evaluated in a series of papers which concluded that an inability to find direct evidence reflects more a lack of appropriate data rather than an absence of any broad-scale declines[17]. Information on the status of pollinator populations is unfortunately limited by the intensity of data gathering. For example, no bee species are listed as threatened or endangered in the Mediterranean region, although this is a recognised centre for bee speciation, which experiences considerable human impacts. The lack of listed species probably reflects the absence of active specialists to compile Red Data Lists for this region, as well as others[18]. Variable impacts from one species to another are evident in monitoring information from Belgium and France, highlighting the difficulty of characterising whole communities by simple statements of trends[19].

The European Pollinator Initiative is currently seeking to document and quantify distribution shifts in key pollinator taxa across Europe. Amongst the innovative approaches they are using is an exercise to survey all possible sources of data. Across the EU and beyond, there are many sources of information relating to pollinator distributions, but these resources are in diverse and incompatible formats, highly fragmented, spread across continents and institutions and employing a number of different languages. By carrying out an inventory of the resources and prioritising their value, an efficient system of searching for and accessing the richest historical resources is being developed[20]. The potential for amateur naturalists to record present distribution records with a high standard of accuracy is evident in the activities of the Bees, Wasp and Ants Recording Society[21].

Additional pollinator taxa besides bees are the focus of monitoring concerns: there are several local and national-level butterfly (Lepidoptera) recording schemes in Europe, notably those in Great Britain, the Netherlands and Germany. Comparison with historical records (1970-1982) showed that half of British resident butterflies have disappeared from over 20% of their range, and a quarter have declined by more than 50%. Many European butterflies are under serious threat because of changing land-use and agriculture intensification[22]. Again, the concentration of data is more a reflection of the location of specialists to gather it, than a reflection of zones of greatest concern.

Strong evidence is available for declines in mammalian and bird pollinators- which, being larger and more visible, more often are included in monitoring schemes. At least 45 species of bats, 36 species on non-flying mammals, 26 species of hummingbirds, 7 species of sunbirds and 70 species of passerine birds - all of which are known to pollinate plants - are of global conservation concern[23].

BOX 1-C: POLLINATORS SPRING OPEN "POP-TOP" FLOWERS

Bright red mistletoe flowers are a feature of the New Zealand temperate rainforests, but something may be amiss with this floral display. Whereas most flowers prominently display their assets- pollen, or nectar, or both, to floral visitors, these mistletoe flowers keep their pollen receiving structures sealed firmly within the flower.

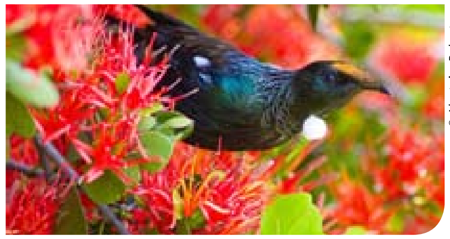
Only "specialist" pollinators- a native honeyeater bird, and some native bees- know how to twist the bud and make it pop open. In the case of the tui, a nectar-loving honeyeater bird, pollen falls onto the bird's head as it sips the nectar that is now available.

Dougal Holmes © University of Canterbury

Peraxilla tetrapetala flower buds

The native bees, being quite small, must work quite some time to "trip" the flower, but they too succeed and gather pollen, often carrying pollen to the next flower they may pry open. With both the honeyeaters and the bees, only native species seem to have had time to learn how to unlock the mistletoe blossoms.

At the turn of the last century, botanists reported forests ablaze with the scarlet blooms of native mistletoes, but today few areas of New Zealand support profuse growth. In most places, unpollinated dead blooms littering the ground are more common than flowers twisted open by birds and bees. Experiments have shown that at several sites in the central Southern Alps of South Island, mistletoe plants produce no more fruits than plants that have been placed inside cages to keep out pollinators. This means that birds and bees are visiting flowers so infrequently- or that the birds are becoming so scarce-that essentially there is no increase at all in pollination over the low rate of self pollination.



© Alastair Robertson

Tui feeding on the endangered mistletoe *Peraxilla* in Pigeon Valley, New Zealand.

from Sessions (2000).

1.4 INDIRECT EVIDENCE FOR POLLINATOR DECLINES

Multiple drivers of pollinator loss have been identified in case studies, and given that these drivers are widespread and are perceived to be increasing around the world[24], then it follows that declines in pollinators may also be widespread.

Habitats required by many pollinators are being lost through changing land-use patterns such as increasing agricultural intensification[25]. Pollinators require a range of resources from their environment for foraging, nesting, reproduction and shelter. The loss of any one of these requirements can cause pollinators to become locally extinct[26]. Temporal datasets documenting pollinator declines are few, but additional evidence in support of such declines comes from snapshot studies across gradients of human disturbance. On melon farm sites in the western United States, wild bee communities become less diverse and abundant as the proportion of natural habitat surrounding farms declines. The most important species for crop pollination became locally extinct throughout large parts of the landscape. All species declined along this gradient, however, so that more resistant species could not compensate for the loss of more sensitive species. The implications for pollinator function are evident: only farms located near natural habitat were able to sustain communities of pollinators sufficient to provide the necessary levels of pollination services[27]. Distance from natural habitat affected pollinator communities and services in a similar way on coffee farms in Costa Rica[28].

Similar effects have been shown for bat pollinated plants and butterfly populations. For example, lower visitation rates by bats and reduced fruit set occurred on a dry forest tree species, *Ceiba grandiflora,* in disturbed habitats in Mexico and Costa Rica[29]. The 'Red Data Book of European Butterflies' reports that many European butterflies are under serious threat because of changing land-use and agriculture intensification[30].

Excessive use or inappropriate application of pesticides and other agro-chemicals is known to have negative impacts on a range of pollinators[31].

Climate change may potentially be one of the most severe threats to pollinator biodiversity[32]. Substantial distribution changes are predicted for groups such as butterflies[33].

Invasive species are globally recognised to have major negative impacts across a wide range of taxa. Two major causes of honeybee declines are parasitic mites (*Varroa jacobsoni* and *Acarapsis woodi*) and the expansion of the range of Africanized honeybees in the US[34]. Introduced honeybees (*Apis mellifera)* has had strongly deleterious impacts on indigenous honeybees (the cliffs bees and Asian hive bees) in the Hindu-Kush Himalaya region[35].

BOX 1-D. UNRULY BEES.

Surveys of pollinator populations are difficult to design, largely due to the very wide variation in pollinator populations. This merits some explanation, as it impacts the ability of scientists to deliver clear assessments of pollinator trends to policymakers. Bees and insects that comprise most pollinator populations are "vagile", meaning that they quickly change or adapt to new situations by moving their location. If conditions at a site are poor with stormy or cold weather that may prevent pollinators from flying, their apparent numbers in a survey may be low. But as conditions improve, they may equally quickly return. It is quite normal for bee populations to double, or to halve, from one year to the next. It is thus difficult to sort out long term trends when short term variation, or "unruliness" in the data may be very high.

An example of a very long term study of Orchid bees (Euglossini) in tropical moist forest in Panaman helps to illustrate this. Over 21 years, no aggregrate trend could be detected, although four individual species declined, and nine increased. The most common set of bee species gradually declined over time, which probably bodes poorly for the pollination services of the forest, although biodiversity (taken in simple terms of species numbers) increased! There were up to fourfold differences in bee abundance among years, and 14-fold changes in species abundance. El-Niño climatic events led to brief increases in bee abundance.

© David Roubik

Orchid bees

A close examination of this data suggests that minimum series of four years (i.e., three intervals) of several counts during the active season may demonstrate genuine trends. Longer term, continuous studies are still needed for meaningful insights on pollinator population shifts in nature.

from Roubik (2004).

1.5 ENDANGERED MUTUALISMS: WHAT HAPPENS WHEN A PLANT LOSES ITS POLLINATOR?

Poor reproduction observed in several rare plants has been linked to the loss of their specialized pollinators. Examples are populations of a snapdragon relative in South Africa[36] and bird-pollinated vines in Hawaii[37]. Highly specialized relationships occur between fig tree species and their pollinator, fig wasps, which can have dramatic effects on ecosystems when "keystone" species such as figs lose their specialized pollinators[38].

However, most pollination systems can be characterized as "somewhat generalized"[39]. In exploiting each other's resources, it is in the interest of both pollinators and plants needing pollination services to remain at least somewhat flexible. Pollination systems are thus reasonably "robust"- most flowers attract and can be pollinated by a range of pollinators that often vary under different climatic conditions. Throughout the range of pollinators, however, some will be much more effective than others. Thus flowers usually will continue to experience visitation even if the most effective pollinators are for some reason eliminated. Pollinators will still visit flowers, but less quantities of pollen may be deposited, or may be deposited at the wrong place on the plant, or the visits may occur at times when the flower is less receptive to receiving pollen.

1.6 MONITORING TRENDS IN POLLINATOR POPULATIONS: BEES

While numerous specific observations of pollinator declines have been documented, it has proven extremely difficult to determine if whole pollinator communities globally, or across entire regions are already widely diminished and threatened by human activities. Even more difficult is to determine which activities of human populations may be responsible for pollinator declines. The inherent difficulty is the "unruliness" of pollinators: as largely composed of vagile insects, their population numbers vary naturally, and tremendously, in time and space (see Box 1-D). In many sites, "normal" bee populations commonly halve or double in one-year intervals, in response to environmental conditions[40].

If a group of organisms have large variability in their population sizes, the effort required to sample that population increases proportionally, to be able to confirm that the results are statistically valid. Bee populations are not only highly variable, but have many locally rare species: "singletons" that may be collected only occasionally in one locality, and do not occur there in large numbers or regularly over considerable time[41]. Characterising this natural variability and diversity in itself could require sampling schemes and resource commitments that could be extremely costly. To distinguish natural long-term trends from those that are caused by human activity is even more challenging.

Effective antidotes to dealing with the diversity, variability, and "unruliness" of pollination population monitoring include the following:

1. Given the limits on time and funding for monitoring pollinators, approaches that maximize information for effort must be sought for future studies. Reliable information on status and trends of pollinators may be documented in a few focused plant-pollinator systems, rather than trying to sample entire faunas.
2. If broad trends across multiple taxa are needed, means of increasing sample sizes (for example by using large numbers of volunteers) will be essential.
3. Regardless of the purpose of the study, standardized unbiased sampling protocols using replicated designs will increase the value of data. Standardization permits statistical testing of changes in bee populations and communities, and allows for rigorous comparison between studies.
4. The significant information resources on species populations and trends that do exist are labour intensive and expensive to access. Since monitoring is a long term effort it is critical that steps are taken to make current information more accessible for future investigations. Proposals for biodiversity research should include a plan for the maintenance and sharing of the digital biodiversity data generated in projects. Species and specimen level data and associated metadata that are generated in funded projects can be made publicly available, for example, through mechanisms cooperating with the Global Biodiversity Information Facility (GBIF)[42].

The fairly daunting challenges of sampling design, combined with the taxonomic impediment that can make monitoring results less meaningful when identifications are uncertain, must be overcome if the objective is to reliably monitor invertebrate pollinator populations and respond to their declines with effective conservation measures.

Several improved monitoring methodologies are under development in multiple regions of the world. A few of these are highlighted here.

Squash Pollinators of the Americas Survey (SPAS). Given the methodological problems of sampling whole pollinator communities, an alternative methodology has been developed and is being tested for a distinctive, but widespread pollination system in the Americas, involving squashes and squash bees. The design is guided by several considerations and principles, including ease of data interpretability (maximum data return for modest effort); strict uniformity and consistency across all sites in methods; data maintenance through easily-available Excel spreadsheets; minimal time commitment; and decentralised data analysis (collaborators own and analyse their own data). In 2004, SPAS (Squash Pollinators of the Americas Survey) surveyed cultivated squashes and pumpkins at 20 sites in 11 US states and Mexico. Wild squash bee populations have been found to be present at all but one site, and providing a much-undervalued natural ecosystem service. In one farm with about 90,000 squash flowers, an estimated 1 million specialist squash bees were effectively visiting and pollinating the squash crop. Yet the grower currently spends US$25,000 annually to rent honey bees for what is probably superfluous pollination service[43].

Beeplot: Monitoring methods for solitary bee species using bee bowls in North America. A group of researchers associated with the North American Pollinator Protection Campaign (NAPPC) have been working on standardized protocols for sampling bees that are applicable to a global monitoring program. Two protocols have been developed: one for sampling over a uniform one-hectare area of habitat over an eight hour period, repeated at least four times a year, and another to sample large landscapes such as protected area, districts or counties, states or provinces, and large physiographic regions, to be repeated at 5 to 20 year intervals. The methods are simple and inexpensive, and have been selected for their accuracy and replicability. The protocols have been implemented at over one hundred sites across the United States and Canada[44].

Sao Paulo+5 Forum Workshop on Survey Methods for bees: assessing status and suggesting best practices. In October 2003 in Sao Paulo, Brazil, with a follow-up session at the 2004 Solitary Bees Workshop in Ceará, Brazil, a working group discussed surveying and monitoring methods for pollinators in natural and cultivated landscapes. Recognizing that results with different methods have been quite variable throughout the world, specific recommendations were made for designing rapid assessment, surveys and monitoring programs for bees. At the follow-up workshop, it was proposed that the different regional pollinator initiatives undertake pilot programmes of comparing the results from different methodologies, deployed simultaneously at sites around the world, to be better able to agree on common standardized approaches[45].

Project Ape Miele Ambiente (Bee-Honey-Environment), Italy: Italy is one of the few countries to have undertaken a countrywide, multi-year monitoring program of its wild bees in agricultural and semi-natural landscapes, from the years 1997-2000. The diversity of the Italian bee fauna was investigated at 52 sites in 8 Italian regions using a transect method. Even at this sampling intensity, just over a third of the historically known Italian bee fauna were collected and recorded. Three species collected were new records for Italy, and 45 species showed an enlarged distribution. 75% of the bees collected were found in agricultural habitats; 81% were found in semi-natural habitats, indicating the large overlap in these communities[46].

ALARM: Assessment of Large Scale Environmental Risks with Tested Methods: a project of the European Pollinator Initiative. The project works to build a knowledge base to support the sustainable conservation and management of pollinators throughout Europe. Researchers in a network across Europe are quantifying distribution shifts in key pollinator groups across Europe, measuring the economic and biodiversity risks associated with the loss of pollination services in agricultural and natural habitats, determining the relative importance of drivers of pollinator loss, developing predictive models for pollinator loss and consequent risks. The project includes standardized monitoring methods to quantify pollinator diversity and abundance in agricultural and natural habitats[47].

1.7 MONITORING TRENDS IN POLLINATOR POPULATIONS: OTHER POLLINATOR TAXA

Other groups of animals that are known to pollinate have been the focus of some monitoring programs:

- **Flies.** The natural population fluctuations in pollinating fly populations are difficult to differentiate from fluctuations caused by human-induced changes. Data on flies is even more limited than that on bees but case studies for example showing the impacts of urbanization on fly populations indicate severe impacts on the biodiversity of flies in human-dominated landscapes[48].

- **Birds.** Hummingbirds in the Western Hemisphere, and sunbirds in the Old World are key pollinators of a number of native plant species, and may contribute to crop pollination of some fruit such as papaya and okra. Hummingbirds, like bats and some butterflies, migrate long distances. With breeding places in one site and over wintering sites in another, their conservation requirements are often complex; efforts in one place may be counteracted by a loss of habitat far away. For hummingbirds, the Arizona-Sonora Desert Museum has established a monitoring system based on collaboration between USA and Mexican institutions[49]. Additionally, many hummingbird species in North America are monitored by the North American Breeding Bird Survey which has data from over 4000 transects run each year across the US, Canada, and Mexico since 1966, largely carried out by volunteers.
- **Bats.** Bats can play important roles in pollination. Where estimates of their importance have been made, the diversity of plants that may be pollinated by bats is impressive. For example, it has been estimated that bats play some part in the pollination of at least 500 Neotropical species of 96 genera[50]. Bats as a group seem to be particularly vulnerable to human impacts on biodiversity; approximately 22% of bat species are considered Threatened and a further 23% as Near Threatened[51]. The long migratory ranges of pollinating bats require conservation monitoring and planning on large, often multiple-country scale. In one case, the sharp declines and habitat destruction have prompted closer monitoring of the migratory nectarivorous Mexican long-nosed bat (*Leptonycteris nivalis*) and lesser long-nosed bat (*Leptonycteris curasoae*). The Programa Para la Conservación de Murciélagos Migratorios (PCMM, Program for the Conservation of Migratory Bats) monitors over 20 caves in 14 states of Mexico[52] where bat colonies remain stable or growing. The survey involves visiting each cave at least once every season, and estimating population sizes, sex ratios, obtaining blood samples, fecal samples and stable carbon isotope samples for subsequent dietary analysis. Although specific, cross-cave comparisons cannot be conducted due to methodological hurdles and lack of standardization, the data are useful to identify the waves of migrating bats and document migratory patterns, seasonal changes in diet, reproductive cycle, and approximate departure and arrival dates for specific regions. This information is being used to establish additional protected areas in Mexico[53] .
- **Pollen limitation studies.** Since one of the ultimate concerns of the International Pollinators Initiative is that plant reproduction is suffering from declines in pollen deposition, monitoring plant reproductive success or pollen deposition deficits may be among the most effective direct measurements of pollinator declines. It has many of the same caveats as the monitoring of pollinator populations and trends will only be detected if the effects of other influences, such as climate and floral herbivory, can be removed.

CONCLUSIONS

Every continent, except for Antarctica, has reports of pollinator declines in at least one region/country. The losses of pollination services have been well documented in many specific instances; what remains lacking is global assessments of changes in the distribution and levels of pollination services. As the recognized drivers of pollinator losses (changing land-use patterns, pesticide use, diseases, invasive species and climate change) are themselves changing in intensity, the global community is justified in taking note and determining the actions that will conserve pollinators. The insidious nature of the loss of ecosystem services- by slow erosion rather than cataclysmic events- demands a careful monitoring system. Several very recent monitoring systems have been initiated on sub-global levels, although their conclusions will be some years away.

View of experts on the way forward

1. Disturbing trends and evidence for loss of pollination services have been recorded in multiple locations and ecological systems; the evidence, while fragmented, tells enough of a similar story in many different contexts that the global community is quite justified in taking action.
2. Policy makers need to have concrete, practical information on pollinator declines,

which can only be provided by a broad, collaborative global effort to effectively monitor pollinator trends and status. This may only be feasible by focusing on manageable indicator groups of selected pollinators.

3 Synergies between different initiatives to document trends in pollinator status should be strengthened. Research councils, other funding agencies and private foundations should promote that proposals for funding for biodiversity research include a plan for the maintenance and sharing of the digital biodiversity data generated in proposed projects and that species and specimen level data and associated metadata that are generated in funded projects are made publicly available.

4 The impact of pollinator loss on plant reproduction is not yet well addressed in most biodiversity monitoring programs, yet ultimately this impact is the underlying focus of concern for pollinator initiatives.

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CHAPTER TWO: ECONOMIC VALUATION OF POLLINATION SERVICES

2.1 GLOBAL ESTIMATES OF THE VALUE OF POLLINATION SERVICES

Estimates of the annual monetary value of pollination vary widely. A value of US$120 billion per year for all pollination ecosystem services was estimated in 1997[1]. Specific estimates on a national basis for the role of pollination in the United States, Canada, Europe, New Zealand and Australia have been used as an estimate of more than US$50 billion in values to global agriculture alone[2]. Beyond this estimate of pollinator contributions to crop production, other aspects of agriculture also depend upon pollinators. Seed production and grazing resources for livestock and wildlife and soil fertility all benefit from pollination services, as do many functions of natural ecosystems. Pollination valuations have suffered from a lack of comprehensive, site-based assessments to properly identify the contribution of pollination to agricultural yields and human livelihoods - using accepted economic methods to assess values - so these values can be compiled into credible national, regional and global estimates. Nonetheless, existing valuations show that the monetary contribution of pollination to agricultural production is significant.

2.2 FOOD SECURITY AND POLLINATION SERVICES: HOW DEPENDENT ARE WE?

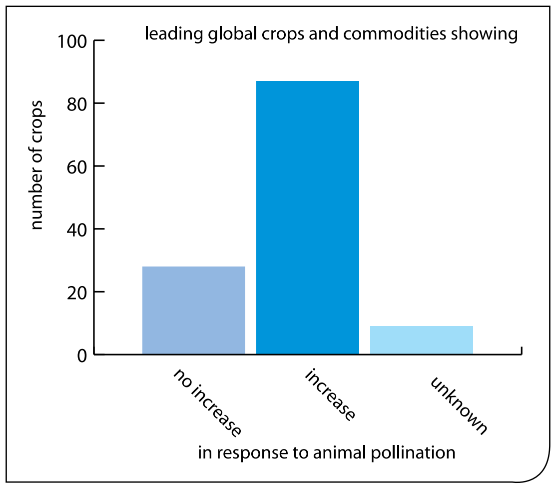
A global study of how much the production of crops that nourish humanity is dependent on animal pollination, based on FAO crop production data,

BOX 2-A: DEPENDENCE OF WORLD CROPS ON POLLINATORS.

Out of the 115 crops whose pollen vectors were determined in a recent global study, over 75% depend to some degree upon animal pollination. Among the leading crops that benefit from animal pollination, 13 are entirely reliant upon animal pollinators, 30 are greatly dependent and 27 are moderately dependent.

A few crops rely entirely on pollinators for reproduction; without pollinators, a crop could only be produced with human help via hand pollination. These include cocoa, one of the most important cash crops in tropical countries, the vitamin-rich and tasty kiwifruit, passion fruit, annona and sapodilla fruits, as well as vanilla, squashes and pumpkins, cantaloupes and watermelons, and Brazil- and macadamia nuts. Most crops showed a production increase between 5 and 50% as a result of pollination by animals (mainly bees).

The authors of this study readily acknowledge, however, that there are multiple gaps in the knowledge of pollination requirements, which may vary between varieties and geographic locations. The understanding of the pollination needs of many crops has recently been revised, as they are grown under increasingly intensive practices where the underappreciated wild pollination service may be impacted. In addition to gaps in knowledge about pollination requirements, there is also a dynamic aspect about knowledge development in this area, as production systems evolve and change. In particular, as production systems intensify, there has been an increase in awareness of the importance (and value) of previously supplied wild pollination services.



from Klein et al. (2007)

reveals that pollinators such as bees, flies, butterflies and moths, and beetles affect 35 percent of the world's crop production[3]. This increased the outputs of 87 of the leading food crops worldwide. Although 60% of the global food production comes from crops that do not depend on animal pollination – mainly staple crops like cereals such as wheat, maize and rice– the remainder, ensuring nutritional diversity, either comes from crops that depend on pollinators or from a small percentage of crops (5%) for which the dependence upon animal pollination is still unknown.

2.3 METHODS FOR VALUING POLLINATION SERVICES

The International Pollinator Initiative, in its plan of action, states the necessity to: "Assess the economic value of pollinators, including evaluation, in economic terms, of different crop-pollinator-pollination systems for optimal use of pollinators in sustainable agricultural systems, through economic analysis of data from various crop-pollinator-pollination systems". Such an assessment could be central to convincing farmers and policy-makers of the value of conserving pollinators. However, several questions arise: how to do this? And, is there a valid methodology that can be applied to the valuation of pollination services?

Over the last decade, there have been several efforts to place a value on biodiversity to human livelihoods, including pollination as a contributing element. The 1997 study[4] mentioned in Section 2.2 presented a global estimate of the value of biodiversity, showing that the value of ecosystem services is large and relatively important compared to the size of the human economic system. The numbers used in this study- estimating the value of pollination services globally at US$120 billion annually- should not be considered precise, but rather indicate orders of magnitude. More recent attempts have addressed some of the earlier imprecisions[5], but not specifically with respect to pollination valuation.

Given these impressive global estimates of pollination's value to humans, it may well be asked why is it so unrecognized in the market place? Many different types of "failure" (market, institutional and global) explain why those values are not recognised or taken into account by markets. Mechanisms to capture values and channel support towards the conservation of the natural resources and ecosystem services that generate those values are discussed below, both from consumer and producer perspectives.

Global efforts to value biodiversity are applied at a macroeconomic level, whereas farmers and local and national decision makers focusing on particular crops need tools to balance the impacts on production of pro-pollinator practices against the impacts of other production practices that negatively affect pollinators - such as use of pesticides. Consumers are also part of the equation, and their values and demands need to be considered.

Methods that have been used to value pollination services[6], have considered, *inter alia*, the market value of all[7] or some[8] of the insect pollinated crops grown; or the value only of the proportion attributable to honey bees[9]. Some have included the value of crops grown from seed derived bee-pollinated plants[10] the legume crops and livestock products dependent on them, or even those legumes that fix nitrogen and thereby reduce nitrate fertiliser requirements[11]. A relatively more sophisticated consumer surplus approach (i.e. one that measures changes in gains to consumers resulting from pollination induced price changes and thereby accounting for the effect of the existence of potential substitute crops- see also next section) was developed by Southwick and Southwick[12].

FAO has recently reviewed and identified methods for the valuation of pollination services for application in farming systems around the world[13]. The methods are being applied in pilot projects assessing the benefits and costs of pollinator-friendly practices in chilli pepper farms in Ghana, and buckwheat, mustard and kitchen gardens in Nepal.

Recent research in coffee agroecosystems in Costa Rica[14] has shown that the pollination services provided by pollinators nesting in forest patches adjacent to coffee plantations may contribute to substantially greater yields of coffee. The economic value of pollination services provided by intact forests was found to be similar to the expected annual earnings from the forested lands if they were cut down and converted to common agricultural uses for the area (see Box 2-B).

2.4 CONSUMER PERSPECTIVES

While pollination is generally conceived as being of value primarily to farmers, the consumer perspective should not be left out. Any comprehensive economic analysis will need to take not only production (yield) changes into account but also price changes. The degree to which a change in pollination translates into a change in yields and production quantities is a first step in the analysis. How this translates into price changes at the farm gate and for consumers is a second and vital step of the analysis and will depend on the relative price elasticities of supply of demand of individual commodities, as well as that of their substitutes (i.e. cross elasticities)[1]. A good example of this type of analysis was carried out by Southwick and Southwick[2]. The overall impact on society's welfare is determined by the change in consumer and producer surplus in the presence of different degrees of pollination. A model of the economics of pollinator deficits[15] concluded that consumers of a commodity affected by a pollinator deficit may suffer because the commodity costs more and becomes less available. Consumers may thus have to pay more for traded commodities because of pollinator declines.

Where commodities are grown in places that exclude their natural pollinators, new markets may be created around pollination services. For example, a considerable business is built around providing bumblebee pollinators to greenhouse-grown tomatoes; without the services provided by bumblebees, tomatoes in the off-season would be far more costly.

Consumer incentives

To create markets that provide incentives for pollinator conservation, consumers would need to be willing to pay more for commodities that have been produced in a manner that does not negatively impact pollinators, or that have been noticeably well-pollinated. Such market incentives may exist in the certification of organic production, since inorganic pesticides are not used. Well-pollinated crops can be of noticeably better quality, and markets are sensitive to quality considerations: in Canada, good pollination in apple orchards resulted in about one extra seed per apple, which produced larger and better formed apples. These improved apples were estimated to provide marginal returns of about 5–6%, or about Can. US$250/ha, compared to orchards with insufficient pollination[16].

BOX 2-B. ECONOMIC VALUE OF WILD POLLINATORS TO COFFEE CROPS

A recent study of the value of wild pollinators to coffee crops in Costa Rica was unique in being conducted at the scale at which land use decisions are made. Dr. Taylor Ricketts and a group of scientists from Stanford University and World Wildlife Fund looked at the value of pollination services from forest-dwelling bees to surrounding coffee farms. They found that coffee fields near tropical forest fragments received more pollinator visits by a more diverse community of bees, higher rates of pollen deposition on flowers, and higher productivity than coffee fields more distant from forest.

Ricketts and his colleagues conducted their study in the Valle Generál in Costa Rica, near the city of San Isidro. They observed bee visits to coffee bushes at different distances from forest– ranging from within 100m to over 1.5 km away. The team found that pollinator diversity near to the forest was much higher than further away. In the nearest sites, visitors to coffee included feral honeybees (*Apis mellifera*) and 10 species of stingless bees (Meliponinae), while far from these forests honeybees were almost the only visitors. The more diverse bee community in sites near forest also visited coffee flowers at twice the rate – and deposited twice the pollen on flowers – as the more depauperate communities occurring far from forest. Pollinators near forest also seemed to provide more stable pollination services over time. Mid-way through the study, honeybee populations crashed. In sites far from forest, where honeybees were almost the only visitors, overall visitation rates declined sharply. In near sites, however, other species increased in abundance, so that overall visitation dropped only slightly. The diversity of available pollinators thus provided a stabilizing form of insurance against declines in any one species.

The team also found that these patterns in pollinator diversity had important consequences on coffee yields in the landscape. Using pollination experiments along the same distance gradient, the team showed that the diverse pollinator community near forest was providing adequate pollination services to coffee. Beyond roughly 1 km from forest, however, pollination services were insufficient, and coffee produced yields approximately 20% lower as a result. Therefore, coffee farmers beyond 1 km from forest suffered 20% lower yields due to inadequate pollination services. Using these results, the team estimated the economic value of the two largest forest patches in the landscape. For a single, large farm, pollination services from these two forest patches represented approximately US$60,000 of additional income per year. This estimate is similar to the expected annual earnings from the forested lands if they were cut down and converted to common agricultural uses for the area.

This study shows that pollination services from wild pollinators can have significant economic value. As agricultural landscapes continue to be intensified and lose their forested components, these pollination services and the productivity of crops may suffer. Forest conservation, therefore, can be in the best interest of both biodiversity and local farmers.

from Ricketts (2004).


© Anthony Mwangi

Optimal pollination results in a good harvest of coffee berries.

2.5 PRODUCER PERSPECTIVES

Pollination services have both market and non-market values.

Market values, private goods and market failures

In countries where commercial pollination services are provided, pollination can be treated as a private good (though not a pure one), which can directly be traded in the marketplace. In this case, the delivery and consumption of pollination services are based on human needs and preferences. But the ability of humans to misperceive pollination needs may be considerable. In many agricultural systems, producers may be paying for pollination services by domesticated honeybees, yet pollination by wild bees may be supplementing or even surpassing managed pollination. In a large farm with over 90,000 squash plants, a grower paid an annual fee of US$25,000 to rent honey bees, yet the squash crop was being adequately pollinated by an estimated one million wild *Peponapis* bees[17]. In no agricultural systems are payments being made to secure wild services, yet pollination clearly has such values if farmers are willing to pay at levels such as these.

Farmers (along with extension workers) may underestimate and undervalue the role of pollination. In a survey carried out in the United Kingdom in 2000, grower's perception of the value of pollination services to their crops was about half the value attributed by the scientific literature. As the survey authors mention, "with crops requiring early pollination, for example apple, the prevalence of natural pollinators is affected by the harshness of the weather in the preceding winter. A survey taken after a run of mild winters may lead to growers underestimating the average impact of honeybee pollination"[18].

Market failures to capture the value of pollination is undoubtedly linked to the fact that animal-mediated pollination is a subtle, almost unnoticed interaction between plants and small insects. As such, it is not easily understood or manipulated by farmers in the same way as fertilizer application or pest control. The standard economic model of a perfect market assumes perfect information, that is, all agents in the market have full information about product characteristics and prices. This is clearly not the case in pollination markets, where there is a large gap of information on the contribution of pollinators, both for buyers (farmers) and sellers (domesticated honey beekeepers, or managers of land with bee nesting sites and habitat- which may be farmers themselves). Education and public awareness for farmers, extension agents and others in the agricultural sector are critically needed before pollination benefits are recognized by markets.

Non-market and social values

Pollination services may be "produced" by forest owners or land owners and bee keepers. Thus farmers who benefit from pollination services may also be the producers of the same since they may be the *de facto* owners and managers of many forest ecosystems, and of areas of wild habitat on their own farms. Other owners of land within an agricultural landscape that may be "providing" pollination services may be local governments, protected area managers, and even departments of transportation, as floral resources for pollinators are often quite rich on road shoulders, where water runs off from the road surface. Pollination services from wild ecosystems are socially desirable, but are not market-based. In such cases, as is argued in the study by the British Department of Food, Environment and Rural Affairs[19], public intervention can assist to assure that pollination services are maintained at an optimal level, for maximum social benefit.

When pollinator habitat is found solely on the farmer's own land, there is no "externality" in the words of economists. This means that the farmer alone benefits. In this case, a well-informed farmer could choose between having more agricultural land with less pollinator habitat and lower yields vs. less agricultural land with higher yields, if he or she was aware of such alternatives.

But it is rarely if never the case that pollinators forage according to farm boundaries, meaning that positive externalities (public goods) occur from farmers having pollinators making use of their farmland. Owners of the land supporting pollinators cannot restrict the neighbouring farmers from benefiting from the pollination services. Such positive externalities and the potential to "free ride" could provide a justification for public intervention in order to ensure a socially optimal provision of pollination services. Valuation could play a role in determining what degree of intervention is justified. However, it should be recognized that it will be very challenging to separate the pollination service values from the other ecosystem services provided by adjacent "wild" lands (e.g. water catchment, provision of pest control services, wildlife habitat, carbon sequestration, aesthetic and cultural values, etc.).

Producer incentives

Incentives that could promote pollinator conservation can be provided on the producer side through *inter alia*:

- Land use restrictions and obligations to maintain natural habitats within agroecosystems. Such goals could also be achieved through market-based instruments e.g. tradeable permits.

- Reduced subsidies provided to intensive farming systems (e.g. agrochemical and fuel subsidies, cheap loans for farm machinery purchase, etc.).
- Payments for environmentally-friendly practices that generate positive externalities (e.g. habitat and wildlife conservation, watershed management, reforestation, bee-keeping, land set-asides).

CONCLUSION

Pollinators provide essential services to humans, providing improved agricultural yield and hence economic returns. In several instances, impressive documentation of the market and non-market values derived from pollination services has been made. Despite this, the economic valuation of pollination services is in a relatively undeveloped stage, and has a number of challenges to overcome, many stemming from the gaps in knowledge and producer understanding of the actual contribution of pollination to crop production. The non-market values of pollination services have not been well defined in an economic sense.

View of experts on the way forward

Pollination services provide a key local benefit arising from biodiversity conservation. The design of mechanisms to capture such values could play an important role in providing local incentives for biodiversity conservation, yet the technical means to quantify such values and inform such a process is still in its early stages of development.

1. More precise and accurate assessments of the agronomic value of pollination management in crop production are urgently needed for herbaceous crops as well as perennial ones (and in this case, it requires that the study be conducted over several years). This should include the impact of pollinator management on the stability of the pollination system.
2. More precise and accurate assessments of the economic valuation of pollination services for all stakeholders, including consumers, are critically needed (this includes, for example, the potential benefits of abundant fruit and vegetables for general well-being of citizens as well as health costs that derive from poor diets lacking in vitamins and minerals).

3. Valuation of pollination services for natural ecosystems- in both their production and consumption functions- is also needed.
4. Farmers, extensions workers, land managers and policy makers need to be better informed of these values, so that they can appropriately account for and address pollination services in their decision-making processes. The development of decision-support tools appropriate for different types of stakeholders would facilitate this process. The scope of agricultural education should include pollination in a more thorough-going manner, including the role of wild pollinators and the management actions, costs and benefits needed to promote their services.

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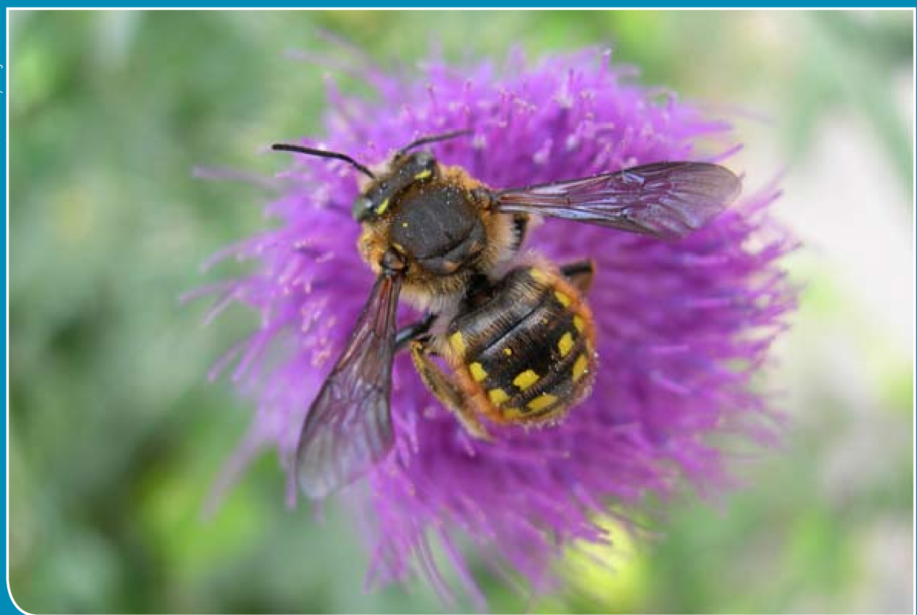

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CHAPTER THREE: THE TAXONOMIC IMPEDIMENT TO POLLINATOR CONSERVATION

3.1 THE IMPORTANCE OF TAXONOMY IN POLLINATOR CONSERVATION

Pollinator faunas and their life-sustaining relationships with flowering plants occupy crucial positions in both natural and agricultural ecosystems. As with all natural resources, inventories of their diversity and distribution are needed in order to conserve and sustainably manage them to the best advantage. Unfortunately, the current state of bee taxonomy imposes severe restraints on the realization of these goals, as it does for other pollinator groups like flies, wasps and beetles. This "Taxonomic Impediment" derives from serious shortfalls in investment in training, research and collections management and some reluctance within the taxonomic community to take advantage of modern approaches to information management so that essential information related to pollinators is accessible to a broad audience. It seriously limits the global capacity to assess and monitor pollinator decline, to conserve pollinator diversity and to manage it sustainably[1].

The International Pollinator Initiative Plan of Action highlighted the urgent need for universities to raise the academic status of taxonomic research by investing in new post-graduate programs with an increased emphasis on training in data management and data sharing. Taxonomy is a field in which it is often difficult to attract new students, yet this is important as taxonomic capacity is essential to pollinator identification, conservation and management. There are a number of dimensions to the challenges that need to be addressed in a targeted effort to surmount the taxonomic impediment: the adequacy and accessibility of identification services, the status of taxonomic knowledge, the provision of tools to assist non-experts in identification.

This report focuses on the taxonomic impediments in relation to bees, the superfamily Apoidea, which are uniformly central to pollination services in every ecosystem of the world[2]. It should not be forgotten, however, that a vast suite of other organisms play important roles in pollination, and the taxonomic impediment of each of these should be reviewed and addressed as well (Box 3-A). Few of these other groups, in fact, have the benefit of such a well-organised and collaborative network of taxonomists as does the Apoidea.

3.2 POLLINATOR DIVERSITY AND HUMAN CAPACITY IN IDENTIFICATION SERVICES

The first taxonomic impediment to face pollination conservation efforts is the correct identification of pollinators; as is often repeated, one cannot begin to save what is not known. At the present time, to identify the pollinators associated with a plant, the services of an expert who can identify pollinators to genus, if not to species level, is needed. Some indication of the variation of diversity in bee groups is illustrated in the equal-area grid map of bumble bees produced by the Natural History Museum (see Box 3-B)[3]. Accessibility and support for identification services is another issue. Many if not most museums and taxonomic services charge fees for identification services. There is increasing recognition that support for taxonomy and identification services are legitimate and critical components of biodiversity conservation projects[4]. Nonetheless, field biologists often neglect to consider the time, effort and resources required for insect identification, and often where funds have been set aside for taxonomic support, these are inadequate[5].

3.2 TAXONOMIC INFORMATION FOR A POLLINATOR INFORMATION MANAGEMENT SYSTEM

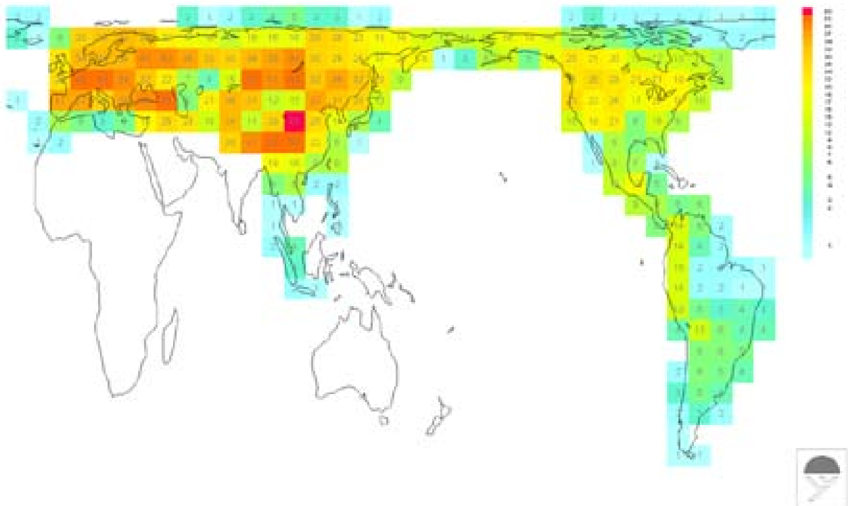
Fundamental to overcoming the taxonomic impediments, and using taxonomic information to inform management, is a need for an up-to-date, comprehensive catalogue of the scientific names of pollinators, linking pollinators to their ecological

BOX 3-A. NON-BEE, NON-BUTTERFLY INSECT FLOWER VISITORS (ANTHOPHILES)

ORDER	SUB-ORDER	FAMILY
COLEOPTERA		
		Polyphaga Meloidae Mordellidae Oedemeridae Melyridae Scarabidae Curculionidae
DIPTERA	Nematocera (shorter mouthparts)	
		Sciaridae Mycetophilidae Cecidomyidae Simuliidae Chironomidae Cerataopogonidae Bibionidae Scatopsidae Tipulidae
	Nematocera (longer mouthparts)	
		Culicidae Bibionidae Sciaridae
	Brachycera (Orthorrhapha)	
		Stratiomyidae Dolichopodidae Lonchopteridae Phoridae Empididae Bombyliidae
	Brachycera (Cyclorrhapha)	
		(Aschiza) Syrphidae (Schizophora) Conopidae Tephrididae Drosophilidae Sphaeroceridae Tachinidae Calliphoridae Muscidae
HYMENOPTERA, OTHER THAN APOIDEA		
		Apocrita, Parasitica Braconidae Ichneumonidae Leucospidae Chrysididae Agaonidae Chrysididae Vespidae Formicidae

from Kevan (2001).

BOX 3-B. EQUAL-AREA MAP OF THE DIVERSITY OF BUMBLE BEES (*BOMBUS* SPP.) AT THE SUBGENERA LEVEL.



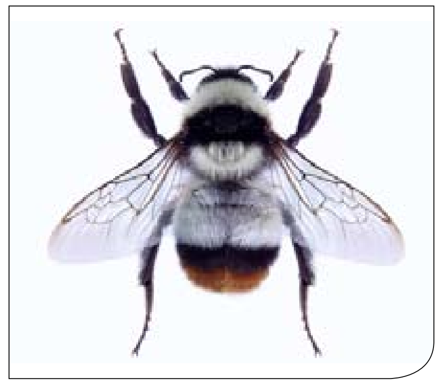
from Williams (1998).

needs. The Global Biodiversity Information Facility (GBIF) is collaborating with FAO to produce a catalogue of the world's approximately 17,000 described bee species. The project will develop an electronic catalogue of the bees, cross-referenced to known biological characteristics (including floral relationships, and ecological linkages), so that the knowledge base on pollinator management is consolidated, widely accessible and as broadly useful as possible. The catalogue will provide critical taxonomic and other primary content needed for the Pollination Information Management System which is coordinated by FAO and currently under development.

3.3 PROVISION OF TOOLS TO ASSIST NON-EXPERTS IN IDENTIFICATION

Where taxonomic services are stretched (as they are throughout the world), the provision of tools and guidance to assist non-experts in identification becomes increasingly valuable. Considerable progress has been made in the last decade in fulfilling the need of pollination biologists, few of whom are taxonomists themselves, to have simplified keys to facilitate the identification of bee genera. A non-exhaustive list of such efforts includes:

- As an initiative to promote the study of Mexican bees, the Programa Cooperativo sobre la Apifauna Mexicana (PCAM) was initiated in 1985, and in 1994 produced "The Bee Genera of North and Central America" in Spanish and English, utilising abundant illustrations to guide users through the decisions of a dichotomous key[6].
- The Centre for Biological Information Technology (CBIT) at the University of Queensland[7] has developed interactive identification and taxonomic information programs. The suite of programs developed permit experts to develop easy-to-use identification keys that allow users to enter several characteristics of a specimen into a key at one time, and manage photos and images to assist in identification. The ALARM project (Assessing LArge-Scale environmental Risks for biodiversity with tested Methods) in Europe is using this software, along with other image processing software to develop a user-friendly identification key to the 72 genera of European bees[8].
- The LUCID software has also been used to develop keys to bumblebees worldwide, through the Natural History Museum in the UK. A key to subgenera for both sexes, and a preliminary key to species from female colour patterns are being trialled.
- With support from the Gordon and Betty Moore Foundation, the University of Queensland has established a program to support the development and implementation of these identification tools in developing countries. The Plant Protection Research Institute in South Africa is using the software to develop a user-friendly key to the African genera of bees.
- A user-friendly guide to the Bees of the Eastern United States is under development[9].



© A. Polaszek

High resolution pictures of bees help make identification keys user-friendly.

- DNA barcoding is a recent development that permits the identification of organisms based upon sequencing a small fragment of their mitochondrial DNA. The long term goal is to produce a DNA database that will permit identification of unknown specimens by comparison to archived sequences. The technology for this work is developing sufficiently rapidly that a hand held identification device may be available within a decade, and extremely useful for enabling greater public participation in monitoring of pollination populations.
- Automated systems for bee identification have been developed that will permit parataxonomists and field workers to scan a bee's wing into a scanner, subject the image to an "artificial intelligence" analysis, and produce an identification down to species level. One of these systems is DAISY[10], a generic pattern matching system which would allow non specialists to identify organisms within speciose arthropod genera using a combination of both morphology and molecular data. The DAISY system has been tested on a significant number of datasets including British bumblebees and Costa Rican hawkmoths. Another system, limited to insects with membraneous wings is ABIS (The Automated Bee Identification System) developed by the University of Bonn.

CONCLUSION

Developing sound management plans for pollinators will hinge on good taxonomic support. Moreover, linked to the taxonomic information about species is other information on biological characteristics (including floral relationships, and ecological linkages) that is important for adaptive management. New approaches to managing pollinator information should help to overcome the taxonomic impediment, although the focus at present has been on bees, and not other key pollinator groups.

View of experts on the way forward

1. Sharing of and open access to publicly funded research data yielding primary species data on pollinators should be encouraged.
2. User-friendly tools to permit more non-specialists to identify pollinators should complement, while they cannot replace, specialist taxonomic services.
3. Taxonomic training and support for taxonomic services merit high respect and support in national and international priorities.

Chapter Three Endnotes

[1] 1stRAPS Case study contribution: 3-002CS.Manifesto
[2] The information supporting this assessment is derived from C. Michener's "The Bees of the World", as well as personal communication with Dr. Michener and colleagues
[3] http://www.nhm.ac.uk/research-curation/projects/bombus/
[4] GEF support to taxonomy: http://www.biodiv.org/doc/ref/gti-gef-support.pdf
[5] 1stRAPS Case study contribution: 3-002CS.Manifesto
[6] Michener, C.D., R.J. McGinley, and B.N. Danforth. 1994. The Bee Genera of North and Central America. Smithsonian University Press, Washington and London.
7 www.cbit.uq.edu.au
[8] 1stRAPS Case study contribution; 3-003CS.Polaszekbeekey
[9] 1stRAPS Case study contribution: 3-00CS. 5ENAbeegenera; also see www.discoverlife.org -click on nature guides)
[10] 1stRAPS Case study contribution: 3-001CS.DAIS

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CHAPTER FOUR: STATE OF ECOLOGICAL KNOWLEDGE OF POLLINATION SERVICES

4.1 THE ECOLOGY OF POLLINATION SERVICES

Although pollination biology has been studied for more than two centuries, appreciation of its significance as an ecosystem service provided by the world's biodiversity is relatively recent and research in this new context is still developing. The science behind biodiversity conservation is itself addressing new complexities: it has been primarily concerned, up until now, with maintaining biodiversity at the level of species. But increasingly, it is recognised that the sustainability of biodiversity conservation is not simply a matter of conserving as many "parts", or species as possible, but also conserving their interactions and linkages—what has been called "the conservation of interaction biodiversity." [1]

The questions being asked are: what are the characteristics of pollinator communities that render them vulnerable to local extinctions, and what are minimum needs for survival? How can the pollination services be maintained at robust and sufficient levels, within human-dominated landscapes as well as natural areas? How are different landscape features related to the persistence of pollinator communities? Are there critical species whose loss will cause cascading effects? How can human interventions in degraded landscapes be used to restore depauperate pollinator communities and re-establish pollination services? Possible answers for several of these questions have been suggested by detailed ecological studies where cause and effects of interactions have been carefully traced in an ecosystem context. Some examples are highlighted in this chapter.

4.2 SIMPLIFICATION

Ecosystems are often simplified through human influence, and this also can impact pollinator populations. In Colorado, USA, bees and pollinating flies in grassland plots away from human settlement were compared with grassland plots in or near urbanized areas. Grasslands with an urban influence have fewer species of bees than grasslands away from urban areas. In addition, grazed areas have low species richness[2]. In the case of pollinators, such local extinctions and simplification mean that not just species are lost. The loss of their services to sustain plant reproduction may have cascading effects throughout an ecosystem.

4.3 FRAGMENTATION

The response of pollinators to land use change is largely driven by the impacts on their resources (food sources and nesting sites). For example the density of stingless bee nests is correlated with the local abundance, size and species of nest trees in tropical forests[3]. But pollinators, particularly bees, do not fit the classic island biogeography model of strict dependence on a natural habitat patch. Bees typically live in habitats where blooming plants and nesting substrates are patchily distributed and spatially disassociated[4]. When natural habitats are fragmented, bee populations and communities reveal a range of responses to fragment size, including increases as well as decreases[5]. This variability in response to fragmentation is likely due to differences in dispersal ability and habitat specificity among pollinator species[6]. At the community level, pollinator richness may initially increase in response to disturbances that are intermediate in intensity and/or frequency, but become depauperate and relatively homogeneous under intense disturbance[7] or in species-poor "climax" habitats[8]. Overall, there is evidence that native bee communities may be able to persist, at levels of substantial diversity and abundance in habitat fragments of modest size. These findings may suggest practical solutions for maintaining bee populations; if land use planning can address the foraging and nesting needs of bees, even small reserves may contribute to sustaining and conserving the ecological services pollinators provide.

4.4 SPECIALIZATION AND GENERALIZATION

The degree of specialization and generalization, both of pollinators and plants, has fascinated naturalists at least since the time of Darwin[9]. Yet several recent conclusions run counter to initial expectations. It has been assumed that specialist plants (with complex flowers whose resources can only be accessed by particular pollinators) have pollinators that then specialize as well, so the relationships become more or less one-on-one mutualisms, or "lock and key". The corollary view to this has been that generalist flowers, easily accessible to many pollinating insects, are visited by generalist insects that gather pollen and nectar from a wide range of flowers. It has thus been predicted that specialized plants will be more affected by habitat fragmentation than will generalized plants. From a set of studies including those carried out in Argentina over the past few years, however, this assumption has been challenged[10]. In a number of systems, specialization appears to be highly asymmetric: specialized plants tend to be pollinated by insects that themselves visit a broad range of other types of flowers. The main food plants of specialist pollinators are more often than not generalist flowers.

This highlights the reasons why the boundaries of the systems impacted by species loss may be extended further than expected. If a particular plant is host to both generalist and specialist pollinators, its loss will surely impact the specialist pollinator, but it may also impact a generalist pollinator that is at the same time the most effective pollinator of another plant. The erosion of pollinator communities through the loss of generalists may initially have little impact on the delivery of pollination services; however, continued loss of pollinators could result in the sudden collapse of services once a crucial threshold is reached.

4.5 LINKS BETWEEN BIODIVERSITY AND POLLINATION EFFECTIVENESS OF INDIVIDUAL PLANTS OR CROPS

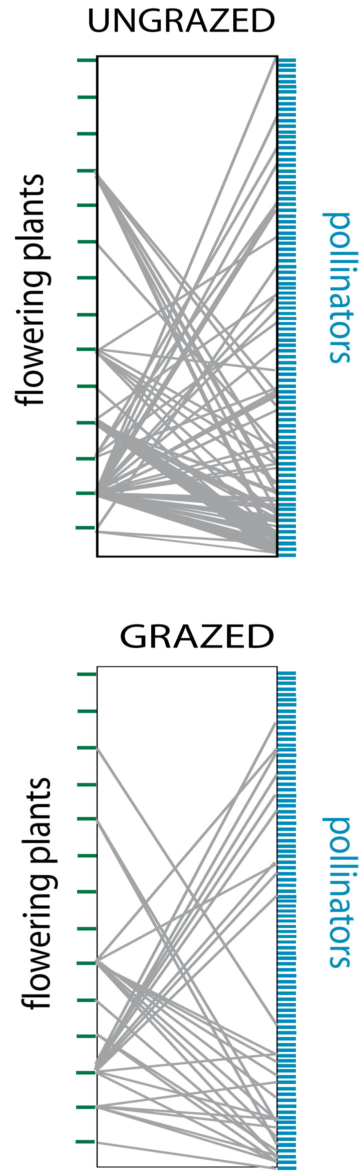
Pollination services have a direct correlation with biodiversity: in several studies, pollination services were best rendered not by a single 'stellar' pollinator, but by a suite of pollinators. Pollinator populations rise and fall, as do all animals, in response to environmental variables such as weather conditions, levels of parasitism, or abundance of nesting sites. Therefore the same plant may be pollinated by different pollinators in different places, but each being specific at its locality in that season. Over time, the same population of plants may have different pollinators in different seasons or years. Pollinators are often quite variable in relation to ambient conditions, and a species that is a relatively unimportant in one year may be of greater importance in the next year[11]. For many crops, the more pollinator visits the better: increased seed set and better quality fruit may result from multiple pollinator visits[12].

4.6 LINKS BETWEEN BIODIVERSITY AND POLLINATION EFFECTIVENESS OF COMMUNITIES: POLLINATION WEBS

The vast majority of plant-pollinator interactions are embedded in a complex web of plant-pollinator interactions. The first quantitative plant-pollinator webs to be constructed, in a meadow in the UK, found a total of 2722 interactions recorded among 26 species of flowering plant and 79 species of pollinator[13]. Since then, the concept of mapping plant-pollinator interactions has been extended to studies in Costa Rica, Argentina, Kenya, Mauritius and the Galapagos Islands[14].

To understand how plant communities respond to changes in the diversity of their pollinating fauna, researchers have experimented with increasing the functional diversity of both plants and pollinators under natural conditions[15], showing that this led to the recruitment of more diverse plant communities. After two years those plant communities pollinated by the most functionally diverse pollinator assemblages contained about 50% more plant species than did plant communities pollinated by less-diverse pollinator assemblages. These results support the concept that a functional diversity of pollination networks may be critical to ecosystem sustainability.

Pollination webs can illustrate the effects of disturbance on ecosystems, as has been shown in studies of livestock grazing in the southern Andes. The effect of livestock grazing was shown not just to impact native species of plants, but to cause serious disruptions to the networks and links between pollinators and plants. Pollination networks are also being used to provide insight into how alien invasive



Plant–pollinator interaction network in one site. Lines indicate pairs of interacting species; frequency of interaction is related to line thickness.

BOX 4-A. LIVESTOCK GRAZING AND POLLINATION WEBS IN THE SOUTHERN ANDES

In the southern Andes, the effect of livestock grazing does not just impact native species of plants. In a region of high endemism, high diversity and one of the highest incidences of animal pollination and seed-dispersal recorded for any temperate biome, livestock grazing has been shown to be capable of modifying the structure of entire networks of interacting species.

Plant–pollinator interactions were looked at in grazed and ungrazed sites. A key interaction in both sites are those between the herb Amancay *Alstroemeria aurea* and the bumblebee *Bombus dahlbomii.* These are the most generalized pollinator and plant species, respectively, in the study system and as such, they interact with a large number of species, many of them rare species. Although the vast majority of these interactions may be virtually irrelevant for the bee and the herb, they are likely to be important for the rare specialists involved in them.

Cattle trampling resulted in less pollen deposited on each flower from the same species, and more deposited- or contaminated- from other species. Thus, by affecting the pollination "quality" (the degree of contamination of pollen with othe pollen grains) cattle indirectly affect the reproduction of Amancay, in spite of no detectable effect on the visitation rate by pollinators.

Amancay is an important resource for a broad guild of flower-visiting insects. It is virtually the only insect-pollinated plant flowering in the summer in the *Nothofagus dombeyii* forest. Many insect species that visit Amancay may not visit other species. Thus, the decreased abundance of Amancay in grazed sites could negatively affect the assemblage of flower visitors.

from Vargas (2004).

species may affect ecosystems. In a re-examination of what is probably the most complete set of observations of animal visitors to flowers, it was shown that on average the flowers of alien plants were visited by significantly fewer animal species than those of native plants, and the web of interactions between flowers and visitors was less richly connected for alien plants than for natives[16].

4.7 ECOLOGICAL RESPONSES TO RECOGNISED THREATS TO POLLINATION SERVICES

Threats to pollination services are thought to be primarily from changing land use patterns, habitat loss, use of agricultural chemicals, climate change, diseases, and alien invasive species. All of these merit greater documentation; for example, there exist very few field (as opposed to laboratory) studies of pesticide applications and its impacts on wild pollinators.

A deeper understanding of how ecosystems, including agroecosystems and their pollinator communities respond to threat and disturbances is also needed. Some evidence from recent research includes:

Lack of a compensating population response to losses

Under anthropogenic disturbance, such as that created by industrial agriculture with larger field sizes, monocultures, and intensive use of agricultural chemicals, the largest and most efficient pollinators of crop plants may be the first lost. In a study of watermelon pollinators in California under a range of cropping systems from organic and near wild habitat, to farms under conventional management and far from wild habitat, bee communities were significantly more diverse and abundant in organic farming systems, near natural habitat. They did not appear to show any classic density-dependent relationships, such that when large, efficient pollinators became locally extinct, they were not replaced by an upsurge in population numbers of other bees present[17].

Increased inbreeding of plants

In tropical forest ecosystems where tropical timber trees are selectively harvested, the greater distances that may result amongst individual trees will have an impact on pollination services. Those species that are pollinated by weakly flying insects show increased levels of inbreeding as the density of reproductive individuals declines, while species pollinated by more strongly flying insects are less affected[18].

Specialization in modes of plant reproduction is an adaptation to ensure wide genetic diversity in a plant population. Populations of water hyacinth, in its native habitat of Brazil, have three different floral types that differ in the length and position of their reproductive organs: stamens and styles. To produce seed, the flowers need to be visited by pollinators that are able to both pick up and transfer pollen from at least one of the three positions. When a specialized bee is missing from water hyacinth habitat, the tristylous system breaks down, and the breeding system becomes more simplified, resulting in loss of genetic diversity[19].

Increased competition for pollinators

Plants that produce relatively large amounts of floral resources or produce flowers over prolonged periods are very successful in attracting pollinators. Where pollinators are in limited supply, such an outcome is likely to have implications for relative seed set among competing species. Many successful alien invaders, such as Lantana (*Lantana camara*), have such characteristics of profuse nectar and prolonged flower production. Such a scenario has been found in Thailand, where the reduction of canopy cover by illegal logging of *Shorea siamensis* in seasonally dry deciduous forest at Huay Kha Khaeng Wildlife Sanctuary in Thailand facilitated an increase in the understory herbaceous cover, including the alien invasive *Chromolaena odorata*. The presence of the alien invasive, which flowers continuously, disrupted the foraging patterns and drew butterfly pollinators away from an important diptocarp canopy tree[20]. Similar effects of alien invasive plant species drawing pollinators away from native flowering plants, and reducing their seed set has been seen in Europe[21] and North America[22].

Increased flowering resources under disturbance

The impact on pollinators in a cloud forest of Cerro Campana in central Panama is an example illustrating a scenario contrary to the one just described above. The disturbances within a protected forest caused considerable regeneration of a secondary growth tree, *Vochysia*, which begins flowering at a young age. From 1978 to 2004, the abundance of a large, seasonal orchid bee increased over 10-fold, probably due to the abundant flowering resource of the *Vochysia*[23].

Displacement of native pollinators

In the savanna-forest region of northern French Guiana, periodic sampling at ground-level flowers of *Mimosa pudica* has contributed to a census dating back to 1977 of bees at several sites. During a seasonal floral dearth, many bees are concentrated at such flower patches. The census has been able to observe the effects of the introduction of the Africanized honeybee. These bees have completely replaced native stingless (Meliponine) bees at flowers near more open areas, but were relatively uncommon in extensively forested areas. The increase in honeybee dominance corresponded to a decrease in total visitation of flowers; in other words, the introduced honeybees drove down pollination diversity[24]. Other studies have found similar competitive effects of introduced pollinators on native species[25].

4.8 RESTORATION AND SOUND ECOLOGICAL MANAGEMENT OF POLLINATOR BIODIVERSITY

Restoration schemes are normally evaluated in terms of whether target species re-establish themselves. While this is useful information, it does not reveal how species interact in restored systems or how sustainable restored systems are. Recent work has used pollination webs to evaluate the success of haymeadow and heathland restoration in the UK. While flower visitation patterns and pollen transport differed between old versus restored meadows and heathland, restoration of plant-pollinator interactions were successful and the restored communities were functioning in broadly similar ways to the older established ecosystems[26].

Understanding those factors that determine the number and type of pollinators found in particular landscapes is essential to knowing how to conserve, manage and restore pollinator communities. If it is known which properties of the habitat are responsible for maintaining the diversity of pollinators then ways of manipulating these properties to support greater biodiversity can be encouraged[27]. Flowering resources are usually identified as the most important resources for pollinators, and indeed, floral abundance and floral diversity are important. In addition, there is an increasing body of evidence suggesting that nest sites and nesting

BOX 4-B. UNDERSTANDING POLLINATOR COMMUNITY ORGANISATION CAN HELP MANAGE POLLINATOR BIODIVERSITY

© Shay Levay

Wild fires - a common disturbance on Mt. Carmel

Photo: Shay Levay

Habropoda tarsata hovering in front of *Anchusa undulata*

The National Reserve on Mt Carmel in Israel - occuring in a region of high bee and flower diversity - was surveyed for two years, to understand the effects of post-fire conditions on pollinators.

Fire may initially have catastrophic effect on the bee communities. Recovery was rapid with a peak in diversity of both flowers and bees in the first 2 years post-fire, followed by a steady decline over the next 50 years. The regeneration of floral communities was closely matched by that of their principal pollinators. Nectar volume, nectar water content, nectar concentration and the diversity of nectar resources were all greatest immediately following fire with a steady decrease as regeneration proceeds.

This process was moderated by the effects of grazing. Bee and flower species richness were highest at moderate grazing intensities, whilst abundance continued to increase even at the highest intensities of grazing. Cattle inhibited the growth of some of the dominant shrubs, creating or maintaining more open patches, where light-demanding herbs could grow and allowing a diverse flora to develop.

Identifying the drivers promoting the habitat properties which produce the greatest benefits to bee (and pollinator) biodiversity is key to understanding how whole communities can be effectively managed. In this study, both fire and grazing are potentially useful tools for creating and maintaining floral communities and providing nesting resources to conserve and protect bee diversity in the region.

from Potts (2004).

resources may also play important roles, particularly for bees. Bees exhibit a diverse array of nesting strategies with respect to the part of the habitat they nest in, the type of substrate they use, and the materials required for nest construction. Indeed, bees have been partitioned into several exclusive guilds on the basis of their nesting habits, known as miners, masons, carpenters, and social nesters. Miners dominate in many open habitats and excavate holes in the ground. Masons generally use pre-existing cavities in which to construct their nests, and these may be pithy or hollow plant stems, small rock cavities, abandoned insect burrows, or even snail shells. Leaf-cutters are a sub-group of masons that use pre-existing cavities and line their nest with freshly gathered leaf material. Carpenters excavate their own nests in woody substrate. Social nesters use larger pre-existing cavities to build large social nests.

Few studies have attempted to quantify the combined effect of these structuring agents, but there are efforts now underway to identify and quantify the diverse resource needs of bees, and link these to the structuring of pollinator communities.

4.9 PRIORITIZING POLLINATOR CONSERVATION EFFORTS

With an increased appreciation of pollination webs, the conservation community is beginning to identify what may be necessary to do to conserve the fine web of interactions and relationships that sustain pollinator services in ecosystems. Pollinator conservation interventions may be different from conventional species conservation projects. For example, in the United Kingdom (one of the few countries where pollinator populations are well documented enough that their abundance, or rarity, is known), there are distinct associations, or compartments in pollinator-plant communities. The shapes of flowers restrict the number of visitors that can "work" flowers appropriately for effective pollination. For example, long tubular flowers can often only be "worked" by long-tongued insects; thus plants and pollinators can be sorted into "flower type/ visitor morphology" compartments. In agricultural landscapes in the UK, under continued ploughing and disturbance, the small insect/small flower compartment may actually be promoted, but the perennial flowers that sustain a large bee/large flower compartment will usually be eliminated. With few flowers to sustain larger bees, the bees will cease to visit resource-poor fields and field margins. As such perennials are often self-incompatible, their reproduction will suffer. One bumblebee, *Bombus hortorum*, is now almost the sole remaining long-tongued visitor to flowers with deep corollas in British farming landscapes. Yet it receives none of the attention or specific efforts to conserve its populations, as does the rare *Bombus sylvarum*[28].

Little is known about the pollinators of rare plants, which is cause for concern given that pollination is essential for the long-term survival of most plant species. Species of arable weeds are among those suffering the greatest declines in the U.K., and recent work sought to determine the likely pollinators of three species of arable weeds: Red Hemp-nettle *Galeopsis angustifolia*, Small-flowered Catchfly *Silene gallica* and Spreading Hedge-parsley *Torilis arvensis*. All three species of rare plant were linked to other plant species in the community by shared pollinators. These other plant species in many cases would constitute the primary food sources for the shared pollinators. Therefore, the long-term survival of rare plant populations is likely to depend on the more common plant species in the community[29].

CONCLUSION

The ecology of pollination services reinforces the need for using an ecosystem approach when addressing the conservation and management of pollination. Pollination services function as a result of dynamic relationships between species and the environment. Pollinator communities have an inherent robustness in that many species often serve as pollinators to specific plants, each with somewhat different effectiveness or responses to environmental change. However, the loss of particular pollinator species then reduces the resilience of the ecosystem to change. The conservation and, where appropriate, restoration of interactions and processes such as pollination is of greater significance for the long-term maintenance of biological diversity than simply protection of species.

View of experts on the way forward

1. A better understanding of factors that affect pollinator populations in different types of ecosystems, and the characteristics of landscapes that maintain robust and healthy levels of pollination services, is needed.

2. Interaction information on pollination should be databased and made available for use by pollination practitioners and land managers, in the same way that purely taxonomic information is now becoming more publicly accessible[30].
3. Species conservation efforts that hinge on plant reproduction should be rethought to consider pollination interactions, where this has not been considered before.

Chapter Four Endnotes

[1] Thompson 1997; Vázquez 2003, 2004.
[2] 1stRAPS Case study contribution: 3.5-003P.urbanisationKearns
[3] Eltz et al. 2002; Samejima et al. 2004.
[4] Cane 2001.
[5] Becker et al. 1991; Aizen & Feinsinger 1994; Donaldson et al. 2002; Tonhasca et al. 2002.
[6] Saville et al. 1997; Law & Lean 1999; Steffan-Dewenter 2003.
[7] Tscharntke et al. 2005; Chacoff & Aizen 2006.
[8] Winfree, Griswold & Kremen 2007; Gikungu 2006.
[9] Darwin 1862.
[10] Aizen et al. 2002; Vazquez & Aizen 2004.
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[12] Alderz 1966; Kremen et al. 2002.
[13] Memmott 1999.
[14] http://www.bio.bris.ac.uk/expedition/origin.htm; Vazquez 2004; Memmott 2004; http://www.homepages.ed.ac.uk/amegilla/pollination%20page; http://www.unizh.ch/uwinst/research/projects/pollination.html
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[16] Memmott & Waser 2002.
[17] Kremen 2004; Kremen & Chaplin-Kramer (in press).
[18] CIFOR annual report 1997: www.cifor.org
[19] Alvos Santos 2004.
[20] Ghazoul 2002.
[21] Chittka & Schürkens 2001.
[22] Brown, Mitchell & Graham 2002.
[23] Roubik 2004.
[24] Roubik 1996.
[25] Thomson 2006.
[26] Memmot 2004; Lyzau Forup 2003; Lyzau Forup and Memmot (in press).
[27] Potts et al. 2003; Potts 2004; Potts et al. 2004; Potts et al. 2005.
[28] Corbet 2000.
[29] Gibson, in submission.
[30] An important component of such a database will be keeping *individual* records (ie, one observation of one pollinator on one plant species at a given place and time) so that statistical biases can be controlled for in analyzing the data. If individual records are not kept, there will be a built-in bias towards concluding that more abundant species are more generalized (because they will, by chance alone, be found to interact with more other species (Winfree, pers. comm.)

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CHAPTER FIVE: INDIGENOUS KNOWLEDGE OF POLLINATION

The role and importance of local knowledge as a basis for participatory development is well recognized. The potential to build socially and ecologically sound approaches to agricultural development by understanding, respecting and utilizing local knowledge systems is great. However, while there is a growing documentation of local management practices with respect to such areas as pest management[1], local management practices of pollination services have received very little attention. This chapter attempts to address why this might be, and how it relates to the characteristics of indigenous knowledge of pollination. A modest body of documentation of local knowledge in indigenous bee management does exist.

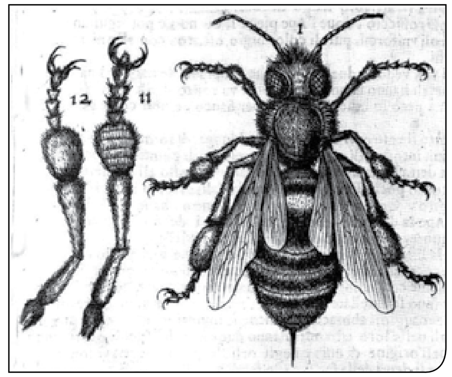
5.1 LOCAL KNOWLEDGE OF POLLINATION SERVICES

An assessment of the state of indigenous knowledge of pollination carried out through visits to selected areas of Bolivia, New Zealand and South Africa in 1998 had a common thread: indigenous knowledge of pollination varies markedly even within a single community[4]. In the Yungas region of the Andes in Bolivia, the range of beliefs and understanding amongst the Ayamara people who inhabit this area were very wide. Some farmers believed that bees were detrimental to flowers because they sucked energy from them, whereas some others had a complex, and very accurate knowledge of what the bees do when they visit flowers and how important bees are for production in certain crops. Despite this, the farmers as a whole did not take measures explicitly to protect pollinator populations in the region. The status of the pollinator community was in any case diverse and healthy, due to the absence of both insecticides and industrial agricultural practices.

Amongst Brazil nut collectors on the Amazonian frontier of Bolivia, in the state of Pando, knowledge of pollination services also varied widely. Some believed that the bees visiting Brazil nut flowers were responsible for making the flowers fall and thus were detrimental to the production. Others said that they knew that the trees needed bees to visit the flowers for fruit to be produced and that the most common bee visitors relied on orchids in the forest when the Brazilnut trees were not blooming. These people's description of the common bee visitors were consistent with the *Eulema* bee species that have been observed in scientific studies of this crop[5]. They said that when there was no forest there were no bees. But again, despite some people's complex knowledge of the bees, measures were not being taken to preserve pollinator habitat. In some areas, ranchers removed all trees except Brazil nut trees, whose production would then fall.

New Zealand has a particularly restricted bee fauna of only 35-50 native bee species all of which are solitary bees. Despite the diverse taxa of wild pollinators- including flies, beetles, bumblebees, and solitary bees visiting kiwifruit flowers - few farmers consider wild pollinators to be an important source of pollination. Most crop pollination was perceived to be performed by commercial (imported) honeybees and other exotic bees including bumblebees[6].

Local knowledge of pollinator behaviour and nesting needs are often strongest when pollinators live in close proximity to people. In Egypt, as economic development grows, the human/pollinator relationship slowly erodes, as can be seen in the case of Egyptian clover[7]. Egyptian clover, *Trifolium alexandrinium*, is the traditional forage crop in Egypt. Planted since at least the time of the Pharaohs, it is grown as an annual crop in the winter and spring. After several cuttings for hay, a few fields are left an extra month to set seed, while the rest of the crop is ploughed under to make way for summer crops. Egyptian clover is part of a mandated crop rotation in much of the Nile delta where cotton is grown for export. Female solitary bees such as some members of the genus *Megachile* pollinate most of the flowers that they visit. Researchers have found that a community of Megachilid bees make their nests in tunnels in the walls of mud houses. This community of bees nesting in mud houses is particularly interesting because of the mutualistic relationship between humans and bees. The bees depend on people to create a dynamic nesting habitat consisting of constantly renewed mud walls and alfalfa and clover fields. In exchange, the bees provide a service to the farmers by pollinating flowers so seed can be harvested for the following year. Many populations of *Megachile* in mud houses have been displaced or eliminated as modern brick and cement block buildings have replaced traditional mud houses; however, researchers are helping farming communities to provide alternative nesting materials. Similarly, in Bolivia, the habits of one particular stingless social bee ("chakalari") is well known locally, in part because it made its hives on the sides of the adobe houses[8].


Anatomy of a bee, Stelluti (1630)

The difficulty of seeing the work of pollinators has surely contributed to the low level of appreciation in much local knowledge. The scientific world was quite late in understanding the service that insects render in visiting flowers[9], and a full appreciation of pollinators, especially bees only came about with the invention of the microscope, around 1595[10].

5.2 LOCAL KNOWLEDGE SYSTEMS AND THE BROADER ENVIRONMENTAL CONTEXT OF POLLINATION

Local knowledge of pollination may not necessarily relate solely to the needs for insect visitation to flowers. Part of local knowledge is knowing what crops can grow in different sites, and that often the ability of a crop to produce in a particular agroecosystem may hinge on the environmental conditions (temperature, lack of rain, etc.) for optimum pollination. This is an aspect of local knowledge that researchers at the International Center of Tropical Agriculture (CIAT) have tried to capture and disseminate through the HOMOLOGUE project[11], with tables on Site Characteristics for Good Crop Performance.

Local knowledge of promoting pollination services may be embedded in a more holistic appreciation of the role of biodiversity on-farm, including its multiple benefits for natural pest control and provision of medicinal plants, as well as providing alternate forage to attract pollinators.

5.3 POLLINATION IN ON-FARM BREEDING

While the majority of the world's staple crops are wind pollinated (rice, wheat, maize) or reproduce vegetatively (cassava, yams, potatoes), many other crops- vegetable crops, horticultural crops- that are dependent on pollination have tended toward greater reliance on self pollination as they have been subjected to modern breeding programs. It is quite possible that cultivars needing greater pollination services have been excluded from cultivation if the breeder did not appreciate the need to provide pollination services, even if those services might result in increased yields. On the other hand, land races growing under the selective pressure of diverse home gardens may have retained characteristics that make them attractive to pollinators (see Box 5-A).

The localised economic importance of many "secondary" crops or multi-purpose plants that may have multiple roles; (for example, as both medicinal plants and forage crops[13]), is often quite large. These plants, which have generally not been subjected to breeding programs, are often quite pollinator dependent[14].

5.4 LOCAL KNOWLEDGE OF WILD BEE MANAGEMENT

In cultures throughout the world, social bees have been honoured through picture and song, appreciated for the production of honey, and amongst some cultures revered as magical or even divine. The long history of interactions between people and honeybees, beginning with the rock paintings of the Mesolithic cave dwellers has been well-documented, including the variety of methods used by human beekeepers, the stratagems used by animal honey-hunters, and the multitude of products humans have derived from bees[15]. In addition to honeybees, there is a long cultural tradition of honey hunting and domestication of other species of honeybees in Asia, and of stingless bees amongst many cultures in Latin America[16]. Traditional taxonomic systems, as well as indigenous understanding of wild bee behavior and biology parallels and often exceeds levels in western science[17].

CONCLUSIONS

Indigenous knowledge of pollination is quite variable, even within one community.

BOX 5-A. BOTTLE GOURDS, PEOPLE AND POLLINATORS IN AFRICA

The use as a container of the cucurbit fruit known as 'bottlegourd' straddles many African cultures. The classic African bottle gourd, *Lagenaria* spp., comes from strong-growing annual climbers with an ancient pan-tropical distribution. It is believed that the gene centre of the bottle gourd is Africa but wild species have not been found; the plants seem to grow naturally around human settlements. What is remarkable about bottle gourds is their amazingly high diversity of fruit size and shape as well as shell colour, texture and thickness. The diversity is different between ethnic groups with some forms being found only in certain community groups where the cultivars are maintained by local custom. The bottle gourd is usually grown in traditional systems where pollination is left to natural factors.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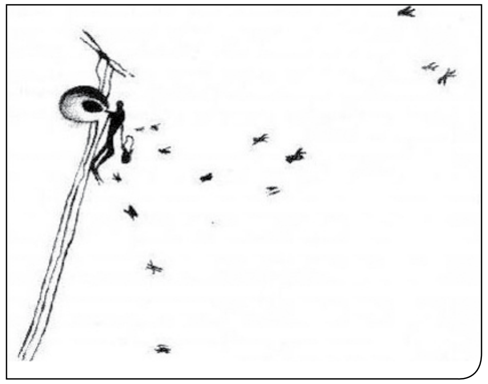
Bottle gourd flowers visited by a honey bee.


© Yasuyuki Morimoto

Bottle gourds grow around human settlements, and have a large diversity of sizes, shapes and colours.

As the species is dependent on insects for pollination it makes sense to believe that insects are also crucial in maintaining this diversity. Unfortunately very little is documented about the plant's biological diversity and little is known about its reproduction mechanisms. A recent study in Kenya looked at the mechanism of pollen transfer in several species of bottle gourd. Four groups of flower visitors comprising hawk moths (*Hippotion celerio*, *Agrius convolvuli*), noctuid moths (Noctuidae), skipper butterflies (*Gorgyra johnstoni*) and honey bees (*Apis mellifera*) were considered active flower visitors. Nightvisiting hawk moths were thought to be the major pollinators of this plant in the locations surveyed.

from Morimoto et al. (2004).



Petroglyph showing honey collection from a wild bee hive, Cave of the Spider, Valencia, Spain

Knowledge often resides with particular individuals with strong or innate understanding of natural history. The understanding of pollinator behaviour needs are reinforced when pollinators live in close proximity to people. Despite some people's or communities' sophisticated understanding of pollination, measures by communities are rarely being taken to preserve pollinator habitat. Indigenous knowledge of honey-producing bees is much greater, and has a long and rich tradition.

View of experts on the way forward

1. Local management practices supporting pollination services and indigenous bee management should serve as the foundation of future recommendations for pro-pollinator management practices.
2. *In-situ* management of plant genetic resources can benefit by greater consideration of the role of pollination in the conservation of plant genetic diversity.

Chapter Five Endnotes

[1] Fliert,van de & Proost 1999; Stoll 2000.
[2] According to the Inter-Commission Task Force (UNEP 1992).
[3] Kauzeni and Madulu 2003.
[4] Mayfield 2004.
[5] Nelson et al.1985.
[6] Ricketts, Williams and Mayfield 2006.
[7] Kamal 2004.
[8] Mayfield 2004.
[9] Sprengel 1793.
[10] Freedberg, 2002.
[11] http://www.ciat.cgiar.org/tropical_fruits/crops.htm
[12] Shetty 2005
[13] Oba et al. 2003
[14] Kamal 2004; Strickler 2001.
[15] Crane 1999.
[16] Cortopassi-Laurino et al 2006; Buchmann 2005; Weaver and Weaver 1981.
[17] Byarugaba 2004.

CHAPTER SIX: PROMOTION OF POLLINATOR-FRIENDLY PRACTICES

6.1 INTRODUCTION

The need for a stronger focus on pollination management for sustainable livelihoods is highlighted in case study contributions to this report from countries as diverse as Nepal, Pakistan, India, China, the United Kingdom, Ghana, Kenya, Egypt, Colombia, Brazil, Panama, Costa Rica, Mexico and the United States[1]. Although the agroecosystems described in these case studies are quite diverse, similar patterns are evident. Almost uniformly, the role of flower visitors to agricultural production is underappreciated. Without deliberate efforts to promote pollination services, these services are vulnerable under agricultural intensification practices. However, research has shown that there are specific practices that farmers and land managers can take to promote the viability of pollination services even under intensification.

6.2 GAPS AND NEEDS IN POLLINATION MANAGEMENT

The lack of pollination management, and the lost opportunities to increase yields and sustainability through deliberate attention to pollination services, are highlighted in pear production systems in China (see Box 6-A)[2]. In this case, as in many other countries worldwide, the development of pollinator-friendly practices, coupled with greater public awareness of the role of pollination, is urgently needed as a key contribution to sustainable agricultural systems.

BOX 6-A. HUMAN "BEES" POLLINATE PEARS IN CHINA

China faces the task of continuing to support high agricultural productivity while both the agricultural land base is declining, and rural incomes are not keeping pace with incomes from other sectors. Cultivation of various fruit trees is considered one of the most important options for income generation, with limited cultivated land. Pears are one of the important temperate fruit crops and their cultivation has been promoted, especially in mountainous and hilly areas of China. Most pear varieties are self-incompatible and cross-pollination by different varieties is required. Remarkably, most of the pear trees are pollinated by hand. Extensive hand pollination began in the mid-1980s when large-scale pear cultivation started. An epidemic of pear lice some years ago led to the adoption of intensive use of insecticides, and since then there has been a dearth of wild and domesticated bees. Growers estimate that without hand pollination, yields would drop by 90 to 95%

The problems of low fruit set became more prominent when cultivation intensified, and attempts to introduce other varieties for cross-pollination were not very successful, in part because the other varieties flowered at times different from the main pear crop. Through hand pollination, farmers have learned the intricacies of how to prepare pollen for pollination and how and when to pollinate pears. The fact that humans are the main pollinators of pears in this area of China has given rise to a number of other dynamics. Some families have planted polliniser trees (that is, other varieties capable of cross-pollinating the flowers on the main pear variety) in home gardens where the flowers cannot be stolen, and are selling the pollen. In some instances, pollen has even been exported to Japan.

Having people replace insect pollinators is leading to new insights in just how demanding it is to utilize human labour for an ecosystem service. In the case of pears in China, farmers now know that when it is sunny, clear and hot, most flowers bloom within one to three days, and pollination must be completed within that time; yet every flower must be "visited" by a human pollinator twice. Usually a person can pollinate 30-40 trees a day. When it is sunny and the temperature is high, and flowers bloom for short periods, labour must be hired to help pollinate flowers. When it is very hot and pear flowers must be pollinated within a very short period, labour costs may double. Thus, weather determines the total labour inputs. Labourers are usually hired from areas where there is experience in carrying out hand pollination; untrained labours are very rarely hired and women are preferred for this work. Each tree is pollinated 2-5 times, and farmers recognize that this actually leads to overpollination, such that they must then spend considerable time thinning out young fruit, but this is preferred over risking insufficient fruit set. Understandably, growers in this area have strongly expressed their requirements for alternatives that can replace or reduce dependence on hand pollination.

from Ya et al. (2004).

© Uma Partap

Hand pollination of pear trees in China

6.3 PRACTICES TO PROMOTE POLLINATION SERVICES

Increasingly, the value of promoting a diversity of wild pollinators rather than solely depending on managed honeybees is gaining recognition[3]. In order to understand the pollination options for agriculture, it is helpful to review the similarities between wild and crop pollination systems and to appreciate why most wild pollination systems utilize a diversity of pollinators. One can envision a situation in which two main pollinators visit a plant[4]. One is a vastly superior pollinator in terms of the amount of pollen transferred from male to female reproductive parts, but is a very erratic visitor, visiting only every other year. The other pollinator is not very good at transferring pollen but is a reliable and constant visitor. In this situation, it would not make sense for the plant to prevent the poor pollinator from visiting since this would eliminate its reproductive potential every other year. Although agricultural systems are simpler and more controlled than natural systems, variation still exists in the visitation rates of each pollinator type and in the ability of pollinator species to pollinate flowers of a given crop. Managed pollinators suffer as much, if not more, from the impacts of parasites and disease. From the standpoint of risk avoidance and optimal and sustainable production, a diversity of pollinators can best maintain healthy, robust pollination services- in wild pollination systems, but equally in crop pollination systems.

Amongst the pollinator-friendly practices that have been recognized are those described in the following sections:

Recognizing pollination as an agricultural input

For quite some time, agronomists have relegated pollination to a relatively minor role in crop production. Recognizing that the majority of world staples (e.g. wheat, rice, maize, potatoes, yam, cassava) are either wind-pollinated, self-pollinated, or are propagated vegetatively, pollination management has not emerged as a uniformly critical element of crop production. But this conception is rapidly changing; the dependence of many horticultural crops on pollinators for percentage fruit set, yield and quality is increasingly recognized[5].

Coffee provides a good case in point; as an autogamous plant, flowers automatically self-pollinate, and pollination has rarely been addressed in coffee research. However, recent studies in Panama[6] and Costa Rica have both shown that coffee bean yield increases 7 to 56% as the result of bee visitations. In Panama, it was observed that there was over 25% fruit retention increases from pollinating visits by bees, and the coffee beans were over 25% heavier and developed faster with open pollination. Yield benefit from open pollination in a 1997 study, chiefly by Africanized honeybees, was 56%. A second study in 2001 did not show such high abundance of honeybees over native bees, but still demonstrated that yield increased by over 50% in flowers visited by bees[7].

Cataloguing the resource needs of pollinator groups

The key resources for pollinators that need to be considered in managing agricultural landscapes for effective pollination services are their habitats for nesting, and adequate nectar and pollen resources over the season when pollinators are active. Habitat considerations for pollinators in agricultural landscapes include the following considerations: tillage practices may destroy the ground nesting sites of bees; pollinators of crops such as watermelon appear to rapidly colonise agricultural fields, nesting immediately adjacent to the flowering crop. Leaving these nesting sites undisturbed, both for the current season's pollination period, but also for maturity of bee larvae, may be important for maintaining populations of wild pollinating bees[8]. Removal of native vegetation in wild habitat patches – for example, for fuelwood, or clearance for agriculture may eliminate woody and live vegetation nesting sites.

Information on the habitat needs and alternate floral resources of specific pollinators are very difficult for field personnel to access. Efforts to bring this information into searchable databases, as described below for stingless bees in Latin America, are very valuable.

Stingless bees are very important pollinators in many tropical regions of the world (*Trigona, Plebeia, Melipona* and related genera[9]). Many stingless bee populations are reliant on the proximity of primary or secondary forest and may be heavily impacted by logging and other means of habitat disturbance. For example, crops as diverse as chayote (*Sechium edule*), longan (*Nephelium longana*) and cupuassu (*Theobroma grandiflorum*) suffered from a shortage of *Trigona* pollination in regions lacking forest remnants. Often, the factor most limiting stingless bee populations are the number of specific tree species providing suitable nest sites, and floral resources. In South America, where stingless bee diversity is highest in the world, there has been considerable effort applied to understanding the ecology and resource needs of stingless bees. The Brazilian Pollinator Initiative has established databases[10] of:

(1) Trees that are used as nesting sites in South and Central America and in Asia.

(2) Floral resources visited by social bees (including stingless bees) in Brazil, as extracted not only from published papers, but also from unpublished papers, or thesis and data of casual observations mentioned in the literature.

(3) Floral resources, a floral calendar, and plant species used as nesting sites for a common and economically important stingless bee in South America, *Tetragonisca angustula* in an urban area.

BOX 6-B. STINGLESS BEES CONSERVATION AND MANAGEMENT IN RIO GRANDE DO SUL, BRAZIL.

In Rio Grande do Sul, a Brazilian state where most land has been altered by agriculture, an initiative on the sustainable use and conservation of stingless bees as a resource for ecosystem services is being developed through a set of pilot projects. These pilot projects are based on local innovations of good practices for management and use of stingless bees.

The first pilot in Cambará do Sul focuses on the management practices of the family Macedo. Their farm was bought 70 years ago by Vilmar Dutra de Carvalho, who soon became aware of the local presence of stingless bees nests and never allowed the cutting of trees that harbored bee nests. With his son Selvio Macedo, the two delighted in observing bees foraging, and Selvio has continued with the protection of this area after his father's death. Selvio knows how to find the endangered *Melipona bicolor* schencki nests (see photo below) and the trees that make hollows available to them. Researchers are helping him in stingless bee conservation and breeding techniques. A pine plantation for a nearby cellulose factory is the most common tree species adjacent to his farm, and stingless bees depend upon the plantation for foraging for pollen. Researchers are working with local community members such as Selvio to diversify land use, incorporating farming, plantation forestry, and ecotourism related to local plants and animals, with consideration of the foraging and nesting needs of stingless bees.


© Vera Imperatriz-Fonseca

The family Macedo and their nests for an endangered stingless bee.


© Vera Imperatriz-Fonseca

Plebia nigricips nests in chalchal trunks

The second pilot concerns the breeding of small *Plebeia nigriceps* colonies by Ildo Lubke, a small farmer that has lived in the same area for 71 years. When he was 8 years old, he received as a gift from his father the first colony of this tiny bee species. During all his life he protected this small bee and learned how to manage their colonies. He constructed nests for the bee colonies using trunks of chal-chal (*Allophylus edulis*) He learned by himself how to divide nests, observed clouds of males and reproductive swarms, how to manage their nests in winter and keep those near in small meliponaries around his house. Now he is teaching his grandson in the management of this bee, that produces a very small quantity of honey but probably is an important local pollinator. He has protected around 300 nests of a species that is almost unknown to science.


© Fernando Dias

The endangered stingless bee, *Melipona bicolor*

The third pilot includes nine smallholder farm families that live in the Atlantic Rainforest, a biodiversity hotspot, in Riozinho and Rolante. They have joined together in an association called Papa-mel, and assist each other in developing techniques to care for stingless bees and honeybees to obtain organic honey. Researchers are working with them to build skills in environmental conservation, and the establishment of nurseries with native plants used by the stingless bees (*Melipona bicolor* schencki and *Melipona marginata*) as food and nests sites. Cooperation between scientists and land users are the two sides of effort that focus the knowledge, protection and sustainable use of local bees for conservation and agricultural improvement.

from Witter, Blochtein & Imperatriz-Fonseca (pers. comm.)

Many proponents of pollinator conservation have noted that much of the ecological knowledge of pollinators is contained in the rather fragmented, inaccessible grey literature of reports and student projects; making these accessible to practitioners is a challenge. The ALARM project has produced an integrated database of European bees which draws together all the fragmented literature and many of the existing databases. The centralized European Bee Database includes species-specific information for a broad range of traits including information on floral preferences, nesting sites, flight seasons and habitat use[11]. This type of information will be very valuable in developing pollination management plans for specific crops and their key pollinators.

Recognizing the value and preserving wild habitat in an agricultural matrix

As resource needs for pollinators are catalogued, it becomes increasingly evident that patches of wild habitat in agricultural landscapes can provide refuges for pollinators that then can service agricultural fields in a radius around such patches[12,13].

Many plants require a special kind of pollination action, called "buzz pollination". The flowers of these plants have a tubular anther, with an opening at the end. Bees must visit the flower, bite the anther and vibrate their wings at a certain frequency, which then causes the pollen to be expelled out of the opening. A surprisingly large number of crops require buzz pollination, including eggplants, tomatoes, blueberries, and cranberries. Honeybees are not very effective at buzz pollination; thus those crops that need this special kind of action are largely dependent on wild pollinating bees. In the Nguruman area of southwestern Kenya, eggplants are being grown in fields cleared from riverine Acacia forest, for the export horticultural market. Important wild bee pollinators of eggplant were identified. Since eggplant provides only pollen and no nectar, visiting bees must visit nectar-bearing flowering plants for food. For most of the year, the wild bees could fulfill their needs for alternative forage from the many flowers of indigenous herbs growing as arable weeds along field edges and paths. But, in the height of the dry season, these herbs dry up. During this time, the eggplant pollinators forage among those riverine Acacia forests that have not yet been cleared for crops; here, understory flowers benefit from the coolness and moisture of the umbrella acacias above. Even if critical for only one month out of the year, this resource is nonetheless essential if pollinator populations are to be sustained and active year-round. The value of the Acacia forest to crop production - because of the needs of pollinators - has protected several forest stands from being cleared[14].

Fostering genetic resilience through pollination

Agricultural practices that were developed during the green revolution of the 1970s resulted in drastic reductions in the genetic diversity used for the production of most

crops in many regions of the world. This reduction stems from the development of hybrid varieties and new breeding techniques that allow for the production of identical genetic varieties in response to market demands for consistent crop products. Some crops now functionally have low levels of genetic diversity that make them highly susceptible to disease epidemics, such as the infamous Irish potato famine. A more recent instance is the susceptibility of five major commercial cultivars of banana to the fungal disease black sigatoka, resulting in Central America countries losing nearly 47% of their banana yield.

Up to 30% of the world's annual harvest of crop plants continues to be lost to pests and diseases, with developing countries experiencing the greatest devastation. The resulting economic and food resource costs are, to a significant extent, a consequence of the continuing evolution of new races of pests and pathogens that are able to overcome resistance genes introduced by modern breeding creating the phenomenon of boom and bust cycles. Breeding programs are in place to develop new varieties and to replace varieties that have lost their resistance. However, the maintenance cost of the current system is high. The International Center for Wheat and Maize (CIMMYT), based in Mexico, reportedly spent 35% of its budget in 1989 on 'maintenance research'[15], serving to reintroduce new genetic material into crops to overcome losses of resistance.

Increasing the genetic diversity of crops is beneficial for disease prevention, for meeting the modern demand for heirloom crop varieties and for preserving local varieties of historical, local and global significance. Cross-pollination of many crops can be used to sustain and reincorporate genetic diversity, particularly where crops are grown in regions with wild relatives.

A case in point is tequila, produced from blue agave (*Agave tequilana*)[16]. Vast fields of blue agave cover the western state of Jalisco in Mexico. However, these agaves are permitted to flower only extremely rarely. The plants are produced in their sixth to ninth year, precisely when they are getting ready to flower and their sugar content is the highest. These agave "heads" are then cooked and pressed, and their juices fermented and distilled, stored, aged, and bottled. Up to 600 brands of tequila existed in Mexico in the late nineties. At around that time, a disease afflicted the agave fields of western Mexico. Up to 40% of the plants were reported to have died in their sixth to eighth year of age, when they were getting ready to be harvested, due to a combination of a fungus and a bacteria.

The agave industry does not rely on plants produced by seed, but rather uses clones of plants produced asexually. The agave plants used for tequila production have undergone a long and sophisticated process of artificial selection. Agave growers say that the plants they have now provide the highest grade of prime matter and therefore the best of tequilas. The only problem is that all these agaves, covering in excess of 400,000 hectares in western Mexico alone, are actually clones of only two plants. It has been suggested that the effects of the disease that affected these agaves was particularly severe due to the low genetic diversity.

There are two species of bats responsible for pollination of these plants. Both species are listed as endangered in the U. S. Endangered Species Act and as threatened in the Mexican legislation. It has been proposed to the Tequila Regulatory Council of Mexico that the disease that has killed a large number of plants might be partially mitigated if a small percentage (of around 0.1%) of the plants are allowed to bloom and bats are then allowed to exchange pollen with the wild agave types in the nearby barrancas. In this fashion, "bat-friendly" tequila could be produced, promoting consumer appreciation for the natural history supporting the production of tequila, enhancement of biological resources for endangered pollinators and also conservation of the biological processes of pollination and sustained genetic diversity.

Appreciation of the habitat needs of long-distance flying pollinators

Many important ecosystem services, including pollination, are delivered by organisms whose populations depend on habitats that may be widely separated- either in time or space- from the location where services are provided. Bees are central-place foragers, which means they return to a centralized nest location between foraging bouts, yet may provide pollination services up to several kilometers away from their nests. Other pollinators, such as moths, may fly remarkably long distances across varied terrain, in search of host plants. Management of mobile organisms and the services they provide requires consideration not only of the local scale where services are delivered, but also the distribution of resources at the landscape scale, and the foraging ranges and dispersal movements of the organisms themselves[17].

A good instance of this is provided by papaya, as it is grown in Kenya. Papaya is a dioecious crop, with separate male and female plants. Farmers often eliminate the male plants, as they are not 'fruitful'; yet they are critical for fruit production. Preliminary observations on Kenyan farms show that various large moth species that fly at sunrise, sunset or during the night are the primary pollinators of most papaya crops. Most moths visit papaya flowers in the hour or two following dusk. This is a fairly narrow window and only the large, fast-flying hawkmoths visit both male and female flowers at this time, and are able to cover the distances between widely dispersed male and female trees on farmers' fields quickly.

Farmers need to protect and encourage hawkmoths for adequate fruit set on papaya. Farms located within wild areas have high yields and traditionally produce the best-tasting fruit. Papaya farmers in agro-biodiverse systems can benefit from protecting hawkmoth pollinators by providing habitat and leaving areas for larval food plants. In addition, as many of these moths travel long distances, they serve as an incentive to protect wild areas adjacent to and within agricultural landscapes[18].

A well-developed initiative has evolved between Mexico, the United States and Canada, to engage citizen scientists in the long-distance migration patterns and resource needs of Monarch butterflies, important pollinators of milkweed plants[19]. The program produces data that relate to a serious conservation issue, while providing resources for children to use in school projects and reports. The program involves more than 2,000 schools, nature centers, and other organizations yearly, and more than 100,000 students and adults participate in tagging activities each fall.

Pollination concerns specific to crops with different breeding systems

Like wild plants, crop species have different breeding systems. The dependence of crops on insect pollination largely depends on the breeding system of the crop. Most insect pollinated crops have both female and male reproductive organs in the same flower, also known as hermaphroditic. Of these, some are self-compatible (meaning they are able to pollinate themselves), and others are self-incompatible, requiring pollen from a different plant. Either of these may rely on insect pollinators. For crops with flowers that may automatically self-pollinate, so that fruits and seeds may be set in the absence of pollinators, the quality and quantity of seed often improves after insect visitation (such as citrus).

Other breeding systems include dioecy (separate male and female plants);

BOX 6-C. PRACTICES TO PROMOTE BUMBLEBEES IN FARMLAND.

Bumblebees are major pollinators of many crops and wildflowers in the temperate northern hemisphere. Many bumblebee species have declined dramatically in these areas, and the declines are linked to the intensification of farming practices.

After WWII in the UK, farmers were encouraged to increase yields on farmed land and to bring unfarmed areas into production. Permanent unimproved grassland was once highly valued for grazing and hay production. Availability of cheap artificial fertilizers and new fast-growing grass varieties meant that farmers could improve productivity by ploughing up ancient grasslands. Hay meadows gave way to monocultures of grasses. Between 1932 and 1984 over 90% of unimproved lowland grassland was lost in the UK. Development grants were also introduced to grub out hedgerows, to plough and re-seed pasture and to drain marshy areas. This lead to a steady decline in the area of unfarmed land and of unimproved and semi-improved farmland.

With the loss of hedgerows and unimproved herb-rich grassland there has been a loss of botanical diversity on farms. The process has been further accelerated by increasing use of herbicides, which directly impact on flowers, and by increasing use of fertilizers which allow a few rapid growing plant species to outcompete and exclude slower growing species. In combination, changes in farming practices have resulted in the decline or loss of many plant species that were formerly common.

Bees are entirely dependent on flowers, since they feed exclusively on pollen and nectar. On farmland, the crops themselves may provide an abundance of food during their brief flowering periods. Leguminous crops (notably clovers, *Trifolium* spp.) used to be an important part of crop rotations in much of Europe, and these are highly preferred food sources, particularly for long-tongued bumblebees. Since the introduction of cheap artificial fertilizers, rotations involving legumes have been almost entirely abandoned.


© David Goulson

B. subterraneus became extinct in the UK in the 1980's and is in danger of extinction throughout Europe

For bumblebees to thrive they require a continuous succession of flowers from April to July, and crops alone are unlikely to provide this. Bumblebees do not store large quantities of honey in the way that honeybees do, and they store little pollen, so they are vulnerable to discontinuities in the food supply. The nest establishment phase in spring when the queen has to singlehandedly gather sufficient forage to feed her first batch of offspring may be the time when availability of flowers is most vital, but few crops flower this early. Thus unless farms contain areas of wildflowers, they will not support bumblebees.

There are good financial reasons for conserving bumblebees. The yields of many field, fruit and seed crops are greatly enhanced by bumblebee visitation. For example field beans are largely dependent on pollination by longer tongued bumblebees. Bumblebees are thought to be more reliable pollinators than honeybees, particularly because they will continue foraging even when it is cold and wet. In a poor spring bumblebee queens may be amongst the only insects that remain active enough to pollinate early-flowering crops such as hard fruits.

In Europe there is now an emphasis on combining the goals of agriculture and conservation. Incentives are in place for farmers to adopt any of a range of schemes which aim to reduce yields and increase farmland wildlife. All of these schemes increase the abundance and diversity of flowers that are available. But the types of flowers are also important. The bumblebees that have declined most in the UK are all medium or long-tongued species, and these prefer perennial flowers; thus schemes where communities of long-lived flowering plants are allowed to develop over time are best. Tussocky grass favored for nesting by above-ground nesting bumblebees is provided by long-term set aside, permanent uncropped field margins and by "beetlebanks". Replanting of hedgerows and repair of damaged hedgerows provides more sites for species that nest underground in holes. Moves to organic farming may aid bumblebees; rich bumblebee communities including rare species have been identified on organic farms. Apart from the obvious avoidance of use of pesticides, organic farms are favourable for bees because they depend heavily on rotations involving legumes such as clover to maintain soil fertility. Above all, unimproved, flower-rich pasture is a very valuable habitat for bumblebee species. It has been argued that the decline of several long-tongued bumblebees in France and Belgium is largely attributable to a decline in the area of leguminous fodder crops once grown to feed horses. Some of the best remaining habitats are grasslands maintained by cattle or by grazing of sheep in the winter only (with animals moved to higher ground in the summer). Essentially all that seems to be required is a consistent regime of moderate or rotational grazing without use of artificial fertilizers.

from Goulson (2004).

monoecy (male and female flowers on the same plant); and andromonoecy (male and hermaphroditic flowers on the same plant). Crops with these breeding systems tend to be very dependent on animal pollination services. Amongst those plants requiring insect pollination, there is a group of plants that are nearly always self- fertile but have separate male and female flowers so that fruit and seed set depends on insect pollination. Several economically important crops exhibiting different breeding systems are provided in Table 6-1.

TABLE 6-1

Breeding systems and representative crops

BREEDING SYSTEM	REPRESENTATIVE CROPS
hermaphroditic	Orange, buckwheat, blueberry, cardamom
monoecious	Melon, watermelon, squash, gourds, oilpalm, coconut
andromonoecious	Cashew, mango
dioecious	Papaya, kiwifruit

The behavior of insects toward some of the crops in these categories becomes more understandable if their role is appreciated. Observations of oil palm flowers in Ghana, for instance, showed that by far the most abundant visitors were oil palm beetles, along with other small beetles[20]. Many beetles do not seem to be so much visitors as residents, clearly remaining on a flower for long periods of time and consuming pollen. However, their efficacy is better understood when the reproductive biology of the plant is appreciated. On palm trees with separate male and female flowers, floral visitors can improve pollination by disturbing the pollen on male flowers, causing some portion to become airborne and thus drift to female flowers[21].

Management of native wild bees instead of domesticated and imported bees

A substantial industry in the rearing and export of managed bee species for pollination has arisen in the last decades, testifying to the economic value of pollination. The domesticated honeybee, *Apis mellifera* (and its several Asian relatives) have been utilized to provide managed pollination systems. But for many crops, honeybees are either not effective or are suboptimal pollinators. While managed honeybee populations can often make up in numbers what each individual bee lacks in effectiveness, honeybee populations have been subjected to a number of serious threats- tracheal mites, disease, the newly mysterious "Colony Collapse Disorder"- which over the past decade have decimated bee populations on several continents, with potentially severe repercussions for agricultural production.

An example is the crisis in pollination of low bush blueberries in the state of Maine in the United States, recognized at least since the early 1990s. Cross-pollination of low bush blueberry by bees is essential for obtaining good fruit set and yield, and historically native wild bees provided this service. Pesticide use and habitat alterations have reduced populations of native bees, particularly in the large Maine blueberry barrens, so that it is now necessary for most growers to rent honey bee colonies. The heavy dependence on honeybees to pollinate low bush blueberry is demonstrated by the fact that in 2002 over 60,000 hives were brought into Maine for pollination of this crop. However, parasites, diseases, the threat of Africanized honeybees, and low profit margins jeopardized the supply of honey bees and contributed to a substantial increase in the rental price per colony. These factors have led to a search for alternatives, focusing on the protection and conservation of the native bees that pollinate lowbush blueberry. Mason and leafcutting bees (*Osmia* spp.), so named for their use of mud or leaves in nest construction, became the first target group for population enhancement because their phenology is well synchronized with blueberry bloom. Reducing insecticide use and encouraging the presence of alternate forage plants along field edges, as well as provision of artificial nesting blocks in fields, dramatically increased the sizes of *Osmia* populations[22].

A focus on wild native bees also stems from concerns over the consequences of introducing alien pollinators, and the potential deleterious impact on native pollinators[23]. Colombia is one country that has been faced with making policy decisions on the importation of a European bumblebee for greenhouse and crop pollination. A group of Colombian researchers have taken stock of the fact that the native bee fauna of Colombia, while diverse, is little studied and the health of its populations is not known. Native bumblebees have an important role to play in conserving watersheds in the highlands of Colombia, where they are able to function effectively even in cold mountain climates. Over the last three years, a group of scientists has been studying the biology and ecology of native bumblebee species in Colombia in their natural habitats and have developed a local technology to rear species under captivity. Once the technology of managing colonies is developed, it is expected that they can be used instead of imported alien bumblebee species, to pollinate greenhouse and field crops to increase fruit quality and production. The group is also addressing good landscape management practices as strategies to assure pollination services and bumblebee diversity conservation[24].

Providing habitat on-farm

Patches of forests and wild habitat in agricultural landscapes are important for maintaining pollinator populations, but overall habitat management on-farm, including field edges, cover crops, and trees on farm also provide critical habitat to pollinators. Identification of measures to ensure season-long nectar and pollen resources for pollinators may include such practices as the planting of trees in cardamom plantations, to provide year round floral resources that sustain wild bees which also pollinate cardamom fields[25].

Specific measures that are recognized in agri-environment scheme prescriptions to conserve and enhance pollinator biodiversity in production landscapes include the following (from the Environmental Stewardship component of the England Rural Development Programme[26]):

- Buffer strips: Sown field margins provide forage (nectar and pollen) and nesting resources for pollinators as well as buffering boundary habitats against agrochemical sprays.
- Sown grasslands: Including pollen and nectar flowers in grassland mixes can increase the diversity, abundance and availability of forage resources.
- Hedgerow management: Careful management of hedges can create and protect habitats suitable for pollinators.
- Permanent grasslands: Establishing grasslands with very low inputs provides long-term habitats for pollinators.

A considerable body of research on measures to conserve specific pollinators has contributed to the proposal and adoption of mitigation measures. The effectiveness of bumblebees as pollinators and their high public profile make them the focus of much conservation effort. Bumblebees are major pollinators of crops (e.g. field beans, oilseed rape, raspberries, currants etc.) and of many wildflowers. Bumblebees have declined greatly in abundance throughout Europe and North America, and several countrywide extinctions in the UK have occurred (see Box 6-C)[27]. Declines in the UK bumblebee fauna of 19 species during the late twentieth century have been such that three species are now considered extinct, and only six remain widespread in the agricultural landscape[28]. The principal cause of these declines is thought to be the intensification of agriculture, especially where this has reduced the amount and distribution of suitable forage resources, and from spillover of diseases from commercially reared bumble bee colonies used in glasshouses to wild colonies[29]. Farm intensification has particularly led to loss of unimproved, species-rich grasslands such as hay meadows, with severe impacts on bumblebee species[30] .

A recent literature review identified key forage plants for bumblebees and highlighted the large number of these, which have declined in the UK countryside as a result of landscape change. A research group in the UK has been evaluating the effectiveness of different habitat management schemes on arable field margins for conserving bumblebee populations, and simultaneously identifying best pollination management practices for farming communities[31]. Preliminary results suggest that introducing suitable forage mixtures to arable field margins can attract high densities of bumblebees, including those of rare species. With appropriate establishment and field management (such as regular cutting in the first year and a yearly autumn cut thereafter at times that encourage greater flowering) these habitats provide forage for much of the season and also benefit other pollinator groups when compared to conventional crop management. Further research is now underway to assess the effects of habitat creation (introduced forage mixtures) and landscape quality on bumblebee populations. This will be important to inform decisions on the appropriate scale of habitat creation required to sustain populations, and could help in the targeting of agri-environmental policies aimed at enhancing pollinator densities in the agricultural landscape. This research suggests that restoration of legume-rich grasslands should be given a high priority, with management carried out on a large scale (spanning areas of >10km^2) to ensure success.

An additional initiative addressing the same problem - the characteristics of agricultural grasslands that are needed to maintain diverse pollinators - has focused particularly on intensive livestock operations. Vegetation composition and structure (often referred to as 'architecture') are of key importance to both the abundance and diversity of invertebrates. However, one of the effects of intensive grassland management is the simplification of the grassland community, or sward, so that it becomes structurally homogenous. Structurally simple swards have reduced (or totally absent) vegetation structure necessary for the foraging and reproduction of many pollinator species.

The benefits of using different field margin treatments rather than intensively managed grass fields in terms of insect and bird biodiversity was assessed by applying field margin treatments that vary the structural diversity. Treatments ranged from relatively simple practical options that farmers might adopt (e.g. raising mowing height, or grazing leniently, or delaying cutting date) to leaving margins uncut or ungrazed throughout the summer, or establishing diverse sown margins with seed and nectar source plant species. Several promising management techniques have been identified that may serve to reconcile the conflicting needs of agricultural production and biodiversity conservation in livestock farms[32].

In the United States, the USDA Natural Resources Conservation Service is working closely with the Xerces Society to integrate pollinators into the current NRCS conservation programs. This has included training field advisors, producing information leaflets, and identifying which of the existing conservation practices can be used to create pollinator habitat on farms.

Understanding the biology and resource requirements of native pollinators under agricultural development

Along with the well-known changes accompanying agricultural development such as larger field sizes and more intensive use of inputs, other more subtle impacts on native pollinators may occur. An example of this is given in the case study contribution from Egypt[33]. Agriculture development in Egypt has progressed rapidly in recent years. In the coming few years, an additional one million acres of new lands are expected to be brought under cultivation. But production in both the new lands and the older fields is becoming limited due to lack of pollination. The lack of pollinating insects in old and new fields is likely to be the result of a combination

issues that have been considered throughout this chapter: loss of habitat and use of pesticides. Alfalfa- a critically important crop for Egypt- needs *megachilid* bees to properly "trip" the flower and pollinate the crop for seed production. Nesting sites of *megachilid* bees- including sites in traditional mud walls as mentioned in chapter 5- are being lost. Researchers in Egypt have documented these problems. They have studied the natural nesting habits and life cycle of a native leaf-cutting bee, as well as the potential for providing artificial nesting material, with the aim to develop a management system for native leaf cutting bees to increase seed production of alfalfa.

As agricultural systems become more intensive, it is important to assess exactly what the impact of this is on the pollinator community, and what measures may be taken to mitigate the impacts. The contributions of wild bee pollinators to pollination of four crops - watermelon, sunflower, almond and tomato - was investigated in the Central Valley of California, one of the most important agricultural regions in North America[34]. The studies were conducted along a gradient of agricultural intensification, from intensively managed farms in a primarily agricultural landscape, to less intensively managed farms in a primarily natural landscape. Over sixty species of wild, unmanaged bees were found visiting crops in this area. Wild bee diversity, abundance and services declined significantly with agricultural intensification. Unfortunately, those visitors that were the most effective pollinators were the first to become locally extinct as the agricultural system became more intensive. Unlike some other insect interactions, other species did not then increase in abundance to compensate for the loss of the most effective pollinators. It was concluded that farmers could undertake certain specific actions to mitigate the loss of pollination services. For example, a suite of wild plants was identified that can provide resources for the most important crop pollinators throughout their adult flight periods. Working together with a non-governmental organization, the researchers have developed information sheets for farmers describing these results in accessible terms, and detailed guidelines on management actions that farmers can take to improve habitat for wild bees on their farms.

It is evident that there are many options for farmers and land managers to promote pollination services even under agricultural intensification. Many of these options start with understanding and appreciating the subtle but important roles of flower visitors.

CONCLUSIONS

Practices to promote pollination services are in the early stages of being identified, as the role of pollination as an agricultural input, along with water, nutrients and pest control, is gaining recognition, even in crops where it was previously discounted. Some identified practices include conservation of patches of wild habitat- such as forests or structurally diverse grasslands- in agricultural landscapes. Others will require targeted assessments and explicit conservation of pollinator resource needs- for example, fallen branches as nesting sites. Often, pollinator-friendly practices will lead farmers and land managers to think (and then to manage) on a landscape scale, as pollinators can range over several kilometres. Case studies showed that use and promotion of indigenous species of bees over alien imports merits consideration. Pro-pollinator practices that seek to reduce and rationalise the use of agricultural chemicals can build on existing good practices for plant protection, and may contribute to win-win solutions for farmers and consumers. Good pollination practices have an important role to play in maintaining genetic diversity. All of these practices need greater examination and documentation in a large diversity of farming systems.

View of experts on the way forward

1. Pollination services should become an integral part of agricultural research and extension.
2. The resource needs of pollinators are an information source that should be made more readily available to the agricultural community, and to land managers.
3. Pollinators should be considered a key component of genetic resource conservation and should be addressed in plant breeding initiatives.
4. Governments should be encouraged to provide incentives (or penalties for failure to do so) to farmers to include pollinator practices as a standard part of good farming practice.

Chapter Six Endnotes

[1] The complete list of case study contributions can be found www.fao.org/ag/AGP/AGPS/C-CAB/Castudies/.
[2] Ya et al. 2004.
[3] Allen-Wardell et al. 1998; Kremen et al. 2002; Kremen & Ricketts 2000.
[4] Mayfield 1998.
[5] Klein et al. 2007.
[6] Roubik 2004b.
[7] Roubik 2004b.
[8] Kremen et al. 2002.
[9] Heard 1999
[10] Imperatriz-Fonseca 2004.
[11] See www.alarmproject.net
[12] Ricketts et al. 2006; Kremen et al. 2002; Klein et al. 2002; Blanch and Cunningham 2006.
[13] Ricketts 2004.
[14] Gemmill-Herren and Ochieng 2008
[15] Bioversity 2006.
[16] Medellin 2004.
[17] Kremen et al 2007.
[18] Martins 2004.
[19] http://www.monarchwatch.org
[20] Kwapong 2004.
[21] Dhileepan 1992; 1994; Mariau et al. 1991; Ponnamma et al. 1986; Syed 1979.
[22] Stubbs and Drummond 2004.
[23] Ings et al. 2006.
[24] Almanza et al. 2004.
[25] Kuruvilla et al. 1995.
[26] http://www.defra.gov.uk/erdp/schemes/es/default.htm
[27] Almanza et al. 2004.
[28] Carvell et al. 2004
[29] Colla et al. 2006
[30] Goulson 2004.
[31] Carvell et al. 2004.
[32] Potts 2004.
[33] Kamal 2004.
[34] Kremen and Vaughn 2004.

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CHAPTER SEVEN: CAPACITY BUILDING IN CONSERVATION AND MANAGEMENT OF POLLINATION SERVICES

7.1 SCOPE OF CAPACITY BUILDING

Capacity building for conservation and management of pollination services must cover a wide range, from formal education at all levels, to the informal building of capacity amongst farmers, land managers, policy makers and other target groups, including the public as a whole. A particular emphasis is needed on building capacity in taxonomy and pollinator identification, since this is one of the major impediments to pollinator conservation.

7.2 FORMAL EDUCATION

Migratory pollinators have the potential to capture the interest and imagination of schoolchildren across borders, and have been featured in several cross-border school programs. The "Wings of Wonder" program connects cultures and students through the hands-on study of migratory wildlife such as monarchs and songbirds on nearby corporate property, in Mexico and the United States.

In a stocktaking report prepared in Ghana for the project development phase of an FAO/UNEP/GEF funded global project on "Conservation and Sustainable Management of Pollinators for Sustainable Agriculture through an Ecosystem Approach", it was noted that some aspects of pollination are covered even in primary school, with definition of the concept of pollination, and some illustration of the types and agents of pollination. At the secondary level in the Ghanaian curriculum, there is good coverage, including highlighting the characteristics of plants that depend on different types of pollination systems. At university level, however, the coverage is actually much less[1].

In several other countries where similar stocktaking assessments have been carried out, the general impression is that there is a lost opportunity to feature pollination biology as a subject in secondary school curriculum. At the university level, courses in pollination biology are available, but not common. Courses that address pollination are offered, for instance, in India and Brazil, but not in many other developing countries. Globally, pollinator conservation has rarely been integrated into courses on conservation biology, and pollination is not generally taught as part of agricultural sciences.

7.3 INFORMAL EDUCATION

Short courses

In the last five years, there have been several short courses on bee identification and pollination that have been developed. Among these have been:

- USA: The Bee Course (since 1999 in Portal, Arizona, with 4-5 international participants each year)[2]
- Africa: The African Bee Course (in 2003 in Ghana and Kenya and again in 2006 and 2008 in Kenya)
- Argentina: "Ecologia de la Polinizacion" course at Universidad Nacional del Comahue, Argentina, in 2005[3]

Farmer and extension training

The following points outline the challenges to building farmer and extension capacity in conserving and managing pollination services:

- The actions that will need to be taken to conserve and manage pollinators are not completely known; to a large extent, capacity must be built in an adaptive way, as knowledge is being gathered.
- Conserving a natural service cannot be done by simple prescriptions; land managers will need to work with the challenges of their local ecology and develop management systems tailored to a specific site.
- Those people most knowledgeable about pollination of a particular crop may be on another continent; therefore long-distance means of sharing information to build capacity needs to be developed.

- The taxonomic impediment creates a formidable barrier to practitioners knowing what their pollinators are and what scientific information is known about them.

BOX 7-A. THE MIGRATORY POLLINATORS PROGRAM: A CROSS BORDER PROGRAM FOR MIGRATORY POLLINATORS

This program, provided by the Arizona Sonoran Desert Museum in the United States, has worked on many different fronts to address the introduction of pollination biology and migratory pollinators into school curricula. They have made use of diverse techniques in providing teacher training. These techniques have included:

• Teacher training workshops covering pollination biology, migratory routes, pollinator importance/value, threats and conservation, and identification of pollinators and key floral resources, including a 22 hour certification based teacher training session on "Migratory Pollinators in the Sonoran Desert" . The program funded follow-up field trips for teachers and their students to experience the natural area first hand and observe pollinators in their habitats.

• Presentations, that reached more than 2,000 students in Sonora, on the climate and natural history of the Sonoran Desert, pollination biology, migration, hummingbirds, and bats. Hummingbird feeders and sugar were distributed to all schools where presentations were made. Teachers were enlisted to collect plant and hummingbird data for the Migratory Pollinator Project.

• Traveling pollinator "trunks" containing pollinator information, activities, and stories, were developed and distributed to 52 schools reaching more than 2,500 students through a team of 16 trained teachers. Pollination wisdom, migration challenges, habitat and conservation, people, nature, and culture were the foci of the education program.


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Monarch butterfly

from Brusca et al. (2007).

The Food and Agriculture Organization of the United Nations is working with partners to develop modules on pollination for Farmer Field Schools. In the United States, researchers have worked together with non-governmental organizations to bring the outcomes of crop pollination research to farmers, natural resource specialists working with farmers, and natural area managers. They have produced a publication, "Farming for Bees. Guidelines for Providing Native Bee Habitat on Farms", that promotes a three-step approach to pollinator conservation on farms, and other outreach material on management of wild pollinators[4].

7.4 PUBLIC AWARENESS AND CAPACITY TO UNDERSTAND THE IMPORTANCE OF POLLINATORS

Primarily scientists have identified the pollination crisis, and the level of awareness of pollination problems is probably highest within scientific communities. Yet it is vitally important that the capacity to understand pollination services is built amongst the public in general and policy makers in particular.

The challenges to increasing public awareness of pollination services are several:

- Pollinators are largely insects, which are more often perceived as pests than as beneficial insects.
- The process of pollination is very subtle, and often has not been understood by farmers, much less the general public.
- Public awareness is easier to raise around the loss of a particular charismatic species; pollinator conservation must find ways to convey to the public that what is endangered are the links and interactions between living things, not the individual species *per se*.

CONCLUSIONS

There is a paucity of attention to pollination services, at all levels of formal and informal education. Nonetheless, a number of initiatives have developed innovative approaches and curriculum material, which can be used as a basis for scaling-up the building of capacity to manage pollination services.

View of Experts on the Way Forward

1. Sharing of curriculum material to introduce pollination considerations in formal and informal education should be encouraged.
2. Building the capacity of policy makers to appreciate the role and contribution of pollinators is critical to raising the profile of the ecosystem service in policy making.

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Bee Course Participants, Portal, Arizona. 2002.

BOX 7-B. THE BEE COURSE

The Bee Course is a workshop offered to conservation biologists, pollination ecologists and other biologists who want to gain greater knowledge of the systematics and biology of bees. Since 1999 the American Museum of Natural History has been holding this yearly course in southern Arizona to teach people from many different biological fields how to identify North American (Mexico, USA, Canada) bee genera. Every course has been oversubscribed, attracting people from beyond the intended geographical range for the course, including Africa, the Middle East and South America. Such short courses have become a model for other courses, such as an Ant Course. The first African Bee Course was convened in Kenya and Ghana in 2003, and again in Kenya in 2006 and 2008 based on the original model and a draft key to African genera of bees.

Chapter Seven Endnotes

[1] Ghana stocktaking report, UNEP/GEF Pollinator Project
[2] http://research.amnh.org/invertzoo/beecourse/
[3] Vásquez 2004.
[4] Kremen and Vaughn 2004.

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CHAPTER EIGHT: MAINSTREAMING CONSERVATION AND MANAGEMENT OF POLLINATION SERVICES

8.1 IMPORTANCE OF MAINSTREAMING

As important as pollination services are to food production and ecosystem regeneration, it generally occurs below the horizon of awareness of policymakers, and has rarely been addressed in explicit policies to conserve and more effectively manage pollination services. Strategic ways are needed to mainstream pollination concerns into the relevant sectors and promote "pro-pollinator" actions. In addition to governmental policy, the role of citizen bodies in promoting pollination services is essential. This chapter discusses the developments in both.

8.2 INTERGOVERNMENTAL INITIATIVES

In recognition of a looming pollination crisis, there has been a mobilization of effort on several levels to address pollination management and conservation. On a global level, the international community has identified the importance of pollinators. Decision III/11 of the United Nations Convention on Biological Diversity (CBD) established the Programme of Work on Agricultural Biodiversity and called for priority attention to be given to components of biological diversity responsible for the maintenance of ecosystem services important for the sustainability of agriculture, including pollinators. In October 1998, the Workshop on the Conservation and Sustainable Use of Pollinators in Agriculture, with an Emphasis on Bees, was held in São Paulo, Brazil. The outcome of this workshop was the São Paulo Declaration on Pollinators, which was submitted by the Government of Brazil to the CBD's fifth meeting of its Subsidiary Body for Scientific, Technical and Technological Advice (SBSTTA 5).

Considering the urgent need to address the issue of the worldwide decline in pollinator diversity, the Conference of the Parties to the Convention Biological Diversity established an International Initiative for the Conservation and Sustainable Use of Pollinators (also known as the International Pollinators Initiative-IPI) in 2000 (COP decision V/5, section II) and requested the development of a plan of action. The CBD Executive Secretary was requested to "invite the Food and Agriculture Organization of the United Nations to facilitate and co-ordinate the Initiative in close co-operation with other relevant organizations." In November 2000, FAO organized a meeting with the participation of key experts to discuss how to elaborate the International Pollinators Initiative. Subsequently, a plan of action was prepared by FAO and the CBD Secretariat. The aim of the International Initiative for the Conservation and Sustainable Use of Pollinators (IPI) is to promote coordinated action worldwide to:

- Monitor pollinator decline, its causes and its impact on pollination services;
- Address the lack of taxonomic information on pollinators;
- Assess the economic value of pollination and the economic impact of the decline of pollination services; and
- Promote the conservation, restoration and sustainable use of pollinator diversity in agriculture and related ecosystems.

8.3 GOVERNMENT POLICY

The principal national sectors in which pollination merits consideration include environment and agriculture.

Environment

National Biodiversity Strategies and Action Plans. Every country that is party to the Convention on Biological Diversity has committed themselves to develop a National Biodiversity Strategy and Action Plan (NBSAP); a number of countries have included consideration of pollination in their NBSAP.

For example, in Pakistan's NBSAP, pollinators are specifically mentioned: "Biodiversity provides free of charge services worth hundreds of billions of rupees every year that are crucial to the well-being of Pakistan's society. These services include clean water, pure air, pollination, soil formation and protection, crop pest control, and the provision of foods, fuel, fibres and drugs. As elsewhere, these services are not widely recognised, nor are they properly valued in economic, or even social terms. Reduction in biodiversity (including local extinction of species) affects these ecosystem services. The sustainability of ecosystems depends to a large extent on the buffering capacity provided by having a rich and healthy diversity of genes, species and habitats. In that respect, biological diversity is like economic diversity in a city; it is essential for long term survival and a sound investment in the future."

South Africa's National Biodiversity Strategy and Action Plan recognizes the dependence of production sectors such as cultivation and plantation forestry on ecosystem services, including pollination.

In the UK, the National Biodiversity Action Plan[1] includes three types of specific action plans, for species, habitats and local planning. Of the 391 species plans, over a hundred of these focus on pollinators; many of the habitat plans address important pollinator habitats.

Clearing house mechanisms. Countries that are Parties to the Convention on Biological Diversity (CBD) and other countries have agreed to develop mechanisms for sharing biodiversity data with the public both on an international basis, through a clearinghouse mechanism[2], and on a national basis[3]. Through the clearinghouse mechanism, the CBD has fostered more efficient biodiversity information management in a number of countries. Pollination trends and news have been featured in the United States biodiversity information management portal[4], and in IABIN (Inter-American Biodiversity Information Network)[5]. IABIN was established in 1996 to provide the networking information infrastructure (such as standards and protocols) and biodiversity information content required by the countries of the Americas to improve decision-making, particularly for issues at the interface of human development and biodiversity conservation.

Protected areas. Pollinators have rarely figured in the design of protected areas, but that is changing. In Mexico, where bats are critical to the vegetation structure of over a vast areas of land and to the economic activities of pulque and tequila producers, concern over their status has prompted the government to amend Mexico's Federal Law of Wildlife to encompass all caves and crevices as protected areas[6]. The

European community has identified and protected 431 Prime Butterfly Areas in 37 sites[7]; in Serbia a Natura 2000 site (seriously threatened habitats protected by EU legislation) was protected because it serves as hoverfly habitat.

It has been noted that for insect pollinators the design of protected areas will require special considerations[8]. There are multiple considerations with respect to pollinator conservation: forage plants, very specific nesting habitats such as soft banks for ground-nesting bees, and the fact that bees, for instance of medium body size, can regularly fly up to two kilometres between nest sites and forage patches. But provided that reserve selection, design, and management can address the foraging and nesting needs of bees, networks of even small reserves could hold hope for sustaining considerable pollinator diversity and the ecological services pollinators provide.

Biodiversity regulations. More than a decade and a half after the adoption of the Convention on Biological Diversity (CBD), many countries are in the process of mainstreaming their commitments into national-level biodiversity regulations. While many of these are in draft form, they offer some strong tools for putting pollinator conservation into policy. For example, where the biological diversity is not in a protected area, Kenya's Environmental Management and Coordination Act provides for the Minister of Environment and Natural Resources "to declare any area of land…to be a protected natural environment for the purpose of promoting and preserving specific ecological processes, natural environment systems, natural beauty or …the preservation of biological diversity in general." In developing the guidelines and regulations to support this Act, a multi-stakeholder biodiversity taskforce first defined "specific ecological processes" to include soil erosion control, watershed services, soil fertility maintenance, microclimate regulation, pollination services, and wildlife migrations. Secondly, they recognized that the Ministry does not have sufficient eyes and ears to identify all such sites of environmental significance that might merit gazettement as a protected natural environment. Thus, provision has been made in the biodiversity regulations, for: "other lead agencies, District Environmental Committees, Provincial Environmental Committees, local communities and other members of civil society (to) propose sites for consideration as Environmentally Significant Areas". Through such measures, a community of coffee farmers, for example, could ask for the protection of a small forest or riparian zone that provides alternative forage and nesting sites to coffee pollinators.

Red Lists. Red Lists are national lists developed using the World Conservation Union (IUCN) criteria to identify levels of threats to species. For threatened pollinators, they can be very effective tools for guiding policy and local activities to prevent species loss. In Europe there are red lists including bees for: Spain, Switzerland, Germany, Great Britain, Lithuania, Latvia, Netherlands, Norway, Poland, Finland and Slovenia. These lists on average contain about a quarter of the total number of bee species in the country and may be up to half (e.g. Germany and Netherlands). The current Brazilian national and regional red lists include 130 terrestrial invertebrate species, of which 42% are butterflies[9]. The red list for North America includes fifty-eight bees and fifty-nine butterflies and moths. Many other countries include hoverflies and butterflies in their national red lists.

National Pollinator Initiatives. Brazil's national pollinator initiative, the Brazilian Pollinator Initiative (BPI) has a unique governmental structure, and has been active on many fronts. Brazil has formulated an Understanding for Technical Cooperation between its Environment and Agriculture ministries regarding research on biodiversity and forests, including pollinator conservation and management. A national committee of the Brazilian Pollinators Initiative is charged with a number of tasks; amongst these, they have undertaken an inventory of pollination demands of each region of the country for crops with pollination management needs, an exercise that will guide the initiative to focus on priority crops[10]. In 2004, the BPI supported a resolution that was adopted in Brazil to regulate the protection and use of native bees, including stingless bee breeding[11]. The resolution sought to rectify the fact that under previous policy, the rearing and management of an introduced bee (the honeybee) was legal, while sustainable use of an important natural resource in Brazil, stingless bees, was not legally recognized. The resolution noted the following factors: 1) the native bees, in any development phase, and living in natural environments outside captivity, are considered part of the wild Brazilian fauna; 2) these bees, their nests, shelters and natural breeding sites belong to the people and they are subject to collective use by the terms of the Federal Constitution; 3) the value of meliponiculture (beekeeping with stingless bees) to the local and regional economy and the importance of pollination by wild bees to the ecosystem stability and to agriculture sustainability; and 4) Brazil has been a major international proponent of the International Pollinators Initiative and its efforts to conserve and sustainably manage pollinators.

Agriculture

In the agricultural sector, pollination has often been overlooked in rural development strategies and is not included as a technological input in most agricultural development packages. High value agriculture is promoted by many governments, and agricultural development institutions offer packages of practices for different types of crops, but most overlook the importance of managing pollination to achieve a sustainable yield. Introducing substantive changes in agricultural development will first require changes in agricultural research and development investment policies, such that the research agenda recognizes pollination as an important aspect of crop productivity and seeks to identify optimal ways to use and conserve pollinators. Changing grower behaviour based on research findings is also another challenge that the policy environment can impact.

The importance of a supportive enabling environment for pollination services in agriculture is highlighted in the case study contribution on blueberries in Maine, USA. A multi-year research project aimed at securing pollination services for lowbush blueberries was funded by the state in Maine in response to a recognized crisis: cross-pollination of lowbush blueberry by bees is essential for obtaining good fruit set and yield[12], yet native wild bees have been heavily impacted by pesticide use and habitat loss. Growers have turned to renting honey bee colonies, yet parasites, diseases, the threat of Africanized honeybees, and low profit margins have jeopardized the supply of honey bees and contributed to a substantial increase in the rental price per colony. The research documented proven techniques of conserving native bees at the same time as reducing costs for honeybee rentals. But despite the fact that the authors of the study produced and disseminated educational publications, presented many grower talks, and conducted demonstration trials on native bee conservation, very few growers have actually adopted the recommendations for the conservation of native bees. The authors conclude that, "we have come to believe that specific local, state, or national incentives, such as tax credits or other mechanisms, are necessary to motivate growers to implement conservation practices."

Pollination and crop production. China has officially recognized pollination as an agricultural input, along with other conventional inputs such as fertilizers and pesticides[13]. But the degree to which pollination can contribute to sustainable crop yields has not been addressed in agricultural policies in most countries.

Pollination and regulation of agricultural chemicals. More than thirty years ago, Rachel Carson wrote the book "Silent Spring", outlining the detrimental effects of pesticides on the environment. Ms. Carson warned the world not just about "Silent Springs" but also about "fruitless falls" – in which there is no pollination and subsequently no fruit, due to pesticide poisonings of pollinators[14]. In many countries, there have been efforts to protect honeybees from poisoning by agricultural chemicals, but toxicity to other wild pollinators is rarely considered in agricultural regulations or included in label warnings.

Pollination and land stewardship programs. In Europe, agri-environmental schemes have been developed to reduce the use of agricultural chemicals and nutrients and to encourage farmers to carry out environmentally beneficial activities on their land[15]. The aim is to enhance biological diversity across a range of plant and animal groups, including pollinators. The cost to the farmer in supplying these environmental services is compensated through payments. Examples of the types of land management activities carried out include:

- Reversion of intensively used land to biologically diverse but unprofitable extensive land uses.
- Reduction in the use of nutrients.
- Reduction or cessation of use of pesticides (e.g. organic farming).
- Creation of nature zones taken out of production.
- Continuation of traditional environmental land management in zones liable to neglect.
- Maintenance of landscape features which are no longer agriculturally viable.

In the United Kingdom, a number of other land stewardship schemes exist, and new ones are under development that will specifically encourage pollinator-friendly options such as[16]:

- Buffer strips. Sown field margins provide forage (nectar and pollen) and nesting resources for pollinators as well as buffering boundary habitats against agrochemical sprays.
- Sown grasslands. Including pollen and nectar flowers in grassland mixes can increase the diversity, abundance and availability of forage resources.
- Hedgerow management. Careful management of hedges can create and protect habitats suitable for pollinators.
- Permanent grasslands. Establishing grasslands with very low inputs provides long-term habitats for pollinators.

8.4 PARTNERSHIPS TO PROMOTE POLLINATORS

In many regions and countries of the world, civil society groupings have formed around the issue of pollinator declines, conservation and sustainable management.

In countries as diverse as Colombia, Kenya and Ghana, national pollinator initiatives have been established and lead by civil society[17]. Often these are organized by national wild bees specialists, addressing scientific issues such as taxonomic identifications, pollinator distributions, community ecology of wild bees and plant-bee interactions. In Kenya, and in Ghana, representatives of the private sector have joined national pollinator initiatives.

Additionally, in a number of regions around the world, pollinator initiatives have been formed, and are building regional capacity in assessment and advocacy for pollinator conservation and use.

The North American Pollinator Protection Campaign (NAPPC) brings together experts in academia, research, government agencies, agriculture, private industry, environmental groups and interested individuals from Mexico, Canada, and the United States[18]. This public-private collaboration has made considerable progress in advancing the pollinator conservation agenda in the minds of the public and decision makers. NAPPC's specific goals are to:

- Strengthen the network of organizations working to conserve and protect pollinator populations.
- Raise awareness and educate about pollinators' contribution to agriculture, ecosystem health, and a healthy and affordable food supply.
- Promote open dialogue about pollinator conservation among individuals, institutions, and groups.
- Encourage collaborative partnerships and actions to multiply success in pollinator protection programs.
- Promote conservation, protection, and restoration of pollinator habitats.
- Document and support scientific, economic, and policy research, spanning a wide range of disciplines, concerning pollinators and pollinator habitat.

NAPPC works through a set of committees, including Conservation, Education, Special Partnerships, and Policies and Practices, that are action oriented: committees are asked to identify their target audiences, the specific behaviors that need to be encouraged with this audience, ways to measure the outcomes of these behaviors, and the benefits and barriers to those behaviors. Amongst the means they have used to advocate for more positive outcomes for pollinators are included information bulletins for target audiences, encouraging research and analysis by proposing a US National Academy of Sciences survey of the status of pollinators in North America, the sponsorship of a "Pollinator Protection Award" to corporate members of the Wildlife Habitat Council that show exceptional pollinator friendly practices, and through advocacy for international, national and regional policies and practices that require or encourage the protection of pollinators or their habitats. The NAPPC Nature's Partners curriculum offers a range of inquiry-based activities suitable for classrooms and gardens. Amongst their present successes in mainstreaming pollination, they are working with the conservationists of the state of Montana to design incentives for farmers, ranchers and landowners who invest in the health of pollinators by planting native and pollinator friendly plants in buffer zones. The hope is to develop this program as a case study to implement in states or regions.

The African Pollinator Initiative (API) is an Africa-wide group of people interested in and committed to protecting, understanding and promoting the essential process of pollination for sustaining livelihoods and conserving biological diversity in Africa. It was established during the first African Pollinator Initiative workshop held in

Kenya in 2002, and has produced a plan of action, a special issue of the International Journal of Tropical Insect Science, featuring pollination research findings in Africa, and an initial stocktaking report of "Crops, Browse and Pollinators in Africa"[19]. The API Plan of Action is organized around four components: Public Education and Awareness, Placing Pollination in the Mainstream, Conservation and Restoration, and Capacity Building.

The European Pollinator Initiative (EPI) was formed in response to growing evidence and concern over local declines of pollinators and loss of pollination services in Europe, and a sense that the problem is more widespread[20]. Although many scientists, governments and NGO's are working to conserve, manage and promote pollinators and the services they provide, there has been relatively little interaction between these groups at the continental level. Research and information exchange has been fragmented and in some cases has overlapped, and it was recognized that the full potential for conserving and sustainably managing pollinators for maximum societal benefit in Europe was far from being met. As a response, EPI has developed the following approaches:

- An interim steering committee has been established to guide the initial development of the EPI.
- Europe has been partitioned into 16 regions and each has a representative who is responsible for co-ordinating local activities. These representatives are informing potentially interested parties in their region and also feeding back information on local issues and concerns relating to pollination.
- In the short-term a centralized expertise database is being constructed.
- Longer term activities are covered by the EPI 'Plan of Action'.

EPI's Plan of Action is organised around the four elements of the International Pollinator Initiative:

(1) Assessment – quantifying the loss of pollinators in Europe and the risks associated with the loss of pollination services. These assessment objectives are already being pursued through the ALARM project[21] and national activities in other countries including Italy and Ireland.

(2) Adaptive management – Identifying the best management practices and technologies to overcome declines in pollinators and the services they provide.

(3) Capacity Building – Build and strengthen alliances and expertise in Europe to increase the benefits from pollination.

(4) Mainstreaming – Supporting national plans for the conservation and sustainable use of pollinators, and increasing the awareness of governments, industry and the public.

Amongst other civil society organizations supporting pollinator conservation is the International Bee Research Association (IBRA), a not-for-profit organization with a worldwide membership that was established in 1949[22]. IBRA aims to increase awareness of the vital role of bees in the environment and encourages the use of bees as wealth creators. It is a global network with a wealth of expertise and an extensive knowledge base that promotes the study and conservation of all bees and their value as bio-indicators.

CONCLUSIONS

Mainstreaming pollinator conservation and sustainable use into public policy requires the efforts of a diverse set of actors, from government agencies, intergovernmental organizations and civil society. Initiatives and efforts have been initiated on several levels. However, concrete and explicit policy approaches to conserve and better manage pollination services have not been well articulated in most countries or regions. Approaches at the local level in developing pro-pollinator policy are also needed, since this is the level at which most actions need to take place.

View of Experts on the Way Forward

1. The conservation of pollinators should be better integrated into regional, national and local policy for the environment, agriculture, and development sectors.
2. Exchange of information on different policy approaches to conserve and better manage pollination services should be encouraged.
3. Local level measures to encourage pollinator-friendly land management decisions merit better identification.

Chapter Eight Endnotes

[1] www.ukbap.org.uk
[2] http://www.biodiv.org/chm/default.aspx
[3] http://www.biodiv.org/chm/stats.asp
[4] http://pollinators.nbii.gov/
[5] http://www.iabin.net/english/about/background.shtml
[6] Medellin 2004.
[7] http://www.bc-europe.org/upload/PBA_summary.pdf; http://www.bc-europe.org/upload/PBA_summary.pdf;
[8] Cane 2001.
[9] Lewinsohn et al 2005.
[10] Brazil first national report, GEF Pollinator Project, FAO.
[11] Brazil first national report, GEF Pollinator Project, FAO.
[12] Free 1993; Delaplane and Mayer 2000.
[13] Uma Partap, ICIMOD, pers. comm.
[14] Carson 1962
[15] Potts 2004b.
[16] Potts 2004b
[17] Para 2004.
[18] Adams 2004.
[19] http://www.arc.agric.za/home.asp?pid=3493.
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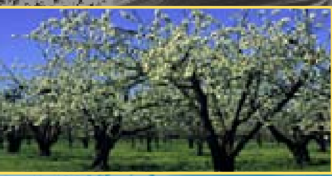
LIST OF ACRONYMS

ABIS	Automated Bee Indentification System
ALARM	Assessment of Large Scale Environmental Risks with Tested Methods
API	African Pollinator Initiative
BPI	Brazilian Pollinator Initiative
CBD	Convention on Biological Diversity
CBIT	Centre for Biological Information Technology
CIMMYT	International Center for Wheat and Maize
COP	Conference of Parties
DAISY	Digital Automated Identification SYstem
DNA	Deoxyribonucleic acid
EPI	European Pollinator Initiative
FAO	Food and Agriculture Organization of the United Nations
GBIF	Global Biodiversity Information Facility
GEF	Global Environment Facility
IABIN	Inter-American Biodiversity Information Network
IBRA	International Bee Research Association
IPI	International Pollinator Initiative, also known as International Initiative for the Conservation and Sustainable Use of Pollinators
IUCN	International Union for the Conservation of Nature, now World Conservation Union
NAPPC	North American Pollinator Protection Campaign
NBSAP	National biodiversity strategy and action plan
PCMM	Programa Para la Conservacion de Murciélagos Migratorios; Program for the Conservation of Migratory Bats
SBSTTA	Subsidiary Body for Scientific, Technical and Technological Advice
SPAS	Squash Pollinators of the Americas Survey
UNEP	United Nations Environment Programme

Pollination is critical for food production and human livelihoods, and directly links wild ecosystems with agricultural production systems. Concerns about the loss of pollinators - wild as well as managed - and the services they provide have continued to mount over the last decades. This first assessment of the status of pollinators addresses progress in different approaches to conserving and sustainably using pollination services.




GLOBAL ACTION ON POLLINATION SERVICES FOR SUSTAINABLE AGRICULTURE

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