Overview of Pollination in Agrobiodiversity Planning:

Principles and Best Practices

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Although agricultural biodiversity was not originally included as a thematic area in the Convention on Biological Diversity when it was first drafted in the early 1990's, it was soon recommended to be included by scientific advisors and biodiversity practioners alike, in view of the fact that agricultural biodiversity has tremendous relevance for linking conservation to economic development. Interestingly, the convention did not restrict itself to the more common and well-known aspects of agricultural biodiversity, such as crop genetic resource conservation, but made a special effort to include functional groups which provide essential ecosystem services, such as pollinators, soil biota and natural pest control agents (Costanza et al 1997, Daily 1997, Pimentel et al 1997).

In fact, in the initial decision to include agricultural biodiversity in the programme of work (DecisionIII/11) two initial issues for conducting case studies were identified: pollinators and soil microorganisms (The Biodiversity Agenda, 1996):

> "Initial issues for conducting case studies:
>
> Pollinators, including consideration of the monitoring of the loss of pollinators worldwide; the identification of the specific causes of pollinator decline, the estimation of the economic cost associated with reduced pollination of crops; the identification and promotion of best practices and technologies for more sustainable agriculture; and the identification and encouragement of the adoption of conservation practices to maintain pollinators or to promote their re-establishment."

Five years later, how far have we gotten in closing in on pollination as an essential ecosystem service to be conserved, and how well have these concerns been integrated into national agricultural or biodiversity planning?

While it is true that too much of the global conservation effort in recent decades has focused on emotional attachments to flagship animals, mostly furry mammals and colourful birds, pollinators are not without their advocates. On the international level, an International Pollinator Initiative has been launched, with a strong lead taken by the Brazilian government. A broad group of stakeholders from research institutes, government and civil society from 15 different countries met in Sao Paulo, Brail in 1998 to draw up a plan of action. Within the United States, a "Forgotten Pollinators" campaign has captured public attention with a book which was featured in Time magazine in 1996, and a move toward converting, for example, the roughs of golf courses into pollinator gardens (Buchmann and Nabhan 1996; Xerces Society webpage: www.xerces.org) . In Europe, special symposia and public programs have also focused public attention on pollinators (Matheson et al. 1996). Other regional initiatives have been launched, in Africa, and North America.

These pollinator initiatives have been fueled by a perception that the number and diversity of pollinator species has gone into a precipitous decline, affecting agroecosystems and native ecosystems alike. It is clear that honeybee populations have been drastically affected by disease and parasites in North America and Europe; the disease has just reached Africa. Africanised honeybees have made their way up the South American continent and Central America to reach the United States, changing ecological dynamics and beekeeping practices on the way. Numbers of native bees appear to be dwindling; some serious declines in the numbers of native species have been reported in Central and North America (Janzen 1974, Torchio 1987, Kevan et al 1990, Kevan et al 1996, Frankie et al 1997, Allen-Wardell et al 1998) and six countries in Europe (Corbet et al 1991, Osborne et al 1991, O'Toole 1994, Banaszak 1995, 1996, Williams 1989, 1996). But before leaping ahead to make recommendations on appropriate interventions in national plans, it is critical to have a common agreement on the extent of the problem. The International Pollinators Initiative program of action began with just this question:

> *" Do we all agree we have a problem of pollinator decline (both in abundance and in species richness) and in pollination deficit which already affects agriculture [including managed forests and rangelands, as well as adjacent natural ecosystems] productivity and sustainability?"*

As always, the data are not really sufficient to answer the question. But a special issue of the on-line journal Conservation Ecology focused on pollinator declines in North America, where the data is more abundant than in many other places (http://www.consecol.org/Journal/index.html). The data for insects in general, and specialist insects such as bees, is politely called "unruly"; even under the best of circumstances, it is difficult to monitor pollinator assemblages over space and time. But two remarkable studies in this journal monitor bee populations over long periods of time, and show long-term persistence of bee communities, even under large scale habitat modification:

a. An extensively replicated, long-term study of orchid-bees (Euglossini) was made in protected tropical moist forest in Panama over a period of 22 consecutive years. Orchid bees were sampled from Parque Soberania, a protected lowland rain forest site in Panama famed for its bird diversity (http://www.nps.gov/centralamerica/panama/bio.html). No aggregate trends were detected in the nearly 2000 samples, although two- to fourfold annual swings in the population densities of individual species were common in this and the other faunal studies that he reviews. No rare or parasitic species showed decreasing trends, while the most common of the set of bee species studied gradually declined as forests reflected increasing anthropogenic impacts. Biodiversity of the bee fauna therefore increased.

b. The bee fauna in the vicinity of Carlinville, Illinois, USA is probably the most thoroughly sampled fauna anywhere in the world, as the result of the exhaustive, detailed collections of Charles Robertson at the turn of the century. Between 1884 and 1916, Robertson observed and collected flower-visiting insects belonging to several orders in a 10-mile radius around Carlinville, about 50 miles (80 km) northeast of St. Louis, Missouri, USA. This same site was revisited 75 years later, providing a remarkable picture of trends over time. It was found that Carlinville's diverse native bee fauna was remarkably persistent when resampled nearly a century later, in the 1970s, despite the dramatic changes in the landscape, as row-crop agriculture increasingly predominated as a land use, with even with its diverse arsenal of insect control tools used over the decades. Unlike the long-term study above, the common bee species did not show impacts, but specialist bees (oligolectic) were most likely to be removed from the system under agricultural development, and generalist bees to be favoured.

These two long-term studies suggest that pollinator declines is a more fine-grained problem than wholesale loss of species. It does seem that bee faunas have a remarkable ability to persist under human impacts, under favourable conditions such as protected areas in the tropics, and a farm landscape that has small reservoirs of natural areas. Nonetheless, even under these favourable conditions, a slow "depauperisation" of the fauna, either through loss of common bee species or of specialized bees may be occurring over time and needs to be mitigated. In non-protected areas, and in areas under agricultural intensification, we have even more reason to work out means of conserving the ecosystem service of pollination, before it is lost.

Given these recent caveats on the call to alarm of pollinator declines, we need to ask, what is the essential, well-documented problem to be addressed by pollination conservation efforts at this time? At least five can be mentioned here:

1. Conservation of effective crop pollinators: There are probably more than 25,000 species of bees worldwide and many of them are known to be efficient pollinators of crops (Crane and Walker 1984, Roubik 1989, O'Toole and Raw 1991). Although most estimates of the economic value of crop pollinators give credit to the honeybee (Apis mellifera) (Southwick and Southwick 1989, 1992), many other species of bees are involved (Richards 1993). For some years several species of wild bees have been managed for the pollination of crops (Bohart 1972, Torchio 1987, 1990, 1991, 1994) and the management of other species for glasshouse crops has developed rapidly during the past few years and the potential of additional is under investigation.

The emphasis in pollinator initiatives has been on suggesting means of reducing the effects of the losses of pollinators to agriculture, however, there is another positive side to the issue. We have little or no information on most of the world's crops to be able to say if they receive adequate visits of pollinators to effect maximum yields, yet detailed research on numerous crops has demonstrated clearly that pollination can be a limiting factor to yields. Many farmers invest heavily in fertilizer and pest control, but do not heed the pollination requirements of their crops. Initatives to conserve pollinators in agroecosystems should enable us to improve the yields of many crops whose production dependson animal visitors.

2. Mitigation of loss of species diversity and redundancy- numbers of species is as important as number of individuals: Depauperate pollinator faunas may offer less of the redundancy that can buffer fruit and seed set against the inevitable and sometimes chaotic population swings of individual pollinator species (Cane and Payne 1993, Roubik 2001). A major problem is emerging for the world's agricultural production reflecting the risk involved in relying on a single species (Buchmann & Nabhan 1996). Recently honeybees in many parts of the world have contracted the pandemic disease – varroatosis caused by minute Varroa mites. Largely due to the presence of this disease in the U.S. (the only country for which reliable data exist) the number of honeybee colonies has decreased by one-third over the past six years. Fruit and vegetable growers in the U.S. and in Europe are complaining of poor fruit sets despite good blooming. As varroatosis has already spread throughout most of the world specialists consider it a matter of time before other countries also become seriously affected. Farmers and growers have begun asking about the use of native bees.

3. Mitigation of habitat change under agricultural development: Chronic agricultural shortfalls in native pollinator abundance in many fruit and seed crops is widespread, especially among self-incompatible crop species (Kevan and Phillips 2001), which has forced the United States to rely on migratory beekeeping. Agriculture increasingly replaces natural plant communities with monocultures, some of which are incapable of sustaining pollinator populations. For instance, grains such as wheat and corn, which are planted every year across 6% of the continental U.S. land area and in up to 20% of some midwestern states (http://www.nass.usda.gov), do not provide for the nectar or pollen needs of any bee species. On the other hand, it appears that small areas of natural habitat in farmland may permit bee species to persist (Marlin and LaBerge 2001).

4. Mitigation of effects of agricultural chemicals: The broad-spectrum insecticides that are commonly used (and abused) are often as toxic to beneficial insects as they are to the target species (Johansen and Mayer 1990). Insecticides are applied not only on agricultural fields but also in backyards and on rangelands, golf courses, parks, forests, and mosquito-ridden marshes and swamps. Chronic herbicide use, as well, may be driving losses of pollinator species, from reductions in plant diversity

5. Overcoming the taxonomic Impediment: Bees and their life-sustaining relationships with flowering plants occupy keystone positions in both natural and agricultural ecosystems (Buchmann & Nabhan 1996). Bee faunas are therefore important natural resources. As with all natural resources, inventories of their diversity and distribution are needed if we are to manage them to our best advantage (O'Toole 1993). Unfortunately, the current state of bee taxonomy imposes severe restraints on the realization of these goals (O'Toole 1996), as it does for other pollinator groups like flies, wasps and beetles. This, the Taxonomic Impediment (TI), derives from serious shortfalls in investment in training, research and collections management. It seriously limits our capability to assess and monitor pollinator decline, to conserve pollinator diversity and to manage it sustainably. Moreover, there is a growing perception that access to sound bee taxonomy will be at a premium because research projects in pollination biology, both of native floras and crop plants, are on the increase and

require bee identifications.

The recent International Pollinator Initiative programme of action highlighted the urgent need for universities to raise the academic status of taxonomic research by investing in new post-graduate programmes, and drew attention to the fact that in the Western Hemisphere, the regard for taxonomy in university courses is like that of other branches of the biological sciences with a result that practising bee taxonomists in North America, Mexico and Brazil account for 61 % of the world total of those 28 scientists associated with major institutions (see the following table). Nevertheless, there is a chilling fact embedded in these figures; 36 % of these specialists are beyond retirement age and only three of them, Charles D. Michener (age 81), Jesus S. Moure (age 87) and João M. F. de Camargo are involved in training a new generation of bee taxonomists. Only in Australia are new bee taxonomists being trained.

Number of practising bee taxonomists associated with major institutions by country or region

USA [1]	Mexico	Brazil [2]	Europe [3]	Africa	China	Japan	Australia
10	1	6	3	2	1	2	3

[1] includes 7 workers officially retired, but still active
[2] includes 2 workers officially retired, but still active
[3] includes 1 worker officially retired, but still active
source: Dias Raw and . Imperatri –Fonseca, 1999

Additionally, it should be noted that almost all the taxonomic resources needed by entomologists working in the developing world are located in museums and other institutions in the developed world. Some means of sharing this information, short of complete repatriation, needs to be worked out.

The principles and best practices described below are all aimed at addressing these particular needs, and can be recommended for adaptation and adoption in national biodiversity strategies or agricultural plans. At present, with the exception of Brazil, most countries mention pollination only in the context of honeybees and honey production, either in National Biodiversity Strategies and Action Plans, or in the context of agricultural planning.

PRINCIPLES

· Pollinator plant relationships should be understood as an ecosystem service for sustainable agriculture. This includes a concerted plan to overcome the taxonomic impediment.

· Conservation and restoration of natural areas are necessary to optimise pollinator services in agricultural systems. In many cases these may be very small patches in otherwise human dominated landscapes. Particular attention should be paid to protection of appropriate nesting sites.

· Negative impacts by humans on pollinators should be minimized; this includes use of agrochemicals, and disturbance of nesting sites.

· Farming practices should promote the conservation and diversity of native pollinators; for this, two extreme situations should be envisaged. On the one hand there is small-scale agriculture amidst undisturbed, natural areas from which pollinators may migrate onto the agricultural plots. On the other hand are the extensive fields with high-tech agriculture, where pollinators are usually locally extinct or present in very low numbers. In these, temporary importation of pollinators is necessary.

Farming practices; in between these two extremes, efforts to minimize the use of agricultural chemicals, and tillage of soils, will benefit pollinator populations.

· Public awareness of the importance of pollinator conservation should be promoted.

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BEST PRACTICES (in no particular order)

1. Hedgerows, field margins, embankments, and other "waste places" provide nesting habitat
for some native bees. Removal of these often unappreciated habitats has been associated with dramatic declines in Germany's native bee fauna since the 1960s (Westrich 1989). Conversely, retention of some of these features has been associated with persistently rich native bee faunas in some Polish agricultural landscapes (Banaszak 1995, 1997). Wooden fences, barns, and even stone walls provide substrates for bees that nest above ground (Westrich 1989).

2. Roadsides, with their partially compacted soils, are frequently favored nesting sites for bees and wasps. In deserts, highway pavement channels rainfall runoff to road edges, inadvertently irrigating linear populations of native wildflowers (Lightfoot and Whitford 1991). This inadvertent creation of habitat has never been well documented, and populations of bees who choose to nest in these sites are often eliminated by roadside maintenance and development. Similarly, trails and paths in southern Africa are often preferred nesting sites for aculeate wasps and bees (Gessand Gess 1993)

3. The potential of gardens: Where native plants and their flowers have been removed or displaced, they have sometimes been replaced, in equal or greater numbers, by introduced species in flower and vegetable gardens, waste places, and disturbed areas. Although some of these flowers are nothing more than the sterile fabrications of plant breeders, in other cases exotic plant species supply novel resources to pollinators with unknown consequences. Berlin, Germany, for instance, with its patchwork of waste places populated by ruderal floras, retains a bee fauna of 262 native bee species (Saure 1996).

4. Effects of small rich gardens: Sakagami and Fukuda (1973) sampled two sites at the University of Hokkaido, Japan. The Botanical Garden was 9 ha and contained mixture of natural and exotic plant species. The University site was 150 ha and contained primarily native
vegetation. Both were isolated from continuous tracts of natural vegetation by the city. Despite its smaller size, the Botanical Garden yielded one-third more species (S = 85, Sa = 144 spcies at the Botanical Garden; S = 77, Sa = 108 species at the University), perhaps as a response to increased floral diversity.

5. Likewise, a study of urban habitat fragmentation and native desert bees (J. H. Cane et al., unpublished manuscript) found that a number of cavity-nesting bee species of Xylocopa and the Megachilidae, including a Larrea specialist, were actually more ubiquitous and abundant at flowers of Larrea tridentata growing well within the city of Tucson, Arizona, than at flowers in outlying desert, perhaps because the older residential neighborhoods that they sampled offered more woody nesting substrates than did the scrub desert. Unfortunately, the study design failed to anticipate shifts in the availability of nesting substrates.

6. On the other hand, with respect to fly fauna (which may be important pollinators as well) Bañkowska's findings: In total, 73 species were collected in the city of Warsaw, compared to 128 species in natural areas containing Warsaw's pre-urban habitat of oak-hornbeam forest. Only 66 species inhabited urban parks, and 46 species inhabited green areas around housing estates. The proportion of phytophagous and terrestrial saprophagous species dropped significantly, with only four species of phytophages present near the housing estates. These four were pests that eat ornamental plants, or weed-eating species. Urban areas were dominated by four syrphid species with broad geographic ranges (maybe don't include this- flies are too unspecific)

7. The Taxonomic Impediment: In order to know what we are losing, we need to know what we have. Thus two best practices are featured here, in overcoming the Taxonomic Impediment, and monitoring pollinators.

It is critically important to be able to identify the components of any country, or commodity's bee fauna. As mentioned above, the current state of bee taxonomy imposes severe restraints on the realization of these goals (O'Toole 1996), as it does for other pollinator groups like flies, wasps and beetles. This, the Taxonomic Impediment (TI), derives from serious shortfalls in investment in training, research and collections management. It seriously limits our capability to assess and monitor pollinator decline, to conserve pollinator diversity and to manage it sustainably. Moreover, there is a growing perception that access to sound bee taxonomy will be at a premium because research projects in pollination biology, both of native floras and crop plants, are on the increase and require bee identifications.

One best practice, in this regard, is the "Bee Course" .....

8. Training of parataxonomists. Where taxonomic services are stretched (as they are throughout the world) training of support staff may provide some needed assistance. Parataxonomist are defined as an auxiliary to the taxonomist and his research. Parataxonomists carry out the following functions:

- · Collecting and sampling, especially in monitoring or faunistic studies, often in association with the taxonomist
- · Preparation and processing of specimens
- · Preliminary sorting to a convenient taxonomic level (subfamily, tribe, genus)

An ideal numerical relationship would be three parataxonomists per independent research taxonomist. Ideally, positions for parataxonomists should be permanent, with the opportunity for a tracked career structure. The appropriate proportion of parataxonomists to taxonomists should facilitate and enhance the service output of every collection facility and thus contribute to the elimination of the Taxonomic Impediment.

It has been suggested that taxonomists and taxonomic services providing institutions should provide training for parataxonomists in accordance with a generally agreed curriculum, on a national or regional basis, either as individual training or in training courses. Undergraduates in biology should be motivated to take an interest in this attractive new career opportunity, which is more than that of a simple technician, especially as it offers collection-related permanence. Parataxonomists should be eligible for academic up grading in their profession after a satisfactory period of activity (Dias Raw and . Imperatri –Fonseca, 1999).

The training of parataxonomists in developing countries has been pioneered by INBIO in Costa Rica (where can we get best info, ask Scott Miller), and more recently by the Department of Invertebrate Zoology at National Museums of Kenya (Wanja, Koen to provide details? Edwin in Taita is doing a great job gathering bees and looking at pollinators…)

Best practice: (INBIO, NMK with KWS)

9. Many taxonomic resources needed by entomologists working in the developing world are located in museums and other institutions in the developed world. Some means of sharing this information, short of complete repatriation, needs to be worked out. The International Pollinators Initiative programme of action has suggested the following mitigation measures:

- · A single web site with access to all databases of type material in the world's museums and other research institutes
- · A single web site to make data associated with specimens available to all bona fide researchers in taxonomy and pollination biology
- · Exchange and transfer of information, especially literature that is not widely available outside the museums and institutions of the developed world using photocopying and scanning facilities

- · Repatriation of data associated with type specimens to appropriate institutions in countries of origin

Best Practices: (Connal can you provide more description of these?)
Ecoport
Going Home

10. Monitoring programmes: The International Pollinator Initiative recognized the critical importance of setting up a valid global monitoring system for understanding the pollinator status worldwide. There is considerable discussion at present about setting up standardized protocols for monitoring bee fauna, which the recent issue of Conservation Ecology addressed. Although there is not a program or agreement on methods yet, several possibilities for efficient, effective monitoring systems are being discussed. For example, comparisons of bees "sampled" at individual plant families vs. the entire flora in the Carpathian Mountains (Osychnyuk 1967) suggest that, although no single plant family could be considered a typical exemplar of the bees for this area, the Asteraceae may provide a reasonable estimate of patterns of bee diversity and abundance. It may be that sampling focused on visitors to a few, generalist flowering families might provide sufficient information for monitoring trends. Even if the bees visiting a single plant species do not fully represent the entire fauna, subsampling from particular plants may capture the essence of the variation or changes in the bee community over space and time resulting from specific human or natural impacts (J. Cane, USDA Bee Biology Lab, Logan, Utah, unpublished data, A. G. Damasceno and F. A. Silveira, unpublished manuscript, Frankie et al. 1997, Minckley et al. 1999; R. L. Minckley and J. Cane, unpublished data). Other sampling protocols including sweep sampling along transects and in standard areas (Silveira and Godínez 1996, Herrera 1988, Minckley et al. 1999) pan-trapping (Leong and Thorp 1999) and trap-nesting (Frankie et al. 1993, 1998) have been developed and can lend themselves to national or regional monitoring programmes.

11. Reforestation effects: Studies have demonstrated changes in bee communities associated with human-induced changes in natural vegetation. Archer (1989) resampled bees from Allerthorpe common, UK, following reforestation. The complete change in dominant vegetation resulted in a decline of species richness (before, Sa = 128; after, Sa = 57) and changes in the composition of the bee community (Archer 1989). While not a best practice, attention should be paid to effects on the bee community in reforestation projects.

12. Persistence in an agricultural matrix: the Carlinville study (Marlin and LaBerge 2001). The land uses and land cover on Macoupin County's 225,464 ha (558,080 acres), which bear directly on the type and availability of habitat for bees and their host plants, varied considerably over two centuries. For example, in the early 1800s, land cover was about 73% prairie and 27% forest. The estimated 59,792 ha (148,000 acres) of forested land in 1820 diminished to 24,644 ha (61,000 acres) by 1924. It then grew to 34,340 ha (85,000 acres) by 1962. Agriculture is the predominant land use; in 1967, 59% of the land was in harvested crops (primarily row crops) and 15% was in pasture. Despite habitat changes and the passage of 75 years, the authors' 1970 and 1972 Carlinville collections show a high degree of similarity with those of Robertson, possibly because diverse habitats within the agricultural matrix contained the host plants and nesting sites required by the bees.

Reproduce Figure 6, and Figure 7, 13, and 15

Sizes and types of farms have changed over time, trending toward row crops and larger fields. The number of farms between 1890 and 1964 decreased by 40% while average farm size increased by 60%. The ascendancy of row crops led to decreases in the diversity of the agricultural economy and land cover. For example, the number of trees in apple orchards decreased from 122,500 in 1910 to 7,820 in 1964. Likewise, the number of milk cows decreased from 18,800 in 1945 to 3,900 in 1967 (Illinois Cooperative Crop Reporting Service 1969). By the 1960s, pesticide use on farmland was common. In southwestern Illinois in 1971, over 80% of the land in corn and soybeans was treated with herbicides. Over half of the corn in Illinois was treated with insecticide in 1971 (Illinois Crop Reporting Service 1972).

The increase in farm size and the maneuvering room required by large, modern farm machinery caused additional changes to the landscape. Early settlers planted hedges or erected
fences between farms and fields. A traditional Illinois hedgerow is shown in Fig. 13. It consists of a narrow band of trees, grasses, and flowering plants. The hedgerows have provided habitat protected from plowing. Since 1950, thousands of kilometers of

hedgerows have been removed as farm and field size have increased. Fence rows were also in decline during our survey. Fig. 14 shows a typical Illinois fence row.

What permitted the bee fauna to persist, given these fairly drastic changes in land use over time? The authors of the Carlinville study suggest two factors, one at a macro landscape level, and the other on a micro level:

Protected riparian areas dissecting farmland: The area provides habitat ranging from open prairie to hills with relatively dense tree cover. The creek and associated topographic relief provided many sites protected from intensive agricultural and residential development between the turn of the century and our survey in the early 1970s.

Hedgerows and fencerows: The small area on either side of fences is protected from plowing. Hedge and fence rows presumably provide habitat for bees because they are unplowed, are not directly exposed to soil-incorporated corn insecticides, and harbor a number of plants that may provide a pollen source. They offer potential nesting sites for both ground- and stem-nesting bees. Additionally, these areas are often somewhat elevated because they trap water- and wind-driven soil particles, creating a low berm of earth. Fig. 15 pictures an overgrown fence row that extends from a road to a wooded area. Such features presumably provide protected corridors through which insects and other species can move about agricultural areas.

There was no evidence of a marked decline in the species composition of this rich bee community during the first seven decades of the past century, despite dramatic changes in land use and agricultural practices over much of the study area. It seems likely that the persistence of many species is directly related to the varied terrain near Carlinville. Although the relatively flat areas are intensively farmed and appear to provide little bee habitat, local landowners retained many other areas in woods, pasture, meadow, and other types of cover. As long as suitable amounts of host plants and such varied habitat remain, the associated bee species seem likely to persist.

13. Management of prairies: Catherine Reed (1995a, b) monitored species richness of insects on prairie flowers in southeastern Minnesota for three years. She worked in eight separate prairie remnants orprairie reconstruction sites,. The focus of the study was to compare diversity in reconstructed sites with diversity in remnant prairie patches. As a result of this study, she has made recommendations for managing prairie/grassland habitats for high insect diversity, which seem to thrive under a fair amount of human intervention and disturbance. Native prairie sites are now managed more intenselywith brush-cutting, burning, and planting of seeds (C. Reed, personal communication).

14. Pollinator Reserve Design. In a recent article, James Cane (Cane and Phillips 2001) have given some thoughts to what would be required in designing pollinator reserves. The note the following:

“The spatial scale of fragmentation must be appreciated: bees of medium body size can regularly fly 1–2 km from nest site to forage patch. Overall, evidence for prolonged persistence of substantial diversity and abundances of native bee communities in habitat fragments of modest size promises practical solutions for maintaining bee populations. Provided that reserve selection, design, and management can address the foraging and nesting needs of bees, networks of even small reserves may hold hope for sustaining considerable pollinator diversity and the ecological services pollinators provide.

Bees and the pollen wasps are the sole central-place foragers among common invertebrate pollinators. Many, if not most, bee species nest underground; others nest aboveground, often in pre-existing tunnels in deadwood or in dead stems whose soft pith they have excavated. A very few species make free-standing nests. Within these broad categories, there may be further specialization, especially among ground nesters, who sometimes have specific requirements with regard to soil texture, moisture, salinity, and aspect (Cane 1991).

Tantalizing insights can be found in habitat fragmentation studies with regard to the prominent role played by the nesting attributes of bees. In the Argentinian study of subtropical dry forest fragmentation, only two bee taxa, Dialictus and Augochlora, were detected in all three continuous forest samples (Aizen and Feinsinger 1994b). Although both these genera consist largely of floral generalists, Dialictus, which are all ground nesters, were present in samples from all forest fragments and in the "agricultural matrix" as well, whereas Augochlora, two subgenera of which nest in rotting tree stumps and logs, fared poorly in small fragments and farmers' fields. Could the contrasting response to deforestation by the bees in these two genera reflect the fact that the small fragments and the agricultural matrix still contain soils that are suitable for Dialictus, but no longer contain the stumps and rotten logs that are the preferred nesting sites of Augochlora? The contrasting responses of these two halictid bee genera to habitat fragmentation may be plausibly explained by differences in their nesting biologies, not their floral biologies,

By viewing fragments as reserves, such studies turn our notion of habitat fragmentation on its head and may generate data and practical insights of critical importance for pollinator conservation. In many regions of the world, the opportunities to set aside massive reserves are limited, impractical, or already past, requiring us to either think small or else give up hope (Shafer 1995, Abensperg-Traun and Smith 1999). There is growing evidence that substantial fractions of native bee communities can persist in habitats that have been modestly, sometimes even drastically, altered by human activities (Reed 1995, Marlin and LaBerge 2001, Williams et al. 2001).

Many conservation-minded researchers advocate planting nectar plants for butterflies but then fail to foster their larval host plants. Bees pose a slightly different problem: immatures have no dispersal potential, whereas adults are expert, vagile navigators. Although we lack evidence for the flight range potentials of smaller bodied bee species, we know that those of honey bee size can, if necessary, readily forage at a distance of 1 km or more from their nesting sites. Hence, invertebrate pollinators do not need continuously favorable habitats to persist, just a suitably scaled patchwork that meets adult and larval needs. The concepts of "habitat complementarity" (Dunning et al. 1992) or "partial habitats" (Westrich 1996, Tepedino et al. 1997) are therefore broadly applicable to invertebrate pollinators. Immature stages of invertebrate pollinators are generally difficult to find and impractical to sample, but, in surveys of adults, the requirements of immatures must be understood and borne in mind when classifying habitat diversity, mapping habitat "fragments," and evaluating change in their habitats.

13. Malaysia, where labor costs for hand pollination are rising sharply, found a solution to its shortage of pollinators for oil palm, Elaeis guineensis. Syed (1979) studied the pollination of this important crop plant in its native West Africa and worked out the relationship between the pollinating weevils, Elaeidobius spp., and the inflorescences of the male and female palms. After careful screening and quarantine, Elaeidobius kamerunicus was released in Malaysian oil palm plantations, where it rapidly became established and spread (Syed et al. 1982). The result continues to be the sustainable and sufficient pollination of crops whose harvests exceed those previously produced by hand pollination, with savings of millions of U.S. dollars per year (Kevan et al. 1986).

14. The success story of the alfalfa leaf-cutter bee (Megachile rotundata) and its culture for the pollination of alfalfa (Medicago sativa), both exotic organisms in North America, is well known. The pioneering work of Bohart (1972) and Hobbs (1967) has given rise to the multimillion-dollar industry of "megachileculture," whose huge economic benefits are described by Olmstead and Woolen (1987). Bohart (1957) also recognized the problem of providing adequate pollination to alfalfa seed production fields, which led to the commercial development of practices for encouraging and maintaining pollinators other than honey bees, especially the alkali bee (Nomia melanderia). On the Canadian prairie, problems with alfalfa pollination and concomitant seed yield declines can be attributed to the expanding agriculture of the 1940s, when fields were larger and more kempt. As aresult of the subsequent reduction in nesting habitat, there were too few native pollinators to provide pollination for any plants except those at the peripheries of large fields (Peck and Bolton 1946, Stephens 1955). In Manitoba, Stephens (1955) recorded yields of 1000 kg/ha from small fields, but only 15 kg/ha from large fields. In Ontario, the contemporaneous decline of alfalfa seed production has been attributed to changing agricultural practices, including the use of insecticides.

The value of pollination to alfalfa seed growers in the Canadian prairies is estimated to be 35% of annual crop production (Blawat and Fingler 1994), although the usual practice there is for seed growers and custom pollination providers or "megachileculturalists" to share the risks, costs, and benefits in various ways. In Saskatchewan, Manitoba, and Alberta, about 30,000 ha of pedigree alfalfa seed was grown each year in 1999 and 2000, with yields of about 200–800 ha/kg worth Can.$0.50–0.75/kg. Based on a calculation of area (30,000 ha) x yield (300 kg/ha) x value (Can.$0.60 kg) x 35%, the value per year of pollination services to the production of pedigree alfalfa seed in these provinces amounted to about Can.$2 million. Pedigree alfalfa seed is grown on about one-third of the total acreage under alfalfa seed production, but common seed has a lower market value. It is reasonable to place the value of pollinators to the alfalfa seed industry at about Can.$6 million per year in the Canadian prairies, whereas the value of megachileculture (including bees for export, specialized equipment, etc.) in Saskatchewan alone, which has about half its prairie acreage in alfalfa seed production, is estimated at Can.$10 million (W. Goertzen, personal communication). Olmstead and Woolen (1987) estimated that, when pollination services were provided to Utah over the period they were studying, the increase in alfalfa production amounted to about a 600% return on investment. These values are representative of the scale of the value of pollination, although a detailed economic analysis based on the different farming systems (e.g., dryland vs. irrigation) has yet to be carried out.

15. Habitat destruction has also been a problem in the pollination of cacao (Theobroma cacao). Overly fastidious management of plantations included the removal of rotting vegetation, the substrate in which the pollinating midges undergo larval development (Winder 1977), and yield reductions ensued. By purposely placing appropriate plant material such as banana (Young 1982) or palm trunks (Ismail and Ibrahim 1986), adequate pollinator forces can be encouraged and maintained.

16. Finding alternatives to the adverse effects of pesticides on pollinators: These adverse effects are well understood, especially from a toxicological viewpoint (Johansen and Mayer 1990), although less is known about their impact on crop reductions. Several works (Kevan 1975b, 1977, Kevan and LaBerge 1979, Kevan and Oppermann 1980, Kevan and Plowright 1995, Kevan et al. 1999) explore the effects of applications of the organophosphorous pesticide Fenitrothion on nontarget habitat and on blueberry pollinators in New Brunswick, Canada. The demise of the pollinators resulted in such severe declines in the blueberry crop in the affected regions that provincial yields were significantly below those of neighboring Nova Scotia and Maine (Kevan 1977, Kevan and Oppermann 1980, Kevan and Plowright 1995), with an annual harvest loss of about 0.75 x 106 kg. Intensity of agricultural activities has also been shown to correlate with lower (by about 50%) populations and diversity of pollinators in apple orchards in British Columbia (Scott-Dupree and Winston 1987) and berry production areas (MacKenzie and Winston 1984). Kevan (1999) presents more details about these and other examples.

Cuba is the best example where as a response to the food crisis after the collapse of its trade relation with the socialist block, the government had a remarkable change of agricultural policy from highly modern, input dependant agricultural to sustainable agriculture. One facet of the programme was the promotion of organic or near organic agriculture and the use of non-chemical technologies. Already before the crisis some scientists had been working on natural ways to control pests and build soil nutrients and had an appropriate infrastructure for research. There was a drastic reduction on pesticide and organic fertiliser use, promoted by the ministries in charge of agriculture, sugarcane and forestry production. By mid-1990s, Cuba was one of the world leaders in the production and use of many biopesticides with over 200 centres located at co-operatives for production of natural enemies of crop pests and biopesticides. IPM technologies, based on monitoring systems, crop rotation, green manuring, intercropping and soil conservation with incorporation of organic manure, have been incorporated into polyculture farming (Rosset & Altieri, 1994; Rosset, 1996; Meadows, 1997; UN, 1999a).

17. Cox et al. (1991), show that the demise of fruit bats (also called flying foxes) (Megachiroptera) through overhunting in South Pacific islands has reduced the pollination and fruit yields of some traditional harvests. On the islands and peninsulas where flying foxes are, or were, frequent, there is a lack of other vertebrate pollinators, and many plants rely solely on flying foxes for pollination. More than 92 genera of flowering plants in 50 different families have been recorded as being visited by flying foxes. Yet the populations of the pollinator have plummeted, and three species have gone extinct. (I believe Paul Cox has worked to establish a nature reserve expressly for flying foxes....need to get more info).

18. Databases containing information on key pollinators of crops, and the costs and uses of pollinator services are essential. Several books are currently out of print, which provide extremely useful information (Free, Roubik, Crane and Evans). Nevertheless, there is a need for more studies that provide economic analyses of the relationships among pollinators, relevant crop production, and the market.

A database on costs and uses of pollinator services is being developed in the Pacific Northwest and California (Burgett 1995). Such databases could be very useful in other areas as well. Kenya, for example is experiencing new demands for pollinator services among horticultural producers, but there is much uncertainty as to how the market should be structured and priced (Onyango, pers. comm..)

19. Opportunities for partnerships and cooperation. The establishing of partnerships and collaborative relationships between institutions in developed countries with those in the developing world to cooperate in the elimination of the Taxonomic Impediment is imperative. One existing projects, specifically related to bee taxonomy, gives an excellent esample: the Programa Coperativo sobre la Apifauna Mexicana (PCAM). Th is is a partnership between bee taxonomists from several institutes in the United States with Mexican colleagues. To date this programme has produced one major, highly illustrated work, which facilitates the identification of all bees from North and Central America to generic level (Ayala et al 1993, Michener et al 1994). Several others are in press.

20. An automated systems for bee identification is under development (Griswold and Wittman?) which will permit parataxonomists and field workers to scan a bee's wing into a scanner, subject the image to an "artificial intellignce" analysis, and produce an identification down to species level. The program presently exists for megachilid bees of XXX. Further development of the system is proposed through a process such that data on bee characters from field workers could be sent to regional institutions at which the automated system is installed.

(need more information from Connal, Dieter)

21. A global list of threatened vertebrate pollinators (Nabhan 1996), produced under the auspices of IUCN's Species Survival Commission currently exists. (where can it be obtained) The International Pollinator Initiative proposes the preparation of a Global Biodiversity Outlook Report on the status of native bees and other pollinators.

22. The International Pollinator Initiative proposes a number of means to raise public awareness of the impending crisis of the decline of pollinators, which up until now is relatively quiet. A major global campaign is needed to make people aware of pollinators and the potential loss of their services.

The following actions are proposed:

· Disseminate high quality and understandable information about pollinators and their conservation to a wide variety of audiences and users
· Define criteria and indicators to evaluate the status of and threats to agricultural production of a reduction in pollination
· Create multilingual manuals on pollinator conservation and restoration for farmers (in local
idioms and adapted to the reality of each country);
· Approach International Standards Organisations to create "bee smart" labels on certification
(like on tuna fish cans) for "pollination friendly" products. Promote pollinator

awareness by
putting charismatic bumblebees and other icons and logos on tomatoes and other fruits.
· Develop other business incentives (and remove disincentives) for pollinator conservation.

The highly readable, popular book “Forgotten Pollinators” is a first step in this direction.

From the case studies:

23. The Philippines NBSAP project I.C.2 seeks to value and account for direct and indirect goods and services from biodiversity and bioresources (Table 2), which at least brings the conservation and management of pollinators within the scope of the action plan.

24. In Mexico, there are efforts to protect migratory bats, which are important pollinators and seed disperses of important crops such as tequila agave and fruit trees, and regulators of insect pests. The Programme for Conservation of Migratory Bats was started in 1994 with participation of the Institute of Ecology of Mexico’s National Autonomous University and the Bats Conservation International (BCI). The programme focused on research and environmental education to protect bats by conserving habitats along migratory corridors. Other conservation measures included amendments of Mexico’s Federal Law of Wildlife to encompass all caves and crevices as protected areas (Walker, 2001). The Arizona-Sonora Desert Museum in conjunction with the Turner Endangered Species fund and the Pollinator Conservation Consortium have begun a project to protect four migratory monitor species (butterflies, doves, bats and hummingbirds) along the nectar corridors of western Mexico and the southwestern United States (Pronatura).

25. Urban gardens and pollination: One of lines towards sustainable agriculture which have emerged in Cuba is intensive organic gardens in urban areas. Community gardens are appearing on vacant rural land. There are reportedly about 5000 thousands gardens producing vegetables within Havana. They have made a significant contribution to total food production while conserving biodiversity (Rosset & Altieri, 1994; Rosset, 1996; Meadows, 1997; UN, 1999a). The National Group of Urban Agriculture is promoting the use of Melipona beecheii in vegetable gardens.

26. Mexico along with the US and Canada is part of the North American Pollinator Campaign (NAPPC) with participation of researchers, state and federal agencies, private industry and conservation and environmental groups which has been recently started with the aim of ensuring sustainable populations of pollinators (NAPPC, 2001)

27. A core group of people in Kenya concerned with pollination as an ecosystem service have undertaken research to:

• document the key pollinators of eggplant, and their alternate forage resources
• pollination patterns in cowpea
• pollination ecology of watermelon
• pollination ecology in semi-arid ecosystems of Laikipia and Tsavo.

From the first of these, which is now complete, we know that two non-honeybee species, Xylcopa caffra and Nomia spp. are effective pollinators of eggplant, and that they make use of other habitats besides farmland. A poster to this effect has been produced for farmers.

28. The African Pollinator Initiative is promoting sharing of information and expertise between South Africa (which has the only bee taxonomist in the continent) and pollination researchers in other areas, such as Kenya, Sudan, Mauritius, Madagascar and Ethiopia. A simplified guide to the stingless bees of Africa is being developed through this collaboration, with the support of ICIPE.

28. In Russia and the CIS countries, the positive effects of apiculture on biodiversity are noted in National Biodiversity Strategies and Action Plans, although information on other pollinators is fragmentary and incomplete. Apiculture is especially developed in the south Siberia, in Altai and North Caucuses. In supporting apiculture, the main way to the conservation and management of honeybees is the development, strengthening and achievements of a capital recovery factor of apiculture. It is not an easy task taking into the account that agricultural crisis in CIS countries. One of the main problems for apiculture development is the lack of organized sales system and product certification (honey, wax, propolisum, queen bee's milk). Overcoming the indicated difficulties will stimulate the recovery and increase the number of populations of natural pollinators, as well as the involvement of the agricultural communities in one of the sustainable and environmental kind of agricultural management of natural recourses. At the moment there is no problem with deficiency of pollinators' in **Russia, in the view of experts**.