Ministry of the Environment

Pollinating Bees

The Conservation Link between Agriculture and Nature

2nd edition

Federative Republic of Brazil

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The Conservation Link Between Agriculture and Nature

MINISTRY OF THE ENVIRONMENT
SECRETARIAT FOR BIODIVERSITY AND FORESTS

Pollinating Bees

The Conservation Link Between Agriculture and Nature

Proceedings of the Workshop on the Conservation and Sustainable Use of Pollinators in Agriculture, with an Emphasis on Bees, held in S. Paulo, Brazil, in October 1998.

Edited by

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With assistance from Associate Editors
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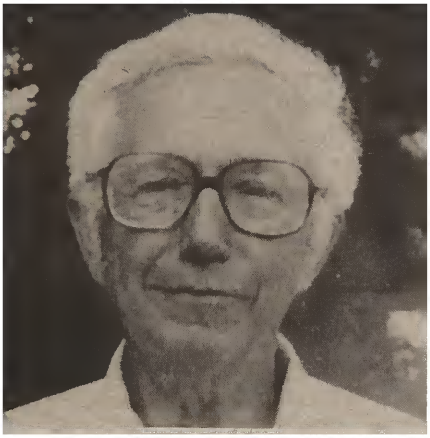
International Bee Research Association – IBRA
International Commission for Plant-Bee Relationships – ICPBR
Secretariat of the Convention on Biological Diversity

DEDICATION

This book is dedicated to honour the memory of Professor Soichi Francisco Sakagami.

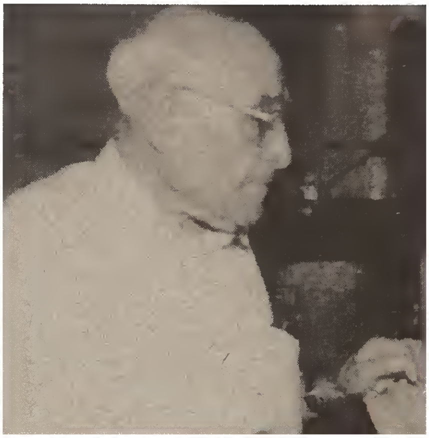
S. F. Sakagami, Professor Emeritus of the Hokkaido University, was born (January 4, 1927) in Ichikawa (Central Japan), and passed away (November 4, 1996) in Sapporo (North Japan). Prof. Sakagami was a very prolific scientist, as he authored over 320 papers and 8 books, of which although concentrated on the Hymenoptera, covered other taxa, as well, like beetles, domestic fowl and cats. As he used to mention, one of the most important milestone of his scientific career, was met around 1957 when he became acquainted with details of the bionomics of the stingless bees. Nicknamed by him as "my biological treasure", these fascinating social insects have motivated his two long visits to Brazil, namely 1962/63 – Curitiba (Father J. S. Moure) & Rio Claro (Prof. W. E. Kerr), and 1971/72 – (Prof. W. E. Kerr & Prof. R. Zucchi). His retirement (March, 1990) assisted the progressive decline of his health but, despite these restrictions, his impressive and indefatigable working capacity remained as before. Unfortunately, he could not accomplish his most cherished dream, that was, to return to Brazil to devote himself almost entirely to the study of "his biological treasure". Nevertheless, his love to Brazil and to the stingless bees will remain forever, as they are carved in the proper title of one of his books. Although published in Japanese (1975), only the book's title was printed in Portuguese following exactly as his own hand-writting: "O meu Brasil e as suas Abelizinhas" *(sic)* (= My Brazil and its Little Bees).

CELEBRATIONS: This book is presented to celebrate the life-time achievements of Professor Charles D. Michener and Padre Jesus S. Moure.



CHARLES D. MICHENER

Prof. Michener, the world's leading authority on bee taxonomy, was born in Pasadena, California, in 1918. He became interested in bees at a young age, publishing his first paper at the age of 17. His PhD. Thesis, published in 1944, represented a milestone in bee classification. Prof. Michener has traveled all over the world studying bees and has spent long periods in Brazil, Africa and Australia. He has published over 400 papers, including several major revisions and books. Prof. Michener is also well-known for his important theoretical contributions to the study of social behavior among insects, in particular on bee societies. He has finished recently the award winning encyclopedic (over 900 pages) book "The Bees of the World", published by Johns Hopkins University Press in 2000.



JESUS SANTIAGO MOURE

Prof. Moure, one of Brazil's most outstanding systematists, was born in Ribeirão Preto, São Paulo, on November 2, 1912. Prof. Moure has dedicated his whole life to the study of bees. His first paper, published in 1938, was on curculionid beetles, and soon after that he started working almost exclusively on bee taxonomy, and presently has over 180 publications and 434 described new species. He was one of the founders of the Brazilian Society of Science Progress. He has assembled, in Curitiba, one of the most important Brazilian zoological collections, as well as the world's largest and most representative collection of Neotropical bees. Prof. Moure has visited all of the most important Natural History museums in the world during his career. He is also recognized for establishing the Graduate program in Entomology at the Federal University of Paraná, in which countless Brazilian zoologists, many of whom are internationally recognized for their work, have obtained their degrees.

Both apidologists have influenced us in one way or another, directly or indirectly. Their important scientific contributions, coupled with their friendship and stimulation, have been a guide and support in our professional lives. We use this book to express collectively our admiration and solidarity.

PREFACE

This book has arisen from an international initiative brought to the present state through activities in Brazil, one of the leading countries in bee biology. The **International Workshop on the Conservation and Sustainable Use of Pollinators in Agriculture, with Emphasis on Bees** was held in São Paulo from 7 to 9 October, 1998 and it is from that event that we present this book. The arrangement we follow is more or less that of the presentations at the Workshop and its intensive discussion sessions.

Session I "The Main Issues in Pollinator and Bee Conservation" comprises 5 Chapters. The eminent Professor Paulo Nogueira-Neto sets the stage in Brazil by considering not only pollination, but also frugivory and seed dispersal as crucial ecological processes to sustainable productivity (**Chapter 1**). The United States of America has become very much concerned about saving wild pollinators and several U.S. federal agencies have taken up the cause (**Chapter 2**). Although the plight of pollinators has been recognized in many countries, there are major problems in their identification because of lack of presently qualified personnel and of funding. Change in funding priorities to include systematics is urgently needed to allow conservation efforts to be scientifically based globally (**Chapter 3**) and nationally (**Chapter 4**). The importance of pollinators to agriculture is presented in **Chapter 5** in a general overview of the pollinator crisis for crop production.

To obtain a global panorama of the approaches to management and conservation of pollinators, 12 Chapters have been grouped into **Session II "The State of the Art in Bee Conservation for Agriculture and Nature".** A broad European perspective is presented in **Chapter 6**, followed by the special and illustrative cases in the Netherlands **(Chapter 7)** and Russia **(Chapter 8)**. Activities in Canada, and advanced centre of applied Melittology (more usually but less accurately termed Apidology), are discussed in **Chapter 9**. The situations in subtropical and tropical regions are discussed for Africa **(Chapters 10 and 11)**, South America, Brazil **(Chapters 12, 13, 14)**, Chile **(Chapter 15)**, and North America, Mexico **(Chapter 16)**. A historical and updated review of the now highly managed and cultured common European bumblebee (Bombus terrestris) used especially for greenhouse pollination is the subject of **Chapter 17**.

Methodology for Assessing Pollinator Diversity and Abundance (Session III) was very high on the list of priorities at the Workshop in São Paulo. Four highly interesting Chapters are presented. **Chapter 18** makes recommendations on the basic concepts and methods used for monitoring bee diversity and populations, with specific instances drawn from California and Costa Rica. The next contribution **(Chapter 19)** presents aspects of theoretical ecology to application in crop and pollinator systems. The taxonomic impediment to monitoring is raised as a serious problem, which may be overcome, in part, through efficient use of computer technology for identification of species of bees through the Automated Bee Identification System (ABIS) **(Chapter 20). Chapter 21** describes how bee diversity and abundance can be approached from the perspective of community ecology (melissocoenology).

Examination of the world literature on crop pollination and pollinator-crop relations reveals that there are major shortfalls in current understandings. Much literature, even for well-known crops of the temperate zone, is now dated because new and improved cultivars that have not been adequately studied dominate modern agriculture and horticulture. Some reports lack scientific and experimental rigour. There is an urgent need for reliable and up-to-date information in crop pollination, and this is especially true for tropical crops, the subject of **Session IV. Chapter 22** presents modern research on pollination in Brazilian cashew, **Chapter 23** similarly explores Brazil nut, and **Chapter 24** exposes the erroneous myth that coffee does not benefit from insect pollination. Also of special importance is a review of pollination in Algaroba trees (Prosopis) in the desert regions of Chile **(Chapter 25). Chapter 26** opens the whole novel panorama of pollination of economically important fruit trees in Brazil with commentary of their actual and potential pollinators.

Session V presents other contributions by abstract. These are included for the sake of completeness and span the gamut of the four Sessions described above.

It was emphasized at the Workshop in São Paulo that the huge diversity of bees in Brazil has major and crucial roles in ecosystem function and sustainability, not only in agricultural environments, but also in forests and urban areas. That emphasis is not peculiarly applicable to Brazil, but, as the Workshop elucidated, is a global issue in almost all terrestrial ecosystems. The Workshop provided an opportunity for the exchange of information between countries of the Southern and Northern Hemispheres. Sorely missing from this book, and from the Workshop, were contributions for Asia, Australia and the Pacific, and even the Mediterranean heartland of bee-keeping, practical pollination, and pollination biology. Future meetings are planned to address these missing elements. **Section VI** presents excerpts of the **São Paulo Declaration on Pollinators** that lead up to the Workshop and have since been embraced by the Convention on Biodiversity and taken up as the **International Pollinators Initiative** by the Food and Agricultural Organization of the United Nations in Rome.

P. G. Kevan, V. Imperatriz-Fonseca

EDITORS' NOTE

This book comprises papers presented at the workshop on the Conservation and Sustainable Use of Pollinators in Agriculture, with an Emphasis on Bees, held at the Universidade de São Paulo, Brazil, In October 1998. The papers were assembled by editorial team, submitted for peer review, and, where necessary, amended. We are pleases that funding has come available to allow publication this year.

The editorial team is indebted to Terry Feltz, Tereza Cristina Giannini, Ines Maria de Morais Imperatriz and Cilulia Maria Rodrigues de Freitas Maury for their help during the preparation of this book.

The editorial team thanks all participants in the Workshop in São Paulo and especially the contributors to this book. We also thank, most sincerely, Dr. Braulio Ferreira Dias who was personally involved in this project; the Brazilian Environment Ministry that promoted this opportunity; and all the sponsors without whose support the Workshop and this book would not have been possible.

Brasília, june 2002

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[Excerpts from " Report on the recommendations of the Workshop on the conservation and sustainable use of Pollinators in Agriculture with Emphasis on bees". Brazilian Ministry of Environment, Brasilia, December 1999.]

PRESENTATION

Pollination is an environmental service essential for the maintenance of ecosystem integrity. Due to its huge diversity, bees have a major and crucial role in ecosystem function and sustainability in forests, agricultural environments and urban areas.

After the first "International Workshop on the Conservation and Sustainable Use of Pollinators in Agriculture, with Emphasis on Bees" from which this book has arisen , Brazil organized two others workshops. The second workshop was held in São Paulo, in October 2003, and was organized by the University of São Paulo - USP in partnership with the Ministry of the Environment – MMA and FAO. The third event was held in Ceará, in April 2004, and was organized by the Federal University of Ceará – UFC in partnership with MMA.

The "International Initiative for the Conservation and Sustainable Use of Pollinators – IPI" (Decision V/5 of the Conference of the Parties) was also discussed during the International Entomology Congress, held in September 2000 in Foz do Iguassu, Brazil, and also in September 2002 and in September 2004 at the National Bee Research Meeting in Ribeirão Preto. Several others Countries and regions, especially North America, Europe and Africa have promoted the IPI implementation.

The Brazilian Pollinators Initiative was formally created through the Inter-Ministry Administrative Ruling N° 218, of 16 March 2005. This legal instrument also created an Advisory Committee composed by representatives of four ministeries, public agencies, civil organizations and experts on themes related to pollination.

Given the importance of this theme to the world biological diversity, the Ministry of the Environment decided to launch at the 8th Conference of Parties of the Convention on Biological Diversity (Curitiba – Paraná – Brazil, 20 – 31 March 2006) the second edition of this book which we hope will help the conservation and sustainable use of components of biodiversity that are directly responsible for the maintenance of ecosystem services.

Paulo Yoshio Kageyama
Director for the National Biodiversity Conservation Programme
Secretariat for Biodiversity and Forests
Ministry of the Environment

PRESENTATION OF THE FIRST EDITION

The vital importance of the sustainable use of biodiversity for society is evident and is clearly demonstrated in this book. The decline in the diversity and number of pollinators and the risks this involves for agriculture sustainability clearly demonstrates the importance of pollination in this sphere. This ecosystem service provided by biodiversity is one of the simplest to demonstrate and for the public to comprehend. This is particularly opportune because the proposal described here could be the basis for a first global initiative to deal with the conservation and sustainable use of the components of biodiversity directly responsible for the maintenance of an ecosystem service.

At the second meeting of its Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) of the Convention on Biological Diversity (CBD) in Montreal, the Brazilian Government proposed to create a work program on Agricultural Biological Diversity, which included a proposal for the establishment of an "International Pollinator Conservation Initiative". Based largely on the Brazilian proposal, the third Conference of the Parties (COP3) in Buenos Aires, 1996, approved Decision III/11 on the "Conservation and Sustainable Use of Agricultural Biological Diversity", which identified pollinators as one of the initial priorities.

As a contribution to the development of this program the Brazilian Ministry of the Environment held an international workshop of experts (Workshop on the Conservation and Sustainable Use of Pollinators in Agriculture, with Emphasis on Bees) to propose a framework for an International Initiative on Pollinators as a key element in this program. It was attended by 61 scientists from 15 countries and five international organizations (CBD Secretariat, FAO, IBRA, IUCN and ICPBR).

The workshop was very successful, with an intense programme that included individual presentations of case studies, poster presentations and workgroups on special topics. The participants agreed on the problem identification and on the steps to be developed. As a consequence, a document was created in Brasília entitled, **The São Paulo Declaration on Pollinators** (1999).

The **São Paulo Declaration on Pollinators** was submitted to the attention of all delegates to the fifth meeting of the Subsidiary Body for Scientific, Technical and Technological Advice – SBSTTA of the Convention on Biological Diversity, held in February 2000 in Montreal. The São Paulo Declaration on Pollinators was endorsed by the fifth Conference of Parties of the CDB, held in Nairobi, Africa in May 2000 (section II of the decision V/5, that reviewed the implementation of decisions III/11 and IV/6, on the program of work on agrobiodiversity). COP 5 established an "**International Initiative for the Conservation and Sustainable Use of Pollinators**", hereafter referred to as International Pollinator Initiative (IPI).

The aim of the IPI is to promote coordinated action worldwide to:

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

It contains four programme elements:

1. Assessments;
2. Adaptative management;
3. Capacity-building;
4. Mainstreaming.

Through decision V/5, the Executive Secretary was requested to undertake the steps for the implementation of the programme of work. FAO (Food and Agriculture Organization of the United Nations) was invited to facilitate and coordinate the International Pollinators Initiative. An initial progress report on the implementation of the programme of work was submitted by FAO to SBSTTA 7, held in Montreal, in November 2001, which included a revised proposal for a work plan to implement the International Pollinator Initiative, based on the proposals presented in the São Paulo Declaration on Pollinators. Such proposal was approved by Decision VI/5 of COP6 of the CDB, held in the Hague, in May 2002.

The Ministry of Environment hopes the implementation of the **International Iniciative for the Conservation and Sustainable Use of Pollinators**, also known as the **International Pollinator Iniciative** (IPI), will provide a concrete opportunity to foster partnerships between agriculture and conservation organizations and to link biodiversity conservation and sustainable use with the maintenance of ecosystem services.

We thank the following institutions for their support to this initiative: the University of São Paulo – USP, the Brazilian Corporation for Agricultural Research – EMBRAPA, the Brazilian Council for Scientific and Technological Development – CNPq, the United Nations Development Program – UNDP (Project BRA 95/012), the Food and Agriculture Organization – FAO, the International Union for Conservation of Nature and Natural Resources - IUCN, the International Bee Research Association – IBRA, the International Commission for Plant-Bee Relationships – ICPBR, and the Secretariat of the Convention on Biological Diversity. We thank also the editors of this book, Peter Kevan and Vera Imperatriz-Fonseca, for their work. Finally, we thank and congratulate the participants of the São Paulo workshop for their significant contribution.

Bráulio F. S. Dias
Director for Biodiversity Conservation
Ministry of Environment, Brazil
Brasília, 2002

Session I

The Main Issues in Pollinator and Bee Conservation

1. Nogueira-Neto, P. "Management of Plants to Maintain and Study Pollinating Bee Species and also to Protect Vertebrate Frugivorous Fauna".
2. Ruggiero, M. and Healy, M. "A Federal Conservation Agency's Interest in Saving Wild Pollinators".
3. O'Toole, C. "Those Other Bees: Changing the Funding Culture."
4. Silveira, F. A. *et al.* "Taxonomic Constraints for the Conservation and Sustainable Use of Wild Pollinators – the Brazilian Wild Bees".
5. Westerkamp, C, and Gottsberger, G. "The Costly Crop Pollination Crisis".

MANAGEMENT OF PLANTS TO MAINTAIN AND STUDY POLLINATING BEE SPECIES, AND ALSO TO PROTECT VERTEBRATE FRUGIVOROUS FAUNA

Paulo Nogueira-Neto

ABSTRACT

In Brazil, two areas of about 2 hectares each (São Simão SP, Luziânia GO) and 3 smaller ones, (Campinas SP, Limeira SP, Xapuri AC) are being established as arboreta with collections of trees and bushes attractive to bees and in some instances attractive also to frugivorous and insectivorous birds. Lists of these plants, and some observations on the bees and the resources they obtain from these flowers are presented. Close to these arboreta the author keeps colonies of several species of tropical and subtropical stingless bees (Meliponinae). *Apis mellifera* colonies also exist nearby.

INTRODUCTION

In 1953, in a book on stingless bees, I published chapters on pollination and also on plants attractive to bees and which I cultivated (Nogueira-Neto 1953). In 1973, and again in 1985, I presented a list of plants that are attractive to birds, according to my personal experience (Nogueira-Neto 1973, 1985). Since 1980, in Luziânia, Goiás, I have been cultivating plants attractive to native bees, and also plants that are attractive to native frugivorous and insectivorous birds or to both, bees and birds. This is an experiment that could be important to the conservation of many bee species which help the pollination of plants used in agriculture or in other ways are also important in our forests.

Through pollination, bees may help some plants to produce more fruit that are valuable to keep birds that also predate on insect pests of agricultural or silvicultural importance. It should be realised that in the tropics such bees and many birds must live and remain in their habitats during the whole year, not only when crop plants are flowering. Eurico Santos and Eusebio de Queiroz (*apud* Kuhlmann and Kuhn 1947 p.188-189) wrote on the importance of insects in the diet of nestlings of seed-eating birds.

Also, when maintaining and restoring native forests, one must protect or reintroduce native bees and birds.

I started the first of these experiments in a mesocerrado (savannahs with medium size trees) in Farm Jatiara, Luziânia, Central Brazil, 100 km South of Brasilia, in deep and red latosol soils. Many observations were made, but in 1994 I realised that the arboretum was too far from the meliponary where I breed and keep stingless bees and too distant from a watercourse and its riverine forest and birds. It was also difficult to irrigate young plants there. Therefore, a better approach was made. An arboretum of around 2 hectares was planted, in yellow-red latosol soil, also in Farm Jatiara, Luziânia, GO, but near a watercourse and near the meliponary.

The soil was treated with lime and fertilised. Another arboretum of the same size, was planted in red soils of basalt origin, a fertile "terra roxa", in Farm Aretuzina, São Simão (SP) near Ribeirão Preto. Three smaller arboreta were also started, one in Farm São Quirino, Campinas (SP), one in Farm Tabajara in Limeira (SP) and another one in the Amazon, Xapuri (Acre), near Bolivia.

The old arboretum of Farm Jatiara was left, but many trees remained and survived. I still learn from them. Also, the native cerrado savannahs of Farm Jatiara are a source of interesting observations. The major different types of Brazilian savannahs are found there: associated grasslands, minicerrados, mesocerrados, and maxicerrados. Each type may be subdivided in open, mid and dense. This cerrado classification was presented by Nogueira-Neto (1991).

In the arboreta many linear groups of different species are cultivated, each group having generally 10 or more individual plants (trees and shrubs). They are planted in contour lines 3 or 6 m apart from the next line. Some species occupy 50 or even 100 m of a line. Most plants are pruned in order to make observations easier. When planting, generally 18% superphosphate is used. Brazilian soils are nearly always poor in phosphates. Afterwards, the plants receive an N P K fertiliser, at least once a year and are weeded when necessary. In the new arboreta many of the plants have not yet begun to flower, but are growing well. However, some have already bloomed intensively.

Some Promising Plants for Research

AGASTACHE (*Agastache anethiodora* (Nutt.) Britt.) - Nectar and pollen. This is a plant of the mint family, native in the prairies of North America. The flowers are very attractive to *Apis mellifera* because of their nectar. They are also very attractive to jataí (*Tetragonisca angustula*) for pollen. It blooms in November and in other times of the year in São Simão and Campinas, State of S. Paulo, and in Luziânia, Goiás. I started to cultivate this plant 45 years ago.

AGLAIA (*Aglaia odorata* Lour.). Nectar. Tree from China. It does not bloom in Central Brazil, but in the State of São Paulo (São Paulo City, Campinas and probably Southwards) it flowers well in June-August. It is very attractive to mandaguari or canudo (*Scaptotrigona postica*) and other meliponines. Its small red fruits are attractive to several birds.

AMOR AGARRADO or CORALITA (*Antigonum leptopus* Hook. et Arn). Nectar. It is an ornamental climber. Flowers are generally red, but there are also plants with white or pink flowers. Very attractive to *Apis mellifera* and to *Scaptotrigona postica.* In Merida, Mexico, I saw many bees of a native *Scaptotrigona* visiting the flowers.

AMOREIRA (*Morus nigra* L.). Fruits much eaten by birds. It grows quickly and produces many fruits (berries). It is native of Europe. No bees visit it, as far as I know.

ASSA-PEIXE (*Vernonia* spp). Chiefly nectar. There are several species. In Southeastern Brazil one of the species most visited by bees is the assa-peixe-roxo (*V. westiniana* Less) that flowers in humid places near the coast and over Serra do Mar. It has purplish flowers, which bloom in April. Another species, *V. polyanthes* Less., has whitish flowers which blooms in June-July. It is the source of one of the best tasting honeys of the world. However, the plant is considered a weed in pastures. *V. polyanthes* and *V. westiniana* are very attractive to *Apis mellifera*, mandaçaia (*Melipona quadrifasciata*) and several other meliponines. Some species, with thicker leaves and white flowers slightly purple, are not so attractive to bees.

CALABURA (*Muntingia calabura* L.). Chiefly nectar for bees and fruits for birds. It is a medium size tree, from Central America. It grows very quickly. It flowers and produces small edible reddish fruits, during the whole year. The fruits are very attractive to several birds. The flowers attract moderate number of *A. mellifera, S. postica* and small meliponines.

CALIANDRA ROSEA - (*Calliandra brevipes* Benth). Nectar. Pink and part whitish, or entirely white flowers. Blooms several times during the year. Very attractive to *A. mellifera*, mandaçaia (*Melipona quadrifasciata*), uruçu amarela (*M. rufiventris rufiventris)* and other bees.

CAPIXINGUI (*Croton floribundus* Spreng). Nectar. Very attractive to *Apis mellifera* and mandaçaia (*M. quadrifasciata*). The seeds are eaten by doves (*Leptoptila* spp) and parrots (Psittacidae). It flowers in November, December and January.

CITRUS (*Citrus* spp). Nectar and pollen. In all publications dealing with tropical plants attractive to bees, *Citrus* cultivars are highly praised and considered important as a source of honey.

CLARAIBA or LOURO PARDO (*Cordia trichotoma* (Vell.) Arrab ex Stend). Nectar. Good timber. In May, June and July, this nice timber and ornamental tree is covered with small white flowers, very attractive to *A. mellifera* and also to mandaçaia (*M. quadrifasciata*).

COQUEIRO JERIVÁ (*Syagrus romanzoffiana* (Cham.) Glassm.). Pollen. Its flowers, in big clusters, are highly attractive to *A. mellifera* and medium size meliponines. Its pollen is so abundant and attractive that often the bee jataí (*Tetragonisca angustula*) gather it from flowers that fall to the ground. It may flower in São Paulo State in any month of the year, but blooms chiefly in the warmer months. It is a palm native to South and Southeastern Brazil, Uruguay and Northeastern Argentina. Its small coconuts have a yellow outside pulp, eaten by birds and wild mammals.

COROA DE CRISTO (*Euphorbia milii* des Moulins). Nectar. Native to Madagascar. Generally very attractive to mirim da terra (*Paratrigona* spp), jataí (*Tetragonisca angustula*), irapuá (*Trigona spinipes*). Sometimes it is also attractive to *A. mellifera* and other bees. In Central and Southeastern Brazil, it flowers much more during the cooler months of the year.

COSMOS (*Cosmos bipinnatus* Cav. and *C. sulphureus* Cav.). Nectar and pollen. These are common ornamental plants, moderately visited by *A. mellifera* and sometimes also by mandaçaia (*Melipona quadrifasciata*) and uruçu amarela (*M. rufiventris*). They flower in several seasons of the year, in the State of São Paulo. Sometimes the plants of *C. sulphureus* grow to approximately 2 m high, not a desirable size.

EUCALIPTUS (*Eucalyptus* spp). Nectar and pollen. It seems that all species of *Eucalyptus* have flowers very attractive to bees. However, E. robusta was more praised than other members of the genus, in the bee literature dealing with *A. mellifera*. The species *E. urophyla* is also being tested.

EXTREMOSA or RESEDÁ ARBÓREO (*Lagerstroemia indica* L.). Pollen. Plant much planted in city walks. As an ornamental, I saw it in Belém do Pará, Amazon, in Xapuri, Acre, Amazon, also in Washington DC USA, in Porto Alegre (Rio Grande do Sul), in São Paulo State and in many other places. Therefore it survives in very different climates. It is attractive to *A. mellifera* and to jataí (*T. angustula*), to mirim da terra (*Paratrigona* sp.), to irapuá (*T. spinipes*), etc. In Southeastern Brazil it flowers more from November to March.

GUARUCAIA or MONJOLEIRO (*Acacia polyphylla* DC.). Chiefly nectar. It is highly attractive to *A. mellifera* and (*S. postica*), because of its nectar. It flowers in January-February.

JERIVÁ = See COQUEIRO JERIVÁ

JUÇARA, PALMITO (*Euterpe edulis* Mart.). Pollen. Very attractive palm, much visited by *A. mellifera* and medium size meliponines. Blooms during the whole year. Grows well in Atlantic Rain Forest (Mata Atlântica), where it is native. The small coconuts are very attractive to frugivorous/insectivorous birds, such as thrush (*Turdus* spp).

LACRE (*Vismia guianensis* Choisy). Pollen. Jandaira amarela de Manaus (*Melipona seminigra merrillae*) brought to its nest a red gum together with seeds from this plant (Absy & Kerr 1977, Kerr *et al.* 1986). I have often seen what seems to be the smashed red fruit, together with the small seeds, brought by uruçu roxa (*M. fuscopilosa*) and uruçu avermelhada (*M. crinita*) to their nests to reinforce their batumem (inside walls of stingless bee's nests). I saw this in Xapuri (AC) in February 1998. David Roubik (personal communication) saw it in Panama.

LIXEIRA BRANCA (*Lippia virgata* Stend.). Nectar. This wild plant is highly attractive to *A. mellifera*. Flowers in August-September. Another *Lippia* attracted *A. mellifera* and mandaçaia (*M. quadrifasciata anthidioides*) in December, in São Simão (SP).

LITCHI or ALICHIA - (*Litchi chinensis* Sonn.). Pollen. In August-September, in Campinas (SP), it is very attractive to borá (*Tetragona clavipes*). Moderately attractive to *A. mellifera*, jataí (*Tetragonisca angustula*) and mirim droriana (*Plebeia droryana*).

MIOSÓTIS CHINÊS (*Cynoglossum amabile* Stapf & Drum). Nectar, in the State of São Paulo. It is an herbaceous plant, some 30-70 cm high, with blue flowers, miosotis like, in spikes. It sometimes attracts mandaguari (*S. postica*), mandaguari amarela (*S. xanthotrica*), mirim da terra (*Paratrigona* spp), mandaçaia (*M. quadrifasciata*) and *A. mellifera*.

MONJOLEIRO = See GUARUCAIA

PALMEIRA ARCONTOFENIX or SEAFORTIA (*Archontophoenix cunninghamiana* H. Wesdl. & Drude). This palm is a native of Australia that grows very well in São Paulo City. Also found in the Gramado region of Rio Grande do Sul, in Santa Catarina and in many other places in Southeastern and Southern Brazil. Several birds, including the small parrot plain parakeet (*Brotogeris tirica*) and the tyrant flycatcher (*Pitangus sulphuratus)* eagerly eat the small red coconuts. The flowers are much visited by *A. mellifera* and small and medium sized meliponines, for pollen.

PALMEIRAS (Palms, Palmae). Nectar and pollen. The flowers are much visited by bees and also several birds eat parts of the small coconuts. Presently, in my arboreta in São Simão (SP) and in Luziânia (GO), a number of different palm species were planted. See also COQUEI-

RO JERIVÁ, JUÇARA.

RESEDÁ ARBÓREO = See EXTREMOSA

RUBIM (*Leonurus sibiricus* L.). Nectar and pollen. Much visited by *A. mellifera.* Small meliponines, chiefly jataí (*T. angustula*) also take their pollen but not the nectar, which is deep inside the corolla. In São Simão (SP) it flowers best in September, October, November.

VITEX (*Vitex negundo* L. var. *incisa* Clarke). Nectar and pollen. Very attractive to honeybee *A. mellifera,* mandaguari (*S. postica*) and jataí (*T. angustula*). Sometimes attracts also mandaçaia (*M. quadrifasciata*) and uruçu nordestina (*M. scutellaris*). Seeds much eaten by a very small parrot (blue-winged parrotlet = *Forpus* sp), in Campinas (SP). It is a Mongolian and Chinese native plant, introduced by me in Brazil, from the USA (Nogueira-Neto 1961).

Other Plants of Interest

The following list of plants, also cultivated in the arboreta mentioned in this paper, are under observation, generally in an initial stage:

ABACATEIROS (*Persea americana* Mill.)
AÇAÍ (*Euterpe oleracea* Mart.)
ABÉLIA (*Abelia chinensis* R.Br.)
ABUTILONS (*Abutilon* spp)
AMENDOEIRA da PRAIA (*Terminalia catappa* L.)
ANGICOS (*Adenanthera* spp and *Piptadenia* spp)
ARECA = PALMEIRA ARECA
AROEIRA (*Astronium urundeuva* (Fr.All.) Engl.)
AROEIRA MANSA (*Schinus terebinthifolius* Raddi)
BIRIBA (*Rollinia mucosa* (Jacq.) Bail).
BEIJO DA SERRA (*Impatiens walleriana* Hook. f.)
BICO DE PAPAGAIO (*Euphorbia pulcherrima* Willd. ex Klot)
CABELUDA (*Plinia glomerata* (Berg) Ansh.)
CABREÚVA (*Myroxylum perviferum* L.f)
CALIANDRA (*Calliandra* spp)
CALICARPA (*Callicarpa* sp.)
CANELA BATALHA (*Cryptocarya aschersoniana* Mez.)
CAMBARÁ (*Gochnatia polymorpha* (Less.) Cabr.)
CAMBUÍ AMARELO (*Myrciaria* sp)
CANUDO de PITO (*Senna bicapsularis* (L.) Roxb.)
CATINGUDA (*Tetradenia riparia* (Hochst.) Codd.)
CIPÓ CABOCLO (*Davilla rugosa* Poir)
COQUEIRO DO LITORAL (*Cocos nucifera* L.)
EMBAÚBAS (*Cecropia* spp)

FIGUEIRAS BRANCAS (*Ficus nymphaeifolia* Mill., *guaranitica* Schodat, etc)
GUEROBA (*Syagrus oleracea* (Mart.) Becc.)
GIRASSOL (*Helianthus annus* L.)
GOIABEIRA (*Psidium guajava* L.)
IBAJAÍ = UVAIA GRANDE
INGÁS (*Inga* spp).
JACARÉ (*Piptadenia gonoacantha* (Mart.) Maclr.).
JAMBOLÃO (*Syzygium jambolano* (Lam) D.C.).
MADRE DE CACAU (*Gliricidia sepium*).
MAGNOLIA AMARELA (*Michelia champaca* L.).
MALVAVISCO (*Malvaviscus arboreus* Cav).
MULUNGU, SUINÃ, CORTICEIRA (*Erythrina verna* Vell., *Erythrina poeppigiana* (Walp.); *Erythrina mulungu* Mart.; *Erythrina falcata* Benth; *Erythrina crista-galli* L. and others).
MURICÍS (*Byrsonima* spp), in the mesocerrado.
MURTA (*Murraya paniculata* (L.) Jack.)
NÊSPERA (*Eriobotrya japonica* Lindl)
PAINEIRA (*Chorisia speciosa* St. Hill.)
PALMEIRA ARECA (*Crysalidocarpus lutescens* Wendl)
PALMEIRA BACABA (*Oenocarpus bacaba* Mart.)
PATAS DE VACA (*Bauhinia* spp)
PESSEGUEIRO (*Prunus persica* (L.) Sieb. & Zucc.)
PITANGUEIRA (*Eugenia uniflora* L.)
PÔNCIRO or LIMÃOZINHO DO JARDIM (*Poncyrus trifoliata* L.)
SABIÁ or SANSÃO (*Mimosa caesalpiniifolia* Benth.)
SARAGUAGI VERMELHO (*Colubrina glandulosa* Perk.)
SANGRA D'AGUA (*Croton urucurana* Baill)
SIBIPIRUNA (*Caesalpinia peltophoroides* Benth.)
TAPETE INGLÊS (*Polygonum capitatum* Korth ex Meissn.)
UVAIA (*Eugenia pyriformis* Camb.)
UVAIA GRANDE or IBAJAÍ (*Hexachlamys edulis* (Berg) Kans. et Legr.)

An important fact related to observations in the cerrado (savannah) and a neighbouring stingless bee (meliponines) breeding station, was observed in Farm Jatiara, Luziânia (Goiás). In 1998, a few days before the end of the long 4 to 5 month dry season, a colony of jataí (*T. angustula*) increased its food reserves very quickly. In August 16 this colony had 5 pots of honey and 10 pots of pollen. In September 22, it had 158 pots of honey and 32 pots of pollen. Also, about that time, a swarm of the same bee species occupied an empty hive. All this, as I said, occurred before the end of the dry season.

DISCUSSION AND CONCLUSIONS

The study of pollination is a large field that requires research on several situations:

A- interactions between plants and pollinators;

B- competition among different pollinators;

C- competition among different plants;

D- influence of other factors related to bees or to plants;

Sometimes it is difficult or impossible to explain with present knowledge, why in some years a bee species does not visit the flowers of a plant that are much visited in other years. This happened several times, during my observations, with flowers of jabuticabeira (*Myrciaria cauliflora*) visited by the stingless bee mandaçaia (*M. quadrifasciata anthidioides*) in Campinas (SP). This is a good example of the fact that we must know more about bees, plants and their interactions.

The relationships between fruit producing plants and the birds that eat them, are also being examined in my arboreta. The activities of such frugivorous birds are important in the dynamics of ecosystems and may be useful to agriculture, in relation to pest control. During their whole lives but chiefly during their breeding season, such birds also eat large amounts of insects. These are the source of vitally needed proteins and their aminoacids, for the adult birds themselves but mostly for their nestlings, which need to grow quickly, to better escape predators. As was told here, Eurico Santos and Eusebio de Queiroz (Kuhlmann & Khun 1947) explained the importance of an insect diet to the nestlings of seed-eater birds.

As already mentioned, an unexpected conclusion from my observations was the fact that in Central Brazil, in the cerrado (savannah), the pollination of many native plants occurs chiefly during the time of the year (September) when the climate attains its maximum dryness. This happens before the end of the 4 to 5 month yearly dry season. Instead of the deep ecological stress that should be expected at that time of the year, many plants are then covered with new leaves, and they also bloom. As a consequence, meliponine bees increase very much their activities, even swarm. At least one of them (jataí, *Tetragonisca angustula*) dramatically increases its food stocks, as was previously mentioned. This means that pollination activities in the cerrado savannahs by the jataí bees, certainly also have a similar increase, at the same time.

One could also speculate about the xeromorphic morphological adaptations of the cerrado plants. These adaptations would save water in the soil, in such a way that most of it would remain there until the last month of the dry season. Then the water kept deep in the soil can be used on a large scale for new plant growth, for flower bloom and consequently for pollination activities. Photoperiodism probably would set the right time of the year for this burst of activities before the end of the dry season.

As a general conclusion, we may say that in the tropical world we still know very little about pollination and pollinators of our native plants and also of many introduced species. Therefore, research projects destined to improve basic knowledge on these matters should be a priority. To do such research, we need to establish more arboreta and to breed more intensively our native bee species, chiefly meliponines. For them, there is already a detailed breeding technology (Nogueira-Neto 1997). They are also, by far, the most common native bee pollinators in tropical America. To encourage their breeding, it is necessary to establish incentives, chiefly a bigger market for their honey. Such honey should be well filtered, properly pasteurised, well kept and well presented to attract buyers. In Pernambuco, Brazil, the honey uruçu nordestina (*Melipona scutellaris*) costs as much as good French champagne.

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THE US FEDERAL CONSERVATION AGENCY'S INTEREST IN SAVING WILD POLLINATORS

Michael Ruggiero and Meghan Healy

ABSTRACT

Management, monitoring, research, education and co-operation combine to illustrate the approach of the United States Department of Interior in pollinator conservation. A listing provides descriptions of selected relevant projects.

INTRODUCTION

Although the agricultural community has focused much attention on the decline of honeybees, an equal or greater threat may be posed by the loss of other pollinators including native bees, butterflies, birds, bats, and other animals. The latter provide, naturally, a major ecological service to nature that is without cost and that is directly dependent upon biological diversity. Insects, birds, or bats pollinate two-thirds of the world's flowering plants. Insects and other animals pollinate more than three-fourths of the world's crop plants. Many rare, threatened, or endangered plants are dependent on native pollinators. Globally, the economic benefit of pollination has been estimated to be as high as $117 billion. Despite this importance, large declines in pollinators have been reported in Europe, Russia, Canada, and Latin America.

Major threats to pollinators in the U.S. include habitat loss and alteration, alien species, and pesticides. Habitat loss along "nectar corridors" threatens migratory bats and hummingbirds. Native plant and habitat restoration cannot succeed without restoration of pollinators as well. Predatory, parasitic, and competitive alien species threaten pollinators directly, while alien pollinators threaten plant genetic diversity. Pesticides do not usually discriminate between pests and pollinators. These threats together can cause major disruption of an essential ecological service that benefits natural ecosystems, rare species, and agriculture. Despite its involvement in many national and international conservation issues, the United States Department of the Interior (DOI) has been only minimally involved in the issue of pollinator decline.

The Department of the Interior is the largest conservation agency in the United States. It is responsible for more than 300 million hectares of federal lands administered by the Bureau of Land Management, U.S. Fish and Wildlife Service, and National Park Service, representing most North American ecosystem types. The Department has a strong biological research program in the U.S. Geological Survey and is also responsible for the implementation and enforcement of the Endangered Species and Migratory Bird Management Acts. It also leads participation in the CITES, RAMSAR, and Migratory Bird Conventions and is an active observer of the Convention on Biological Diversity. The problem of pollinators should be an important consideration in our discussions of environmental policy, particularly in relation to endangered species, biological diversity, agriculture, and ecosystem management and restoration.

TABLE 1 provides a compilation of selected pollinator-related activities taking place on DOI lands or through DOI programs.

TABLE 1. SELECTED POLLINATOR PROJECTS AT THE DEPARTMENT OF THE INTERIOR

Location	Project/Activity Description
Alabama	Pollination Biology of Alabama leather flower. Alabama leather flower, *Clematis socialis*, is a critically endangered plant known from only four localities in northeastern Alabama. Objectives of project are to survey floral visitors to determine visitation frequency of insect species; pollination efficiency of floral visitors; describe floral rewards offered by *C. socialis*; and document seasonal timing of flower and achene production. (Boyd)
Alabama, Georgia, North Carolina	Pollination biology of the green pitcher plant, *Sarracenia oreophila*. The revised recovery plan for the species noted the need for pollination studies such as this in order to further recovery of the species. Pollinators include only queens of the genus *Bombus*. (Folkerts)
Arizona (Organ Pipe National Park)	Management and studies of lesser long-nosed bat. The endangered lesser long-nosed bat is a primary pollinator of saguaro and organ pipe cactus and several species of agave. The largest known maternity colony in the U.S. is in the park. The colony is protected from human disturbance and monitored on a regular basis. Research focuses on pollination effectiveness of the bat and other life history attributes. NPS co-operates with AZ, BLM, FWS, and Mexico to co-ordinate activities. (Rowlands)
	Monitoring Africanized honeybees. AHB colonies when found in the park are destroyed. Effects of AHB are not understood. (Rowlands)
	Moth pollinators of cacti. Park contains the only known population of the *Cereus cactus* in the U.S. The senita moth is it chief pollinator. The pollinator populations may be affected by pesticide drift from neighbouring lands. (Rowlands)
California (Pinnacles National Monument)	Study of bee fauna and pollen sources. More than 400 species of bees and wasps have been identified. Have interpretative programs and planning a display. (Griswold)
	Study of pollination of Indian warrior, *Pedicularia densiflora*. Study of pollination biology of Indian warrior, *Pedicularia densiflora*, is planned for the coming year. (Fesnock)
	Pollen sampling from bees and wasps at Pinnacles National Monument. Pollen sampled from bees, wasps, and plants. Results will improve understanding of bee-plant associations. (Griswold)

TABLE 1. SELECTED POLLINATOR PROJECTS AT THE DEPARTMENT OF THE INTERIOR

Location	Project/Activity Description
California (Cache Creek Watershed)	Restoring pollinator habitat for native plant communities and agriculture. Document links of wildland habitat, pollinators, and pollinator services. (Kremen)
California and Oregon Grizzly Peak and Kenney Meadows NRA)	Franklin's bumble bee. Study of distribution and abundance of endemic bumblebee on FWS, BLM, and FS lands. (Thorpe)
Georgia (Okefenokee Swamp)	Pollinator limitation, pollination processes, and the biology of reproduction in *Sarracenia minor* and *S. psittacitina.* Studies of pollinator and plant distribution and interactions. (Folkerts)
Hawaii (Haleakala National Park)	Argentine ants and silversword pollinators. The alien predatory Argentine ant threatens native bee and moth pollinators of the threatened Haleakala silversword in Hawaii. The ant also imperils the silversword, due to the plants dependence on insect pollinators. Bait trials (Maxforce) are being conducted in Cupertino with the Clorox Technical Center. University of Arizona researchers are studying interactions between native and alien pollinators of silversword. (Loope)
	Mechanisms of invasion of intact Hawaiian rain forest by non-native plant species. Efforts are aimed at understanding growth rates phenology, breeding systems and pollination, seed predation, seed bank size and longevity, and factors necessary for seedling establishment of the following invasive alien species: Kahili ginger (*Hedychium gardnerianum*), clidemia (*Clidemia hirta*), and strawberry guava (*Psidium cattleianum*). (Loope)
	Endangered honeycreeper pollinates and depends on nectar from imperilled Hawaiian plants. Study of relationship among honeycreeper, Ohia-lehiua, and threats by pigs. (Pratt)
Indiana, Michigan, Wisconsin	Karner Blue butterfly studies. Study of habitat availability and host plant distribution and use by the butterfly. (Grundel)
Indiana (Indiana Dune National Lakeshore)	Study of plant guilds and pollinators. Study of plant guilds and pollinators in isolated prairie parks.
	Pollination of Pitcher's thistle study. Study of pollination of threatened or endangered Pitcher's thistle is ongoing.
Maine (Acadia National Park)	Changes in pollinator diversity. Park has an extensive collection of insects, spanning 30 years, from early 20th Century by Johnson and Procter. Preliminary planning has been done to compare current and historical diversity. (Ginsberg)
Maryland (Chesapeake & Ohio Canal National Historic Park)	Native plant and pollinators initiative. Survey and monitoring of native plant pollinators and design of management and recovery plans. (Southard)

TABLE 1. SELECTED POLLINATOR PROJECTS AT THE DEPARTMENT OF THE INTERIOR

Location	Project/Activity Description
Mississippi (Gulf Islands National Seashore)	A new monolectic coastal bee, *Hesperapis oraria* Snelling and Stage (Hymenoptera: Melittidae), with a review of desert disjuncts in the southeastern U.S. Study of rare bee (new species) and host plant. (Cane)
Mississippi (Mississippi Sandhill Crane National Wildlife Refuge)	Pollination in pitcher plant communities. Study of hybridisation and relationship with *Bombus, Apis,* and megachilids. (Folkerts)
New Jersey, New York (Gateway National Recreation Area)	Native habitat restoration for pollinators. Fifteen years of restoration and management to provide and enhance habitats for invertebrate species, especially Lepidoptera (butterflies and moths) and Odonata (dragon- and damselflies). This involves special mowing regimes, planting nectar and pollen sources, and providing cover for overwintering species. Butterflies are monitored in Cupertino with the New York City Butterfly Club and the North American Butterfly Association. (Reipe)
New Mexico, Texas	Status and reproductive biology of *Lepidospartum burgessii.* *Lepidospartum burgessii* (Burgess broomscrub or gypsum scalebroom) was identified by FWS as a species of concern. Mode of pollination is not known. This project will provide FWS and BLM information on the basic biology of the species, including reproduction. Specific studies have included assessment of habitat conditions, insect visitors, and flowering of the plant on BLM land.
North Dakota (Theodore Roosevelt National Park)	Effect of leafy spurge infestation on native flowering plants in hardwood draws of Theodore Roosevelt National Park. Study of the effect of leafy spurge on native plant pollination and subsequent seed set in hardwood draws in the park. (Larson)
Oregon (Crater Lake National Park)	Inventory of Bombus. Monitoring of distribution and abundance of *Bombus* spp. (Ferguson)
Pennsylvania (Valley Forge National Historic Park)	Tallgrass meadows program. Park manages 700 acres as tallgrass meadows to mimic historic landscape. Meadow management regime favours use by pollinator species. (Lambert)
Southwestern U.S.	Bat population data. Synthesis of population data for three pollinator species of bat populations. (O'Shea)
	Bat pollinators in the southwestern U.S. Distribution and abundance of three bat species, *Leptonycteris* (2 spp.) and *Choeronycteris mexicana* in southwestern U.S. (Bogan)
Western U.S.	Reproductive characteristics of 32 species of rare plants. Study of pollinator/pollination systems for rare plants on various DOI lands. (Tepedino)

TABLE 1. SELECTED POLLINATOR PROJECTS AT THE DEPARTMENT OF THE INTERIOR

Location	Project/Activity Description
	Long-term monitoring of pollinators on DOI lands. Study of vernal pool habitats and pollinators. Permanent plots to study native and introduced bee interactions. (Thorpe, Frankie)
U.S.	Butterfly inventories of national parks and wildlife refuges. Surveys and intensive studies butterflies, moths, and pollinators in selected national parks and wildlife refuges. (Opler)
U.S., Mexico	Protection of migratory bats. Many trans-border species including Mexican free-tailed bats (*Tadarida brasiliensis*), long-nosed bats (*Leptonycteris curasoae, Leptonycteris nivalis*), Mexican long tongued bats (*Choeronycteris mexicana*) and hoary bats (*Lasiurus cinereus*) have all experienced drastic population declines. BCI and FWS are collaborating in the implementation of a long-term program to educate the public about the value of bats and how to differentiate vampire bats from other bats such as the long-nosed bats important to pollination. (FWS)
U.S., Canada, Mexico	Protection of monarch butterflies. Although not considered an endangered species, the Monarch Butterfly's (*Danaus plexippus*) largest population is particularly vulnerable because of its lengthy migration, dependency on nectar sources along the way and especially its need to hibernate in massive numbers in very few places in the central highlands of Mexico where their habitat is vulnerable to survival needs of the local inhabitants, outsider exploitation of natural resources and of course, natural and often extreme fluctuations in the weather. Since 1995 the Borderlands Program has collaborated with Mexican non-governmental organisations that work to protect the Monarch Butterfly, providing $140,450 in funding support. One organisation, PROFAUNA, A.C., implements a tri-national environmental education program inviting teachers and students along the Monarch's migratory route from Canada to Mexico to report sightings and other important information. Another organisation, Alternare, A.C., works with the inhabitants of the Monarch Butterfly Reserve in central Mexico teaching them how to better manage the natural resources in the Reserve--the Monarch's winter habitat--including alternatives to overexploitation of the forest. (FWS)

The Department is beginning an organised effort to address the pollinator issue at the national level. It hopes to develop highly visible demonstration projects at our national parks, wildlife refuges, and other Interior lands to publicise our commitment to pollinator conservation. Several actions are proposed in the areas of management, monitoring, research, education, and Cupertino.

1. Management: Review, assess, and revise DOI policies and practices to minimise impacts on pollinators and maximise their conservation. For example, review pesticide use, mowing and maintenance, fire management, and other practices. Review species recovery plans and make sure that we're not forgetting to restore ecological relationships like pollination as well as species.

2. Monitoring: Develop local and regional inventory and monitoring programs to assess the status and trends of pollinators on lands, as well as regional and national trends.

3. Research: Determine important relationships between pollinators and rare, threatened, and endangered species. Determine effects of land management practices on pollinator conservation. Determine contribution of native pollinators on DOI lands to surrounding agricultural and other lands. Assess effects of surrounding land management practices to native pollinators on DOI lands. Develop joint research strategies among conservation and agricultural agencies.

4. Education: Train DOI land and resource managers on the importance of pollinator conservation. Educate the public on the importance of pollinator conservation. Develop highly visible demonstration projects to publicise DOI approach.

5. Cupertino: Work with other national, international, regional, and local pollinator conservation programs. Raise issue at national and international forums.

Protection of wild pollinators and the services they provide will take a concerted effort by both the conservation and agricultural communities, public and private. Protecting wild pollinators will ensure the continuation of the services they provide to nature, agriculture, and society.

THOSE OTHER BEES: CHANGING THE FUNDING CULTURE

Christopher O'Toole

ABSTRACT

This paper discusses the problems surrounding the conservation of native bee populations and suggests possible approaches to solving the current problem.

INTRODUCTION

We are creating this book because there are perceived problems with the conservation of wild pollinators. The range of expertise represented in this book allows me to take for granted that we are in broad agreement with the following statements centred on these problems:

Statement 1: the pandemic of varroatosis throws into sharp relief the need to understand better the ecology and conservation needs of non-*Apis* bees because it is from among these bees that we need to recruit manageable pollinators as an alternative to the honeybee.

Statement 2: native bees are under ever-increasing threat because of habitat destruction and reduced floral diversity associated with intensive agriculture, over-grazing, de-forestation and building development.

Statement 3: native bees are of vital importance not only as potential managed pollinators of crops, but also as pollinators of native floras: they occupy keystone positions and without them, ecosystems would eventually collapse.

The above problems are discussed in detail by, for examples, Kevan 1975, 1987, 1991; Parker *et al.* 1987; Kevan *et al.* 1990; O'Toole 1991, 1993, 1994; Richards 1993; Buchmann and Nabhan 1996; Kearns and Inouye 1997.

The Solutions

If we can be in broad agreement about the nature of the problems, which confront us, can we be also agree on the necessary range of solutions? Well, if we think of these problems simply as nice, academic, practical exercises, then the answer has to be yes. We all know now roughly what to do. If the World Bank gave us a blank cheque, we could get on with the job. We could probably do it for the cost of one NASA space project or even less.

You can detect the drift of my argument: it is all a matter of priorities, of what priority our government funding agencies give to the research projects competing for attention and investment. Of course, we should be sending probes into deep space, but if we can afford to do this, can we afford not to fund the necessary research on wild bees? The future health of our planet may well depend on it. In the meantime, we have to accept that biology will always suffer from physics envy!

So if the first step is to get governments and other funding agencies to re-adjust their funding priorities, then this step is, by definition, a political one. We must be assertive and get on to the propaganda and lobbying bandwagon.

Immediately, though, we are confronted with a fact of political life: politicians and senior bureaucrats are not interested in issues *per se*: they are interested in perceptions and how these affect them in the brokerage of power and influence.

Moreover, my experience in the European political arena is that people are almost totally ignorant of the existence of bees other than honeybees. They see bee issues as those relating to apicultural practice and the control of honeybee diseases.

We need, therefore, a propaganda exercise which raises the profile of native bees, to help politicians and other decision-makers put a spin on wild pollinator issues that they can feel comfortable with, one which is sufficiently novel to attract and keep their attention. We are, after all, competing with the very powerful lobbies, which, quite legitimately, represent the conservation needs and interests of, say, birds and star species such as the Siberian Tiger and Giant Panda.

One way of changing the culture is to promote bees as rather more than just another bullet point in the biodiversity crisis: we need to get politicians and other decision-makers to see our native bee faunas as important natural resources.

In this context, an economic value can be put on bees as pollinators not only of crops, but as keystone mutualists which are vital management agents in the conservation of habitats and therefore, of floras and faunas.

If we succeed in changing perceptions in this way, then we have another weapon in our armoury.

This brings me to a particular problem we have in Europe with bee conservation. In Britain, for, example, although 25% of our native bees are on the *Red Data Book* list of endangered or threatened species, bees are specifically excluded from the Berne Convention. This is the result of an accident of bureaucratic history. When the Berne Convention was being drawn up, a consortium of European biologists was contracted to produce lists of either endangered species or species of special ecological importance worthy of conservation. None of these biologists were entomologists with any interest in knowledge of bees. As a result, no bees were submitted to the Convention authorities.

We now have a situation in Europe where funding bids to European Union agencies to support research or meetings on the conservation of non-*Apis* bees are automatically refused on the grounds that no bees are covered by the Berne Convention. We must change this and I appeal to this meeting to support a resolution, which can be sent to the appropriate authorities in Brussels, calling for a change in this ludicrous policy. I would like us to call on the appropriate authorities to ensure that those bees listed in the various national *Red Data Books* and their conservation needs be recognised by the Berne Convention.

This brings me to my final point, which is one, which I have laboured on other occasions, at other venues and one, which I make no apologies for labouring once again.

Assuming that we are successful in persuading Governments and other agencies that bees and their pollination services are a vital natural resource and that their ecology and conservation biology be placed high on the funding agenda for research funding, we are immediately faced with yet another problem to overcome.

We are now in the embarrassing situation that our understanding of pollination biology is accelerating faster that our understanding of bee taxonomy. For much of the Old World, there are few modern revisionary monographs which make it easy to identify bees.

We also find ourselves in a logically indefensible position: if bees are a vital natural resource, then they need to be inventoried. How else are we to manage them to our best advantage? But without much greater investment in taxonomic research, how can we make the necessary inventories of our resources?

This really is an acute problem. We don't even have an agreed list of bee species for western Europe. Then, in the Old World, the average age of practising bee taxonomists is 50+ (O'Toole, 1996) and we are not training a new generation of specialists in this field (Daly, 1995). Despite the fig leaf of academic respectability conferred by Cladistic Theory, for most universities in the Old World, taxonomy is still regarded a "merely a branch of descriptive natural history" and it is still difficult to get academic authorities to foster post-graduate studies in pure taxonomy, especially in projects.which result in practical benefits such as identification keys.

What does this mean for those of us who are concerned with the ecology, conservation and faunistics of bees? Researchers are ill served by the current state of bee taxonomy. Moreover, while we can devise the most beautiful projects in these fields, without sound bee taxonomy, they are simply not viable.

It is highly desirable, therefore, that we encourage people planning to do this research to include in their funding applications, provision for taxonomic support. It is even more desirable that we foster a grant-aiding culture that is sympathetic to providing core funding for major revisionary work in bee taxonomy.

The punch-line, then, is this: without more serious investment in bee taxonomy, we are in danger of not really knowing what it is we are trying to conserve. I will finish, therefore, with a list of suggested solutions to the problems I have outlined:

1. Set up an electronic network of active bee systematists: who is doing what and where.
2. Survey the bee material held by the larger national museums: this is a major resource for any concerted effort in bee systematics.
3. Organise co-ordinated surveys of bee faunas of major threatened habitats.
4. Seek funding for revisions of bee genera that are major pollinators of native floras and/or crops species.

5. Work towards a world inventory of bees.
6. Set up a world database of bee-flower visitation records.
7. Change the funding culture, so that core funding is available for basic research in bee taxonomy.
8. As a long term objective, set up centres of excellence in bee taxonomy where training can be given at the post-graduate level.
9. Establish more partnerships along the lines of PCAM (Programa Cooperativo sobre la Apifauna Mexicana; Michener *et al.* 1994; Michener 1996).

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TAXONOMIC CONSTRAINTS FOR THE CONSERVATION AND SUSTAINABLE USE OF WILD POLLINATORS – THE BRAZILIAN WILD BEES

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ABSTRACT

This paper analyses the taxanomic resources available for the identification of Brazilian bees. It looks at the taxanomic keys and how easy it would be for non-taxonomists to use them. It also looks at the current Brazilian bee classifications and how far research has come in this area. Recommendations are made as to how to go about improving the quality of identifications made in research by technicians and biologists and improving current taxanomic keys using both new research and preserving old collections. It also emphasizes the need for new research in systematics.

INTRODUCTION

Thousands of wild species from many different animal groups including mammals, birds and insects, play important roles as pollinators of cultivated and wild plants. It is generally agreed that bees are the one group that pollinates the largest number of plant species (Roubik 1995a).

Because of the recent crisis in the apicultural industry in temperate countries, and given the fact that honeybees are not efficient pollinators of many crops and wild plants, interest is growing in the sustainable use of wild insects and other animals for this task (Roubik 1995b). However, several limitations exist to the employment of these pollinators. We cannot use pollinators which we do not know exist, nor where or when to find, or even how to manage and we cannot use pollinators if we do not know which plants they pollinate.

To get the necessary information, we need to undertake regional faunal surveys as well as surveys of the plants visited by each species. In this way we can build a database of potential pollinators of wild and cultivated plants on which we can further study the bionomics and develop management techniques for specific pollinators. However, collecting specimens at flowers is not enough, it is necessary to be able to identify them to species so that communication about them can be exchanged and information about them can be found.

In this chapter we analyse the taxonomic impediment for those interested in recognising, conserving and employing potential pollinators, taking the Brazilian wild bee species as examples. We give special attention to publications containing taxonomic keys, because these are indispensable for the non-taxonomist for identifying the organisms with which he/she works. We also discuss the importance of sound classifications.

Knowledge of Brazilian-Bee Taxonomy: Development and Current Status

Linnaeus (1767) started the study of Brazilian bee taxonomy by describing several native species. During the 18th and 19th centuries, several European scientific expeditions to Brazil were organised by European countries and institutions. The bees collected during those trips were deposited in European museums and described by researchers like Fabricius (1793, 1804), Spinola (1853), and Smith (1854, 1879). In the late 1800's and early 1900's, Friese (1899, 1900) published monographs of Neotropical bees that included Brazilian species.

At the turn of the century, Curt Schrottky and Adolph Ducke were the first bee taxonomists to work in Brazilian institutions (Obrecht and Huber 1993; Nomura 1995) and published on Brazilian bees until the early 1920's. The next bee taxonomist to work in Brazil was also the first Brazilian bee taxonomist: Father Jesus Santiago Moure. He started publishing on bees in 1940 and is still active as a Professor Emeritus. Currently, there are 6 active bee taxonomists in Brazil.

Until recently, most of the taxonomic studies done on Brazilian bees were only species descriptions in association with comprehensive, systematic revisions. Besides, even monographic works like those of Friese (1899, 1900) were based only on the original descriptions, without examining of the material. Those studies were also based on small series of specimens, generally from restricted regions. The result of all this was a plethora of synonymies and a complete confusion on the identity of species.

Schrottky (1902) made the first and last attempt to bring together all known taxonomic knowledge of Brazilian bees. His was a compilation of taxonomic descriptions and keys to genera and species and carried on many of the weaknesses of the preceding works.

Moure study of Brazilian bee type material in European and North American museums contributed greatly to the recognition of synonymies (*e.g.* Moure 1960a,b). He also recognised many new genera and subgenera (*e.g.* Moure 1945, 1947, 1950, 1951) and, alone or with others, contributed to the classification of important groups of the Brazilian bee fauna (*e.g.* Moure 1946; Moure and Michener 1955; Michener and Moure 1957; Hurd and Moure 1963). His contributions have been a sound basis for other taxonomists, but non-taxonomists could not readily employ the knowledge gained through his work because he produced few comprehensive reviews of species.

The number of generic revisions through time may measure the development of knowledge about the identity of Brazilian bee species because these papers are the ones most likely to offer the information necessary for sound identification of specimens. Table 1 shows the number of genera occurring in Brazil that were revised in the last five decades and the number of Brazilian species included in those reviews. Only the taxonomic work done in the last 50 years is considered because the earlier works include so many synonymies (of species and supraspecific taxa) that it is almost impossible for a non-taxonomist to use them for identifying bees.

TABLE 1. Evolution of the "taxonomic effort" in the last five decades on Brazilian bee taxa. GR = number of generic revisions including Brazilian bees. SI = number of species inclu-

ded in those genera.

	DECADES					**TOTAL**
	1950's	**1960's**	**1970's**	**1980's**	**1990's**	
GR	1	11	9	15	28	59[a]
SI	8	69	18	78	122	295[b]

a) Five genera where revised twice in the period. Each one was counted only once.
b) For the genera reviewed twice in the period, only the total number of species included in the last revision was considered.

Table 1 shows that the taxonomic effort has been increasing in the last decades. The number of genera reviewed is almost twice in the 90's compared to the 80's. But, at the current pace of 2.8 genera per year, it will take taxonomists another 60 years to review the remaining genera known to occur in Brazil. Moreover, it should be kept in mind that as bee sampling continues and as regions previously unsampled or undersampled are surveyed, new species belonging to the genera already reviewed are being continuously discovered. For example, the number of known Brazilian species of *Gaesischia* and *Melissoptila* were, respectively, 15 and 12, when they were first reviewed by Urban (1968a,b). When these genera were reviewed again, the number of Brazilian species known in each of them increased to 25 and 31, respectively (Urban 1989, 1998).

If we look at species rather than at genera, things get even worse. While the genera revised in the last 50 years represent about 25% of the genera known to occur in Brazil, the species included in then resent only 6% - 10% of the 3,000 - 5,000 species estimated to occur in Brazil (Table 2). Some of the unreviewed genera are the richest in species of the Brazilian bee fauna. Some examples are: in Anthophoridae, *Paratetrapedia* accounts for up to 8% of local bee assemblages and *Centris* up to 13%; in Halictidae, *Augochlora* and *Augochloropsis* contribute, each, up to 10% of local faunas and, in Megachilidae, *Megachile* may represent up to 25% of the total number of species in a given area (Silveira and Campos 1995; Pinheiro-Machado *et al.* this book). Thus, if we consider the rate of 12 species reviewed per year during the 1990's, we conclude that it will take taxonomists from 200 to 400 years to review all the bee species estimated to occur in Brazil.

The "taxonomic effort" as measured by the number of genera reviewed is also not evenly distributed among families (Table 2). Thus, while about 55% of the genera in Megachilidae were reviewed at least once in the last 50 years, this number decreases to only about 30% in Apidae and Anthophoridae, 16% in Halictidae, and 7% in Colletidae and Andrenidae. This uneven distribution also occurs within each family. In Anthophoridae, for example, 50% of the reviewed genera belong to the Eucerini, which is one (although one of the largest) of 18 tribes in that family known to occur in Brazil.

TABLE 2. Distribution of the "taxonomic effort" among the bee families represented in Brazil. TG = total number of genera in each family; GR = number of genera reviewed in the last 50 years; SI = number of Brazilian species included in the reviews. % SI = percentage contribution of each family to the total number of species reviewed.

	BEE FAMILIES						TOTAL
	Andrenidae	Anthophoridae	Apidae	Colletidae	Halictidae	Megachilidae	
TG	14	68	29	29	31	31	**202**
GR	1	24	9	2	5	17	**58**
SI	1	123	72	7	29	61	**293**
% SI	0.3	42.0	24.7	2.4	9.9	20.9	**100.0**

Taxonomic Knowledge as an Impediment to the Conservation and Use of Bees.

The analysis of faunistic surveys made in Brazil in the last 40 years show how the lack of taxonomic knowledge has impacted the results of other studies. Below we make an analysis of 46 such surveys. The sources of these data can be found in Pinheiro-Machado *et al.* (this volume). Of the 3,187 morphospecies recognized in 46 surveys, only 26% could be positively identified; 6% were recognized as new species; 4% had dubious identification (confer, affinis) and 64% could not be identified at all (Table 3).

TABLE 3. Status of identification of species in 46 surveys of local and regional bee faunas in Brazil expressed as a percentage of the total number of species collected in each family. aff = affinis (similar to, but different from); cf = confer (probably equal to, but deserving confirmation); sp = species that could not be identified; nd = species which were already recognized as new by taxonomists, but which had not been described up to the publication of the survey; id = identified; u = undescribed species recognized as new; N = total number of species in all surveys.

FAMILY	Status of Identification of Species (percentages)						N
	Dubious			Certain			
	aff	cf	Sp.	u	nd	id	
Andrenidae	–	1.0	63.7	14.5	5.7	15.0	193
Apide	2.1	4.7	32.1	2.6	1.6	56.8	190
Anthophoridae	0.6	5.4	56.7	2.9	1.5	33.0	946
Colletidae	0.9	4.3	63.9	7.4	1.3	22.2	230
Halictidae	0.9	3.2	73.3	3.2	1.1	18.4	1013
Megachilidae	0.3	2.0	70.1	2.9	1.3	23.4	615
TOTAL	**0.7**	**3.6**	**64.0**	**4.0**	**1.6**	**26.0**	3187

It should be clear that the total numbers of species in Table 3 are overestimations of the numbers of species collected in all surveys analysed. This is because species that could not be identified are being considered more than once if they were collected in more than one of the survey. The percentages, however, may be interpreted as the chance that any morphospecies has to be identified in a sample of bees collected in Brazil.

It is clear, from Table 3, that bees from different groups have different chances of being identified. Thus, although apids are identified 56% of the time, andrenids are determined only 17% of the time. It is interesting to note that the number of species that are actually identified in each family is quite different from the number of species in each family that was included in taxonomic reviews (Table 4). That difference may be taken as a measure of how reliant people who are working with bee biology and ecology are as taxonomists even for the identification of the 26% of bees that are recognisable. From the above, two assumptions can be made: 1) species included in reviews can be identified by non-taxonomists through the use of the published keys and 2) bees not included in reviews can only be identified with certainty by taxonomists. Table 4 shows us that, as a whole, 64% of bees identified in the Brazilian faunistic surveys had to be identified by taxonomists. This number varies among families, from 33% in Apidae to 97% in Andrenidae.

Of course, there are common bees not included in reviews that are easily identified by non-specialists. However, many researchers working with bee biology and ecology are not able even to sort their bees to tribal, let alone generic level. This makes it impossible for them to use the few available keys to species and as a consequence, their dependence on taxonomists is still greater.

TABLE 4. Dependence of taxonomists for bee species identification in Brazil. SI = Number of species included in generic reviews in each family; ID = Number of species identified in each family in 46 local faunistic surveys. % = Percentage of ID that is not included in taxonomic reviews.

	Andrenidae	Anthophoridae	Apidae	Colletidae	Halictidae	Megachilidae	TOTAL
SI	1	125	72	7	29	61	**295**
ID	29	312	108	51	186	144	**830**
%	**97**	**60**	**33**	**86**	**84**	**58**	**64**

The degree of taxonomic knowledge also varies from region to region and from biome to biome (Table 5). Thus, although 37% of the species in temperate grasslands could not be identified or had dubious identification, this number increases to 71% in temperate/subtropical rainforests and savannah-like cerrados of central Brazil.

TABLE 5. Status of species identification in a number of surveys (NS) in different biomes in Brazil expressed as a percentage of total (N) of species in all surveys. aff = affinis (similar to, but different from); cf = confer (probably equal to, but deserving confirmation); id = identified; u = undescribed species recognized as new; nd = species which were already recognised as new by taxonomists, but which had not been described up to the publication of the survey; sp = species that could not be identified.

Biogeographical Realms and Provincences (Udvardy, 1975)	**NS**	**Status of Identification of Species** **Dubious**			**Certain**			**N**
		aff	**cf**	**sp.**	**u**	**nd**	**id**	
Tropical Humid Forests	11	1.1	3.3	43.4	4.9	2.4	44.9	880
Tropical Savannahs (Cerrado)	12	0.9	5.6	51.0	2.5	0.4	29.5	1119
Tropical Dry Forests/Woodlands (Caatinga)	2	-	3.9	36.4	-	-	59.7	77
Subtropical/Temperate Rainforests	13	0.2	1.5	69.3	1.6	1.8	25.6	311
Temperate Grasslands	9	_	0.8	36.1	7.1	1.6	54.4	509
TOTAL	**47**	**0.7**	**3.6**	**64.0**	**4.0**	**1.6**	**26.0**	**3187**

In general, ease of identification is inversely correlated to species richness of the biome (measured by the average number of species found in each survey), however, there are discrepancies for several reasons. The number of identified species tends to raise, for example: 1) when relatively well studied groups are well represented in the regional assemblages; 2) when the regional fauna is well represented in the collections of active taxonomists and 3) when the number of endemic species is low.

DISCUSSION

It is obvious that Brazilian bees are largely unknown and our ability to identify them for other studies is hampered by a lack of taxonomic knowledge.

In the last 40 years, faunistic surveys produced a large amount of data on bee biogeography and ecology, including data on plants visited by bees. Such surveys are the obvious sources of data for those interested in starting searches for potential native pollinators of wild and cultivated plants. However, these data are largely inaccessible because more than 60% of the species are not correctly identified. How can we search for information or start a research program on, in a hypothetical example, the bionomy of *Paratetrapedia* sp.1? How can a conservation biologist be concerned with the preservation of an unnamed or unidentified species?

This situation is an incentive for the introduction of foreign pollinators, for which bionomical and management knowledge is readily available. Introduction of foreign pollinators, however, is a practice we should avoid. Some of its drawbacks were already pointed out by Bohart (in Mcgregor 1976). Important points to consider are: 1) imported species may not be effective as pollinators in the new environment as they were in their native habitats; 2) imported species may introduce new parasites and diseases; 3) imported species may outcompete native species at nesting sites and/or food sources, which may lead to pollination problems in non-target cultivated and wild plants.

The identification of Brazilian bees to tribal or generic levels is still basically a task for specialists. Currently, there are only six active bee taxonomists in Brazil (of which two are retired and one has a temporary position. Given the great diversity of bees and the growing need for species identification, specialists will be needed to handle this job. Moreover, the primary work of taxonomists is not identification of specimens, but to study the organisms, develop classificatory schemes that organise our knowledge about them, and facilitate the communication of this knowledge to others. This kind of work is also what makes identification of species possible. When taxonomists are overloaded with other peoples' specimens for identification, they are unable to produce the very knowledge needed for identification to be made by themselves and by others.

Although the lack of taxonomic literature can be pointed out as a factor that inhibits biologists, conservationists and managers of wild pollinators from devoting time and energy to the identification of bees, there are other points to be made. With taxonomy's loss of prestige during the latter part of this century, training of biologists in this subject ceased in most Biology programs. As a result, professionals are not acquainted with the aims, methods and literature related to systematics, feeling themselves unable to deal with the task of identification. With the lack of interest in Systematics at universities, progressively fewer students are recruited to do taxonomic work and the few of them that do want to pursue a carrier in systematics are discouraged by the lack of positions for taxonomists in research and teaching institutions.

Up to now the problem of identification has been emphasised. However, another way the lack of taxonomic knowledge in an impediment to the sustainable use of wild pollinators is the lack of robust phylogenetic hypotheses. These hypotheses give us predictive power with which we can save time and energy, focusing our search for species with given abilities. A way to focus the search for a native pollinator species of an introduced plant, for instances, is to look for species closely related to the known pollinator(s) of that plant. Classifications by themselves are frequently not good estimators of phylogenetic relatedness because most of them include paraphyletic groups in which evolutionary relationships are often masked.

Phylogenetic analyses of bee taxa are being produced at a pace slower than that of other taxonomic works. The relationships among higher taxa, such as families or tribes, have been addressed recently (*e.g.* Roig-Alsina and Michener 1993; Alexander and Michener 1995; Silveira 1995), but studies including phylogenetic analyses among species of a genus are still rare (*e.g.* Camargo and Moure 1994, 1996). Unfortunately, these are the more useful ones for searching for pollinator species.

CONCLUSIONS

Although we have concentrated our discussion on Brazilian bees, the problems discussed above are certainly the same for other organisms and other countries, tropical and temperate. The crisis through which taxonomy is passing is an international one and the consequences of this crisis are similar everywhere. To ameliorate the situation by removing the taxonomic impediment for the conservation and sustainable use of wild pollinators, the following needs are presented.

- We urgently need comprehensive taxonomic revisions and phylogenetic studies of bee taxa in Brazil. We should invest in alternative presentations of taxonomic literature for use by non-taxonomists such as computer based interactive keys posted on the Internet.

- For taxonomic work to be undertaken at the necessary pace, the formation and employment of new bee systematists must be encouraged and supported. This is not just for scientific reasons, but because a lack of knowledge will eventually negatively effect human food supply through pollination shortages.

- Biôlogists, in general, should be encouraged and trained to use taxonomic literature and to recognize at least the major taxonomic groups they work with.

- Technicians should be trained in the identification of important groups. The technicians, similar to the parataxonomists of the "Instituto Nacional de Biodiversidad" of Costa Rica, are not to be fully trained taxonomists, but would be able to identify bees belonging to regional or national faunas and assist taxonomists in their work.

- For taxonomic and identification work to be feasible, the creation of new collections should be encouraged, and especially the maintenance and improvement of the existing ones should be supported.

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THE COSTLY CROP POLLINATION CRISIS

Christian Westerkamp and Gerhard Gottsberger

ABSTRACT

Floral diversity in crops calls for an adequate diversity of pollinators. In practice, however, all animal pollination is often and simplistically ascribed to a single uniform organism, the honeybee, *Apis mellifera*. These bees are clearly overcharged with the demand to pollinate flowers worldwide and poor fruit set results in many crops. Growers usually try to remedy this pollination crisis through the application of expensive assisting techniques. When these also fail, they may (for some high value crops) resort to hand-pollination with hand-collected pollen, which forces extremely high prices. Use of natural pollinators, on the other hand, is free of charge. As some knowledge about these beneficial interactions is already available for many species, it is recommended to discriminate it via an Internet-based database. In order to inform individuals of the basic biology of pollination, teaching programs are also suggested. These investments would be worth while through avoiding wasted effort and recurrent costs from ineffective and "assisted pollination." It pays to apply and promote diversity in crop pollination.

INTRODUCTION

Most crops need pollination, even in the times of genetic engineering and progress in plant propagation via cell culture or cuttings. This applies to the production of fruit and seed for consumption as well as to the provision of (hybrid) seed for sowing.

Although biodiversity has been widely discussed for more than a decade, pollination of the immense diversity of flowers (not only crops but of many other plants) is simplistically often and erroneously credited worldwide to a single organism, the honeybee (*Apis mellifera* L.). For its honey production, this species of African and southern European origin was brought into domestication over much of the world long ago, so bee-keeping techniques are well known. It is an eager flower visitor, but a often poor pollinator (Westerkamp 1991). It is simply overcharged with the demand that it pollinates the entirety of flowers, whether wild or domesticated. With the decline of natural pollinators caused by increasing environmental destruction, this dependency on a single ill-adapted pollinator consequentially leads to the current pollination crisis in nature as well as in agriculture. For the time being, the high cost of this dependency, is only beginning to be recognized in crop production. To the general public, the pollination crisis became apparent only with the recent decline of beekeeping, especially in North America. Even in the scientific community, the crop pollination crisis is mainly perceived as a honeybee-related problem (e.g., Allen-Wardell *et al.* 1998; Kearns *et al.* 1998).

Expensive Uniformity

Honeybees are not available free of charge. As they form perennial colonies, the hives have to be tended year-round which nowadays often even includes the expensive application of remedies for pest control. Thus, it costs to hire and maintain honeybees, colony by colony. As crop fields or orchards do not flower year round and often cover large areas, hives have to be moved into them in large numbers. This in some cases includes long-distance transportation, e.g. from Florida, Texas or South Carolina to the Californian almond orchards (Watanabe 1994).

When pollination problems arise, one of the first reactions by growers is to increase the number of bees per area. This is partially based on the correct observation that novice bees, which are still learning how to handle a flower, are better pollinators than experienced bees. Crops then are inundated with colonies in order to saturate them with bees. Tens of hives per hectare result in huge numbers of bees, which by far outnumber the insect quantity the crop can nourish. This can lead to starvation of the colonies. In a few cases, this "pollination by brute force" (Morse 1991) works by the principle that many poor pollinators are, of course, better than no pollinators at all. These numbers of hives have to be multiplied by the basic hiring and transport charges per colony.

Some crop flowers do not meet all requirements of the bees, so food has to be added to nourish the colonies and to avoid a drift of the bees to other flowers. In the case of flowers that provide only pollen, sugar syrup has to be fed to the bees. In kiwi orchards, for example, up to 800 honeybee colonies per square kilometer have to be provided, which requires the employment of extra personnel during kiwi bloom.

Competing bloom can be often much more attractive than the target crop. Measures then are taken to get rid of the rival, *e.g.,* mowing or the application of herbicides. Other alternatives are to augment attractivity of the crop and/or reduce that of the competitor. Repellents are used on non-crops while attractants (sugar water, flavored by floral odors or bee pheromones) are sprayed onto the target. For examples readers should refer to Free (1993).

The often highly esteemed floral constancy of honeybees is deleterious in cases of a separation of male and female floral phases in time (dichogamy) and/or space (dicliny, dioecy). The same applies if multifloral species with self-incompatibility are considered. Compatible pollen then has to be introduced into the target plant. Similar to the classical methods of caprification in (wasp pollinated) figs or the placing of male inflorescence in wind pollinated date palms, bouquets offering compatible pollen are placed within or even grafted onto crop plants. If this also does not help transporting the right pollen to the stigma, enpollination is applied, i.e., the use of an apparatus *(e.g.,* a pollen dispenser) that dusts bees with compatible pollen when leaving the hive. This process, however, requires the availability of hand-collected pollen which is another cost by item.

If all these methods of supplemental pollination fail, man has to take over and hand pollinate. Examples are: vanilla and in some instances atemoya, passion fruit, cacao and pears. In the simplest cases this only means selfing. Nevertheless, even this may end up in a 40% share of pollination in the production costs of (*e.g.* vanilla). Costs of hand pollinating vast areas of oil palm diminished greatly in Southeast Asia once the legitimate pollinating weevil was introduced (Roubik (Ed.)1995).

Often, however, hand-collected pollen is needed which doubles the manpower required. This pollen then is transferred to the female parts using, e.g., camel hair brushes, bee-sticks (bee thoraxes glued onto tooth picks), hand-held pollen guns or even large sprayers, similar to those used in crop protection. In the latter method, pollen is suspended in aqueous or dry (talc, *Lycopodium* spores) media. To escape the extremely high costs of hand pollination, a topical spraying of flowers with hormones (growth substances which make the ovary swell) has been suggested for certain crops, but this is also labor-intensive and the resulting "fruits" have only the aspect of true fruits.

All these expenses for honeybees and honeybee-derived follow-up costs arise every new season anew and for each single grower. It is, however, not astonishing that a species that has to be uniform in size and behaviour for the sake of correct data transfer during dance communication cannot cope with the extreme diversity of floral form and function world wide. This is especially true if one considers the behavioral peculiarities of the honeybee (Westerkamp 1991). As a perennial species, the honey bee colonies are more or less "immortal" and the colony of bees cannot specialize on particular species but each individual must learn how to handle actual flowers. They then prefer the path of least resistance, which provides nectar and/or pollen, but often this does not necessarily result in pollination.

Profitable Diversity

There is, however, a solution to the problems outlined above that helps to reduce costs: the use of a natural pollinator of the plant species under consideration. The diversity of flowers then is reflected in the diversity of pollinators. One can refer to Roubik (Ed.)(1995) for more detailed examples.

.Most flowers in nature as well as in crops are mellitophilous, i.e., adapted to pollination by bees. But as shown above, bee does not equal honey bee. So, the choice of the right bee species depends of the requirements of the flower to be pollinated.

In passion fruit flowers (*Passiflora edulis*, Passifloraceae) it is a series of extraordinarily large bees (e.g., *Xylocopa* spp. or *Centris* spp.) that fit the flower. While drinking nectar, they neatly fill the space between the perch on the corona (the 'crown of thorns') and the "roof," first formed by the anthers and later by the stigmas. Carpenter bees (*Xylocopa* spp.) are encountered in many of the countries where the Neotropical passifloras are cultivated these days. They just have to be fostered by providing them with dead wood that they needed for nesting. Costly hand pollination can thus be avoided.

The nectar-holding tube of red clover (*Trifolium pratense*, Fabaceae) is too long for most bees. Only, e.g., long-tongued bumblebees are able to reach the food and thus pollinate. Only after the importation of these bees, which had already been suggested by Darwin, red clover (also imported from Europe) set seed in New Zealand and could be sown for cattle fodder.

Only bees that are not deterred by the exploding flowers of alfalfa (*Medicago sativa*, Fabaceae), are able to pollinate them. Althoughthere is a long list of pollinator species, the alfalfa leafcutter bee, *Megachile rotundata*, is usually employed as the main pollinator. Two to three thousand bees per hectare suffice compared to 20 to 25 hives containing tens of thousands of honeybees, as formerly suggested. These alfalfa leafcutter bees, once acquired, readily reproduce within the fields; thus they even may produce a surplus of bees which may be sold to other growers.

Barbados cherries or acerolas (*Malpighia glabra*, Malpighiaceae) provide fatty oils as attractants. They are dependent on oil-collecting bees mainly of the genus *Centris* but also other genera.

Instead of vibrating tomato (*Solanum lycopersicum*, Solanaceae) flowers manually with hand-held vibrators ('electric bees'), buzz-foraging bees can do the job. Since it was learned how to circumvent bumblebee hibernation, *Bombus terrestris* colonies are commercially produced for year-round tomato pollination even in greenhouses.

Honeybees are poor pollinators of apples (*Malus domestica*, Rosaceae), pears (*Pyrus* spp., Rosaceae), cherries (*Prunus* spp., Rosaceae), and almonds (*Prunus amygdalus* Batsch, Rosaceae). Instead of trucking them over long distances, applying 2-6 colonies per hectare, which are replaced every fourth day to have as many novice bees as possible, the use of certain megachilid bees is advocated. As few as 300 blue orchard bees (*Osmia lignaria*) or 80 hornfaced mason bees (*Osmia cornifrons*) suffice (Batra 1994).

Pollinator diversity should by no means be restricted to bees, however. All floral syndromes are also represented in crops to a certain extent ranging from wind to vertebrate pollination.

Nitidulid beetles are the only pollinators of sugar apple (*Annona squamosa*), cherimoya (*Annona cherimola*) or atemoya (hybrid between these two species). Only these beetles are attracted to and able to open the neatly closed floral chambers, which serve as copulation sites. This pollinator force might be simply augmented by providing the beetles with rotting fruit for breeding.

The curculionid beetle, *Elaeidobius camerunicus*, not only pollinates, but also breeds in (spent male) inflorescence of its target plant, the oil palm (*Elaeis guineensis*, Arecaceae). Its introduction from their native home, west Africa, to the main recent growing area of oil palms, southeast Asia, resulted in annual savings of ca. US$ 100 million because hand pollination was no longer needed and fruit set improved.

Cacao (*Theobroma cacao*, Sterculiaceae) is pollinated by tiny midges of the Ceratopogonidae and the papaya (*Carica papaya*, Caricaceae) depends on night-flying moths for pollen transfer.

Pineapple guava (*Feijoa sellowiana*, Myrtaceae), on the other hand, relies on large, fruit-eating birds as pollinators. These birds consume the succulent sweet petals of the large flowers while honeybees foraging for pollen just act as thieves. Durian (*Durio zibethinus*, Bombacaceae) depends on pollinating bats.

Natural pollinators are available free provided that they are not exterminated by overuse of pesticides or by other farm management practices and that the crop is cultivated in its native area. To survive, pollinators, of course, need environmental conditions suitable for them. The conditions must satisfy all behavioral needs and these are usually more than just "crop-only-deserts". Considering that in most cases the active period of solitary bees, which form the most essential group of pollinators, coincides with the flowering time of the target crop, these pollinators need only short-term investment and not year-round care, as do honeybees.

So, in some cases, set-asides are needed (Banaszak 1992) to provide, amoung other things, sufficient nesting sites and additional food plants. If pollinators are totally missing, they have to be re-established there. One should refrain, however, from the worldwide faunal and floral adulteration through importation of exotic species are practiced since colonial times.

Consequences

The knowledge about the right pollinators for most crops is already available, in some cases, since ancient times. It just has to be applied. In those cases where information is missing, it is, of course, cheaper to invest once in research by specialists than go on paying dearly and yearly for non-functioning pollinators, as outlined above.

Since the information on pollinators is widely scattered in the technical literature, in different languages and even indirectly between the lines, it is not easily accessible to the particular growers or to local and regional agricultural advisers. They are simply unable to review the wealth of knowledge in scientific publications. To spread the fundamental information, an Internet-based data bank should be set up as soon as possible in a joint effort from all pollination biologists willing to share data.

For some crops even basic knowledge on floral functioning and on pollination is missing. Therefore, teaching program should be established to impart the basics of pollination science so that gaps in knowledge can be filled. The dissemination of information that diversity pays, not only in crop pollination but also in nature is important to global productivity and sustainability (Kevan 1993, 1999).

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Session II

The State of the Art in Bee Conservation for Agriculture and Nature

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7. Ruijter, A. de "Pollinator Diversity and Sustainable Agriculture in the Netherlands".
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17. Velthuis, H.H.W. "The Historical Background of the Domestication of the Bumble-Bee *Bombus terrestris* and its Introduction in Agriculture".

INSECT POLLINATION AND CROP PRODUCTION: A EUROPEAN PERSPECTIVE

Ingrid H. Williams

ABSTRACT

The dependence of crop production in Europe on pollination by insects is reviewed. The botanical diversity of the 140 crop species, identified as benefiting from insect pollination, requires a diversity of insect pollinators. The native European honey bee is undoubtedly the insect species that contributes most to crop pollination, a contribution (to 30 selected crops only) evaluated at ca. 4250 million dollars a decade ago. Species of bumble bee are also of considerable importance, both to field crops, when sufficiently abundant and, because they can now be reared commercially, for the managed pollination of many protected crops. The contribution of native species of solitary bees is poorly understood. The main concerns of pollination scientists in relation to sustainable pollination are outlined. Population density and agriculture are exerting major pressures on land use. There is much documented evidence that European bee fauna is diminishing largely due to habitat deterioration and bee disease; the consequences for pollination are feared to be severe. More research into the pollination requirements of plants and the development of land use strategies and agricultural policies sympathetic to bee populations is being called for. Although the European Commission recognises the need for more environmentally friendly agricultural policies, it does not appear to appreciate the crucial role of pollinator diversity to the functioning of agricultural production systems to ensure continuity of supply of high quality and varied food for Europe or the dangers of over-dependence on the services of a single pollinator, the honey bee.

Terms of reference

The Terms of Reference of this International Workshop on '*The Conservation and Sustainable Use of Pollinators in Agriculture, with Emphasis on Bees*' (defined by the Conference of the Parties of the Convention on Biological Diversity in Annex 3 of its Decision III/11) are to: 1. Monitor the loss of pollinators world wide, 2. Identify specific causes of pollinator decline, 3. Estimate the economic cost associated with reduced pollination of crops, 4. Identify and promote best practices and technologies for more sustainable agriculture, 5. Identify and encourage conservation practices to maintain or re-establish pollinators. During the last decade, similar issues have been considered by pollination scientists in Europe. Here, I review briefly their concerns, findings and recommendations, and implications of these for agri-environmental policies needed to ensure conservation and sustainable use of pollinators for European agriculture.

Population density and agriculture

Population density and agriculture exert major pressures on land use in Europe. The 15 current member states of the European Union (EU) have a population of ca. 332 million and a land area of 324 million hectares of which 44% is utilised agricultural area and 33% is woodland; furthermore much of the non-cultivated land is also man-managed. Eastward enlargement of the EU is expected to increase the population by 100 million and expand the agricultural area by 50%. The agriculture is diverse and intensive, supplying a variety of high quality food and other products for its multicultural population.

Which crops need pollinators?

Crop production in Europe is highly dependent on pollination by insects. At least 264 crop species from 60 plant families are grown in the EU; nothing has been published about the pollination requirements of a third of these species but of the remainder, 84% depend on, or benefit from, insect pollination (Williams 1994).

Which insects pollinate crops?

The botanical diversity of morphology, degree of self-compatibility and sexuality of the flowers of crops grown requires a diversity of insect vectors for efficient pollination (Williams 1994, 1996). The flowers of most outdoor crops are visited by an assemblage of insects, typically including the honey bee, several species of bumble bee, a few species of solitary bee, and on more open flowers species of flies, beetles, butterflies, or thrips. Some beetles pollinate cucurbits and oilseeds, butterflies pollinate blackberry, clovers and tobacco while some flies are used commercially to pollinate protected crops of onion, chive, carrot, strawberry and blackberry. However, on the basis of abundance and foraging behaviour, bees are the most important pollinators.

The native European honey bee (*Apis mellifera*) is undoubtedly the insect species that contributes most to crop pollination (Williams 1994). It is abundant and readily available; in the EU there are estimated to be ca.7.5 million colonies managed by ca.500,000 beekeepers. It is the only pollinator available for supplementary pollination of field crops. As a generalist feeder, it visits and pollinates most of the crops grown, yet on a single foraging trip is highly constant to species making it a reliable cross-pollinator, although not necessarily the most efficient one for all crops.

Bumble bees are important too (Osborne and Williams 1996). They are efficient pollinators of crops wherever they are sufficiently abundant and particularly important in northern Europe in weather too cool for honey bees. They are generalists with a broad flower choice but species differ in tongue length and hence flower preferences; long-tongued species, such as *Bombus hortorum* and *Bombus pascuorum* are important pollinators of crops with deep corollas such as field bean and red clover. Because of their ability to buzz-pollinate, they are better pollinators than honey bees of solanaceous and ericaceous crops. Since methods for the continuous rearing of bumble bees were developed in the late 1980s, the use of bumble bees (*Bombus terrestris* L.) for the managed pollination of protected fruit crops of aubergine, blueberry, melon, raspberry, red currant, strawberry, sweet pepper and tomato and of protected seed crops of carrot, cauliflower and brussels sprout has grown dramatically and their potential for the pollination of some high value outdoor field crops, such as almond, apple, blueberry, cherry, cranberry, peach, pear and plum is being assessed.

The contribution of the several hundred species of native solitary bees in the pollination of field crops is less well understood (Williams 1996). Solitary bees are rarely as numerous on crops as the honey bee and bumble bees and their abundance is restricted by the proximity of suitable nesting sites. Nevertheless some species of *Andrena, Osmia* and *Anthophora* can make a useful contribution to early flowering fruit when other bees are scarce and species of *Megachile* are important pollinators of legumes. Associated with their short flying season and seasonality is a synchronisation of their foraging activity to a limited number of plant species that flower at that time and have accessible pollen and nectar. Most have short tongues *(Hylaeus, Colletes, Andrena, Halictus, Sphecodes)* whereas others have tongues longer than that of the honey bee (e.g. Anthophora). Solitary bee species can be especially useful pollinators of particular crops; the alfalfa leaf-cutting bee (*Megachile rotundata* Fab.) is used on a small scale for the pollination of lucerne and white clover and management methods are being investigated for a few species of stem-nesting *Osmia* and *Megachile,* for use in the pollination of selected orchard and soft fruits, field legume and seed crops (Williams 1996).

Economics of crop pollination by bees

An economic evaluation of the contribution of bee pollination to the production of 30 insect-pollinated crops was published more than a decade ago (Borneck and Bricout 1989). These authors attributed to each crop a value, 'the coefficient of incidence', based on its dependence on insect pollination and attributed 85% of insect pollination to honey bees. They calculated that the crops had a combined annual market value of 65,000 million ecus, that insect pollination contributed 5000 million ecus and that pollination by honey bees contributed 4250 million ecus (1 ecu = ca. 1$). There is a need to update this evaluation and include more than 30 of the 177 crops grown in the EU that benefit from bee pollination. More recently, the value of honey bees and bumble bees as pollinators of major selected UK crops for which market statistics are available, has been estimated to be £172 million for outdoor crops (rape, beans, tree and soft fruit) and £30 million for glasshouse crops (tomatoes and sweet peppers) (Carreck and Williams 1998).

Loss of pollinators and causes for decline

European bee fauna is diminishing (Banaszak 1995). Habitat deterioration and bee disease have been identified as major causes of decline. In response to the concern that changes in land use and beekeeping practice within the Community may result in a shortage of bees for crop and wild flower pollination, the Scientific and Technical Options Assessment (STOA) of the European Parliament commissioned a desk study on `Bees and the pollination of crops and wild flowers: changes in the European Community' (Corbet, Williams and Osborne 1991a). This examined: 1. which crops and wild flowers in the Community depend on bees for their pollination and how the role of bees as pollinators can be assessed (Corbet, Williams and Osborne 1991b), 2. recent changes in habitats and land use and their predicted effects on bee pollination (Osborne, Williams and Corbet 1991), 3. recent changes in the numbers and distribution of honey bees and wild bees and their consequences for crop production and the reproductive success of wild flowers (Williams, Corbet and Osborne 1991).

The STOA report documents serious regional losses of bumble bee species, marked decreases in the numbers of managed honey bees and the listing of numerous species of solitary bee in national Red Data Books. It recognises that: a) the distribution and abundance of bees depends largely on the availability of a seasonal succession of forage flowers and nest sites; b) fragmentation and destruction of semi-natural habitats, particularly open biotypes such as garique, heaths, unimproved grassland and undisturbed areas of farmland, is a cause of the decline of wild bee populations and of reduced food supply for honey bees; c) intensively cultivated arable land is an inhospitable environment for bees.

It warns that the impact of inadequate populations of pollinators will be far reaching. If bee pollinated flowers do not set seed, the integrity of Europe's remaining semi-natural vegetation will be destroyed. This in turn will deprive many other herbivorous or seed-eating insects, birds and small mammals of their host plants and/or food, with consequent further loss of species diversity. Crops dependent on pollination by bees will give decreased yields and may no longer be grown profitably. Their loss will cause further depletion of nectar resources for the remaining bees.This vicious circle, resulting from the mutual interdependence of bee-pollinated plant and pollinator, makes the future survival of both inextricably linked.' it concludes that appropriate agricultural and environmental policies and co-ordinated research and development programmes are needed urgently to ensure adequate pollination of bee-pollinated crops and wild flowers in the European Union.

Further data on recent quantitative and qualitative changes in bee fauna composition as a consequence of changes to ecosystem management and environmental pollution, were presented at an international colloquium convened in Poland to discuss 'Trends of changes in the fauna of wild bees in Europe' (Banaszak 1995).These included data from various countries and habitats of Europe, including many from Central and Eastern Europe.

The *Varroa mite*, which entered Germany in 1977 and had invaded Greece, Italy, France and Holland by 1992, continues to spread and devastate honey bee populations on mainland Europe. In 1992, it was discovered in England and has since spread throughout the UK; beekeepers are increasingly unable to meet the demand from growers for colonies for pollination. In 1998, *Varroa* was reported from Ireland.

Current status and future pollination needs

Following the STOA report, the EU Commission convened a workshop of EU pollination experts in Brussels, to discuss further the current status of bees as pollinators of EU crops and native plants and the future pollination needs of European agriculture (Bruneau 1993). This workshop recommended (Williams 1993) that:

1. **Research** be encouraged to determine which crops and wild flowers are bee pollinated, which bee species pollinate them best and at what densities and the economic benefits of bee pollination per crop and per region.

2. Relevant **research and development and agricultural policies** be adopted to ensure adequate populations of appropriate pollinators for different crops in different regions. Particular attention should be given to develop and improve techniques for the rearing of solitary bees and bumblebees, support bee taxonomic research, promote a thriving beekeeping industry and pollination services and advice to growers, encourage the use of native rather than exotic bees, monitor movement of commercially reared bees and the impact of *Varroa*, and investigate the impact of honey bee introductions on native bee populations.

3. **Land use policies** be promoted to encourage appropriate management of agricultural, forested, semi-natural, conservation and amenity areas to improve habitats for wild and managed bees. Particular attention should be given to conserve and restore natural vegetation, minimise soil surface disturbance which destroys nest sites, promote perennial

herbaceous vegetation, bee forage seed mixtures and legumes and develop pesticides safe for bees.

Concern that interspecific competition for food (pollen/nectar/oil) resources between honey bees and other bee species was leading to reduced reproductive success of wild bees and loss of diversity was the subject of a workshop convened in the Netherlands in 1997. The workshop concluded that there was insufficient published data on competition between honey bees and wild bees in Europe to allow general conclusions to be made on the existence or absence of harmful competition. Most studies were small scale experiments, of short duration and without sufficient replication. It recommended more research on the ecology and taxonomy of bees to include key factors (food and nest site availability, parasites, diseases, predators) affecting the population dynamics of wild bee species and the richness and abundance of bee communities in different habitats. Landscape scale studies on the foraging ranges and behaviour of different species, particularly in relation to the temporal and spatial arrangement of resources, their quantity and quality were also recommended.

Land management for bees

Conservation of bees in agroecosystems depends on habitat management sympathetic to their survival. Available land management options have been explored in at least three recent meetings, all convened in the UK. In 1993, a symposium (Matheson 1994) explored EU and UK Government land use policies, especially as they affect bee forage plants through land use changes, set-aside programmes, management of hedgerows, field margins and woodland and the planting of forage crops specifically for bees. Another symposium in 1995 (Matheson *et al.* 1996), was organised around four themes: a) the effects of habitat degradation on bees and opportunities for improvement of different habitat types, b) the importance of bee diversity to crop, wild plant and rare plant genetic diversity, c) the effects on native bee faunas and floras of introducing honey bees and bumble bees and d) the key role of bee systematics as a vital scientific discipline enabling the monitoring and understanding of bee diversity. In 1998, a workshop examined specific examples of habitat restoration for wildlife and bee diversity improvement (Jones 1998).

EU agri-environmental policies

Agenda 2000 - Agriculture, the policy document of the European Commission, which outlines its Common Agricultural Policy (CAP) into the first decade of the next century acknowledges 'the crucial role that agriculture plays, in producing high quality food, in maintaining a living countryside, in protecting landscapes and preserving cultural values' It recommends increasing budgetary resources and co-financing of 'services which call for an extra effort by farmers, such as organic farming, maintenance of semi-natural habitats, traditional orchards or hedgerows, alpine cattle keeping, upkeep of wetlands, buffer strips along rivers or field margins.' Improved management of such farming systems and habitats could bring benefits for bees.

However, there is no evidence that the EU Commission has taken note of the concerns and recommendations made by its pollination scientists as outlined above. Lobbying by the beekeeping industry has resulted in some increased funding to support beekeeping and, in particular, to fund research into Varroa. But there appears to be little recognition of the dependence of EU crop production on a diversity of bees or of the dangers of over-dependence on the services of a single pollinator, the honey bee. Hopefully, by highlighting these issues at International Fora, this Workshop will help focus the attention of the EU Commission on the crucial role of pollinator diversity to the functioning of agricultural production systems and foster its support for research and policy development to conserve and promote the sustainable use of pollinators in Europe.

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POLLINATOR DIVERSITY AND SUSTAINABLE AGRICULTURE IN THE NETHERLANDS

Arie de Ruijter

ABSTRACT

In densely populated countries of Europe pollinator diversity is under great pressure. Wild bee species are in decline, as is the number of honey bee hives. Reasons for declines and taxonomic impediments are discussed. A warning that sustainable agriculture does not necessarily assume pollinator conservation is given.

The Netherlands is a densely populated country (450 inhabitants per square kilometre), but it is nevertheless an important producer of agricultural products. Land use in the Netherlands is becoming more and more intensive and this means that pollinator diversity has come under great pressure.

The Status of Wild Bee Species

Of 322 species of bees, 60 species have not been seen after 1980. Of these 60 species 13 disappeared before 1950, 15 species in the fifties, 16 in the sixties and another 16 in the seventies. This looks like a rather constant rate of decline. We know less about the abundance of bees. Several species show a decline in abundance, but some generalists seem to thrive well. In the genus Bombus for example, several species have become very rare (*e.g. B. sylvarum, B. muscorum*), others are still very common (*B. terrestris, B. pascuorum*). Even in this well-known genus, we do not know the reasons for these differences. Another problem we have to deal with is taxonomy. In our institute we reared *B. terrestris, B. lucorum, Bombus cryptarum and B.* magnus and although it seems obvious that these are four different species, the status of *B. cryptarum* and even *B. magnus* is still disputed. We know even less of the taxonomy of many other genera.

Economic importance

Managed and wild pollinators play an important role in the pollination of agricultural crops. In 1992 the ministry of agriculture estimated the contribution of pollinating insects at about 200 million Dutch guilders a year (=100 million US$). Managed honeybees, bumblebees (*Bombus terrestris*) and solitary bees (*Osmia rufa*) are used for the pollination of fruit crops, vegetables and seeds. In 1995 we introduced insect pollination of greenhouse tomatoes, using honeybees as pollinators. This worked very well as long as the windows were closed or provided with gauze to keep the bees inside. Of course when Mr. De Jonghe in Belgium found out three years later that bumblebees could do the same job with the windows open, we started to use bumblebees for the pollination of greenhouse tomatoes. We also developed a management system for the use of *Osmia rufa* in seed production. In order to study the biology of this important species, we tried and succeeded rearing them in the laboratory.

The Status Of Honeybees

Simultaneously with the decline in wild bee species, the number of honeybee colonies has gone down from about 160.000 just after the second world war to about 80.000 today.

Reasons For The Decline

Although the reasons for the decline of individual wild bee species are not always clear, it is generally agreed that the loss of food plants and nesting sites are the most important factors. As a result of changes in agricultural practice, during the last 50 years the numbers of flowering plants have decreased substantially. From the variety of crops grown in the past, only high yield field crops (such as potatoes, wheat and sugar beets) are still grown in large areas. Due to the use of herbicides many weeds have disappeared from crop fields. In a country like the Netherlands, there are no refugia like mountain areas or land that is not suitable for agriculture. The Dutch have drained the swamps, pumped water out of lakes and even use the bottom of the sea for agriculture.

Conservation Measures

Recently attempts have been made to change the management systems for different types of habitats. Roadsides, field margins and waterways are now managed in a way to increase the diversity of plants. Under set-aside regulations farmers can now use a variety of plant species on land that is temporarily not used for agricultural production. The plants on these lists are sustaining a variety of game, birds and flower visiting insects.

The government supports measures that make agriculture more sustainable. The use of pesticides is cut down and there are strong regulations on the use of manure and fertilisers. Fragmentation of the landscape makes rare species more susceptible to extinction. For this reason the government's policy is to maintain and recreate corridors between important habitats and to enlarge small natural reserve areas by buying farmland and turning it into nature areas. There is still a lot of discussion about this policy. Probably there were less opposition against these measures if the management systems would be less strict. A diverse approach with room to try different strategies would probably give the best results in the end. A diverse, multifunctional landscape creates chances for a diversity of pollinators.

A Warning

Sustainable agriculture does not automatically lead to the conservation of pollinator diversity. In particular the production of large amounts of biomass for energy may result in desert-like habitats. We have to be aware that what is being build up by carefully managing the landscape, is not torn down by large-scale biomass projects.

Research

At our institute Ambrosiushoeve, with respect to pollinator diversity, we are running two research projects at the moment. The first one deals with the effect of pollination by managed honeybees and other insects on blackberry. Blackberry is a wild plant in the Netherlands that grows both in natural and semi-natural habitats. The berries are an important food source for birds. The other project deals with managed bees and wild pollinators in fruit orchards. After an inventory of the different species present in fruit orchards, we want to focus on the needs of different species (food, shelter, nesting sites) and describe the measures fruit growers can take themselves in order to maintain a local population of pollinating insects.

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PROBLEMS OF CONSERVATION AND SUSTAINABLE USE OF NATIVE BEES IN RUSSIA

Mikhail V. Berezin and Vasilii B. Beiko

ABSTRACT

At the present time in Russia populations of many species of bees, including bumble bees, are strongly influenced by various anthropogenic factors. For example, there were 31 bumble species in Moscow region 50 years ago, by now 7 species have disappeared, populations of 8 species have been severely reduced, those of 5 species have been moderately reduced, and only 9 bumble bee species remain stable. Thirty-seven endangered bee species, including 18 bumble bee species, are included in The Moscow region Red Data Book and 10 bee species are included in The Russia Red Data Book. In Russia the Red Data Book lists form a legal basis for bee conservation in State Natural Reserves, National Parks and in smaller reserve. Two principal uses of native bees in Russia are in pollination of forage legumes and crops. In Russia over 40 species of solitary bees are active pollinators of alfalfa flowers and more than 30 bumble bee species are the best pollinators of red clover. Curiously, Russian farmers actively imported *Megachile rotundata* from North America for alfalfa pollination. Since the 1970s there are several firms breeding *Osmia* and *Megachile* in USSR. But nowadays these programs have ceased for economical reasons. The studies on effective use of bumble bees for crop pollination and rearing of bumble bee colonies in laboratory conditions in Russia began early this century. Since 1994 some Russian greenhouse agrofirms began importing bumble bee colonies of *Bombus terrestris* from Western Europe for pollination of tomatoes and other Solanaceae. Recently some Russian firms have begun producing bumble bee colonies.

INTRODUCTION

Native bees are among the most significant insect pollinators of many entomophilous plants and, therefore, have an important role in the terrestrial ecosystems.

There are more than 2000 bee species inhabiting the former USSR (Radchenko and Pesenko 1994). The main Russian studies on bee diversity and significance of natural bee populations for cross pollination of crops were carried out in the last 80 years (Gubin 1933; Pesenko 1982 and others). In Russia over 40 species of solitary bees are active pollinators of alfalfa flowers (*Medicago sativa*) including *Rophitoides canus* (Eversmann), *Melitturga clavicornis* (Latr.), *Melitta leporina* (Panzer), *Halictus quadricinctus* Fabricius, *Andrena ovatula* (Kirby), *Megachile centuncularis* (L.) and others (Pesenko 1982). More than 30 bumble bee species, particularly *Bombus pascuorum* Scopoly, *B. lapidarius* (L.) and *B. hortorum* (L.), are the best pollinators of red clover (*Trifolium pratense*). At the present time in Russia populations of many species of bees, including bumble bees, are strongly influenced by various anthropogenic factors, the most important of which are destruction of habitats and food resources, chemical pollution of the environment and recreational pressure on biotopes.

For example, there were 31 bumble species in Moscow region (47.000 km^2) 50 years ago, by now 7 species have disappeared, populations of 8 species have been severely reduced, those of 5 species have been moderately reduced, and only 9 bumble bee species remained stable (Table 1). In contrast, *Bombus terrestris* (L.) increased in number, while *Bombus schrencki* F. Morawitz was recorded for the first time in the region (Berezin *et al.* 1995; Panfilov 1957). Thirty seven endangered bee species, including 18 bumble bees species, are included in The Moscow region Red Data Book (1998) and 10 solitary native bee species are included in The Russia Red Data Book (1997). There were 20 bee species in The USSR Red Data Book (1984). The total number of protected bee species in some regions of Russia is listed in Table 2. The Red Data Book lists form a legal basis for bee conservation in Russia. Generally, conservation measures for native bees include protection of food sources and nesting sites. In Russia it takes place in State Natural Reserves, National Parks and in smaller reserve (microreserve) Protected Natural Areas of lower status.

Protected Natural Areas for bees incorporate nesting sites, usually with large nest aggregations or colonies of solitary bees and sites with food plants. For example, in Moscow region all nest aggregations of large solitary bees from Anthophoridae and Megachilidae families consisting of over 20 nests (except some common bees, such as *Osmia rufa*), colonies of some spring Andrenidae species (over100 nests), and melittid *Dasypoda* species (over1000 nests) should be protected (Berezin *et al.*1988). Smaller nest aggregations should be protected in case the nesting species is included in the Red Data Book list. Some special parasitic species of bees require protection. Searching for the bee colonies and habitats needing protection are executed successfully by schoolboys, students and volunteers according to the non governmental Programme "BIOSHIELD" of The All Russian Society of Nature Conservation (Berezin 1988). Two principal uses of native bees in Russia are in pollination of forage legumes and crops. Seed production of red clover and alfalfa requires bumble bees and Megachilidae bees, especially *Megachile rotundata* imported from Canada and USA, while some species of *Osmia* (*e.g. O. rufa*) are applied in pollination of crops. Since the 70s there are several firms breeding *Osmia* and *Megachile*, mainly in southern Russia (Krasnodar region) and West Siberia. There was also an experimental factory for producing artificial nests and equipment for breeding of megachilid bees (Pesenko 1982). But nowadays these programs ceased because of economic reasons.

The studies on effective use of bumble bees for crop pollination in Russia began early this century. They are based on the method of free attraction of overwintering bumble bee queens to artificial nests placed on protected territories (Skorikov 1922; Grebennikov 1982 and others). In different years the average efficiency of this method was less than 30% (Grebennikov 1982). Another method includes the "compulsory" nesting of natural bumble bee queens in laboratory with preservation of their free foraging outdoors (Rechkin and Dolgov 1984). But all these methods cannot be determined as breeding sensu stricto for use of bumble bee queens removed from natural ecosystems. The methods were adapted for application under open ground conditions where their efficiency was masked by low level of agrotechnology.

More recently, a method for bumble bee gardening "Bomboretum" was proposed in West Siberia by Bogatyrev (Bogatyrev 1992).

On the other side, the studies on artificial bumble bee breeding in some European and Canadian agricultural firms and Universities have resulted in the highly efficient technology for industrial bumble bee keeping and bumble bee pollination, especially for greenhouse use (Eijnde 1990). So in 1994 96 approximately 70 Russian greenhouse agrofirms imported about 7000 bumble bee colonies of *Bombus terrestris* from Israel, Holland, Belgium, mainly for pollination of tomatoes and other Solanaceae. Recently some Russian agrofirms have begun producing bumble bee colonies (mainly *B. terrestris*) for crop pollination. More attention should be given to the problems of gene and parasite introduction from imported greenhouse bumble bee populations to natural populations and vice versa.

Another problem of native bees' conservation is the impact of beekeeping on wild bee populations. Wild bees suffer from dense populations of honey bees in competition for nectar and pollen. For example, at the Prioksko Terrasnyi State Reserve (Moscow region) mass honey bee foraging has a strong depressing effect on native populations of anthophorid and megachilid bees (Beiko 1990; Beiko and Volkova 1993).

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TABLE 1: Changes in *Bombus* populations of the Moscow region for the last 50 years.

Bombus species	Years		Changes
	1947 1952 (by: Panfilov)	1981 1997 (original)	
1. B. confusus	3	0	not found
2. B. maculidorsis	4		decreased
3. B. veteranus	6	3	decreased
4. B. silvarum	5	3	decreased

5. *B. ruderarius*	4	4	stable
6. *B. solstitialis*	5	2	decreased
7. *B. tristis*	3	2	decreased*
8. *B. subbaicalens*	2	2	stable
9. *B. muscorum*	2	2	stable
10. *B. schrencki*	0	2	increased
11. *B. pascuorum*	6	6	stable
12. *B. hortorum*	5	5	decreased*
13. *B. ruderatus*	1	0	not found
14. *B. consobrinus*	1	1	stable
15. *B. pomorum*	3	2	decreased*
16. *B. distinguendus*	3	3	stable
17. *B. subterraneus*	5	3	decreased
18. *B. fragrans*	1	0	not found
19. *B. lucorum*	6	6	stable
20. *B. patagiatus*	1	0	not found
21. *B. sporadicus*	1	0	not found
22. *B. terrestris*	1	3	increase
23. *B. soroensis*	3	2	decreased*
24. *B. semenoviellus*	2	1	decreased
25. *B. serrisquama*	1	1	stable
26. *B. lapidarius*	5	5	stable
27. *B. sicheli*	1	0	not found
28. *B. hypnorum*	5	4	decreased*
29. *B. jonellus*	3	1	decreased
30. *B. modestus*	1	0	not found
31. *B. pratorum*	5	3	decreased

* the quantitative change is probably insignificant

Interpretation of grades of bumble bee relative abundance:

0	not found
1	found locally, rare in all biotopes
2	found everywhere, rare in all biotopes
3	found everywhere, rare or common
4	found everywhere, common everywhere
5	found everywhere, locally numerous
6	found everywhere, numerous everywhere

TABLE 2: Species composition of Bees in some Regional Red Data books of Russia.

Taxons	Regions and Publication Years							
	Russia	Moscow	Mid-Russia	Orenburg	Saratov	Archangelsk	Karelia	Ural
	1984	1999	1998	1996	1998	1996	1995	1995
INSECTA	202	95	281	34	31	72	50	221
HYMENOPTERA	24	24	44	7	8	12	9	44
BEES	20	10	37	7	5	9	9	7
Colletidae	0	0	1	0	0	0	0	0
Andrenidae	1	0	2	0	0	1	0	3
Halictidae	1	0	2	0	0	1	0	0
Megachilidae	1	0	2	0	0	1	0	1
Anthophoridae	2	1	10	0	2	1	1	0
Apidae	15	9	18	7	3	5	8	3

ASPECTS OF BEE BIODIVERSITY, CROP POLLINATION, AND CONSERVATION IN CANADA

K.W. Richards and P.G. Kevan

ABSTRACT

The risks to pollinator biodiversity in Canada are examined through a generalised model with inputs on environmental sensitivity, pressure indices, and societal response as they relate to the agriculture/environment interface. About 3,500 species of bees occur in America north of Mexico. Few genera are found in the USA and Canada that do not also occur in Mexico, however there are far fewer species in Canada. Canada has focused on the development on a few non-Apis species as well as the European honey bee as managed pollinators for specific crops with success for the alfalfa leafcutter bee, *Megachile rotundata*. The economic value of bee-affected pollination in Canada is great. Proposals for habitat management programs have resulted in little positive action, especially in agricultural systems. Nevertheless, Canadian society has responded to protect the environment and biodiversity. Over 3500 publicly owned protected areas and 550 private areas are recognised across the country. About 8% of the Canadian land base is protected through legislative programs. Numerous factors have influenced pollinator biodiversity and pollination including agriculture (cropland, pasture, irrigation, pesticides), forestry, urbanisation, access (road, rail, airports), utilities, extraction sites (mines, oil/gas), and pollution. Biotic factors of parasites, predators and diseases have also played a more natural role in regulating pollinator biodiversity. All these factors are influenced by human beings and may have long-term, negative consequences resulting in shortages of pollinator populations reserved for crop pollination. In reality, these pressures play a minor role in regulating/decreasing the density/diversity of pollinators compared to environmental factors (weather conditions, availability of nesting sites, food sources).

INTRODUCTION

Canada is committed to sustainable development; bringing together economic, social, and environmental goals and ensuring that Canadians' needs are met today and in the future while we live in balance with other components of the earth's ecosystems. Achieving environmentally sustainable agriculture is a process of continuous improvement, energised and carried out by members of the agriculture sector and supported by government. Canada is also committed to preserving biodiversity, as it is the key activity in sustaining the earth's resources and productivity for the future. In December 1993, Canada became one of the first industrialised countries in the world to ratify the international Convention on Biological Diversity. Extensive discussion on agricultural biodiversity has occurred since that time and a review of the biodiversity of pollinators in agriculture and the environment was undertaken.

This topic is an excellent example of the value added by a forum such as the Convention on Biological Diversity, which brings agriculturists and environmentalists to work together on common problems. Thus, the aim of our review is to summarise the relative risks of the major crop pollinators in Canada, and discuss important aspects of pollinator biodiversity and crop pollination, factors affecting pollinator biodiversity and general trends in Canada as they relate to the agriculture/environment interface.

In general, the risk to pollinator biodiversity can be addressed in a generalised model (Rubec *et al.* 1992) with three main attributes: 1) environmental sensitivity, 2) pressure index, and 3) societal response through remediation. The modified model (Fig. 1) attempts to show the relationship between the different indices with a bias towards pollinators. Canadian data are insufficient for all indices, but as new data sets become available, they could be added to the model for a more complete and detailed representation of the risk to pollinator biodiversity in Canada.

Environmental sensitivity

Across Canada bees can be encountered from early spring to late autumn in nearly any type of terrestrial habitat, from the Arctic, Pacific or Atlantic coasts to the alpine regions of the Rocky Mountains: in cool rainforests as well as in hot prairies, in woodlands as well as in meadows, in orchards and cropland, even in gardens. But the bee fauna that can be observed changes from habitat to habitat and from season to season. This is because habitats of bees differ greatly in respect to their size, their microclimate, their physical structure and their vegetation. Furthermore, many bees are highly seasonal, having only one generation a year, and time their emergence to coincide with the peak of flowering of their particular food plants in their specific habitats.

Many of the crops grown in Canada are entomophilous and dependent on bees for pollination. The honey bee, *Apis mellifera,* as the most widely available and easily managed generalist pollinator, has in recent decades played a vital and dominant role in the pollination of entomophilous crops. However, research is demonstrating that bee species differ in their effectiveness and efficiency as pollinators of particular crops; some are better pollinated by various species of native bee than by the honey bee. Optimum crop pollination can only be achieved if the appropriate pollinator species are available to visit the flowers. Changes in land use and agricultural and apicultural practices have resulted in declining populations of native bee and managed bee populations in Canada at a time when greater crop diversification and consumer demand for high quality produce and variety of food, particularly fruit and vegetables, demands a greater variety of bee species for pollination. The importance of maintaining bee diversity in agroecosystems and developing management methods for a diversity of pollinators must not be overlooked if Canada is to sustain efficiently its production of high quality food and other agricultural products.

Canadian pollinator biodiversity

In America north of Mexico there are about 3,500 species of bees (Krombein *et al.* 1979). Few genera are found in the United States and Canada that do not also occur in Mexico, species diversity is much less in Canada. Somewhat more than 2,700 of North American species are pollen collecting bees while slightly more than 700 species (or about 21%) are cleptoparasitic species. Only about 800 species of bees occur east of the Mississippi River and thus the apifauna of the larger and more ecologically diverse western portion of America north of Mexico is more than three times richer. Because it is well established that the apifaunas of arid regions are consistently much richer in species than any other climatic regions, it is not surprising that most of the North American species of bees are to be found in the southwestern United States and adjacent northern Mexico. Six of the seven recognised families of bees (Colletidae, Andrenidae, Halictidae, Melittidae, Megachilidae and Apidae) are present in Canada and among the largest genera in our fauna are *Andrena, Perdita, Nomada, Dialictus, Halictus, Osmia, Megachile, Melissodes, Bombus and Colletes* (Krombein *et al.* 1979; Danks 1979). The actual number of species existing in Canada is unknown, but is estimated to be between 520 (Krombein *et al.* 1979) and 977 (Danks 1979). Several of our species are Holarctic in distribution and at least two species of economic importance, the alfalfa leafcutter bee, *Megachile rotundata*, and the European honey bee, *A. mellifera*, are introduced.

Canadian agriculture depends mainly on four groups of bees, which are managed commercially for pollination of its crops. These are the honey bees, the alfalfa leafcutter bees, bumble bees and mason bees. A few other native bee species have potential for commercial crop pollination, but their role is poorly understood, with the exception of the assemblage of native bees associated with the lowbush blueberry pollination and the hoary squash bee (*Pepmapis pminosa*) on squash and pumpkin. Most reports are simply records of flower visitations with sometimes an indication of their density. The following summarises briefly important attributes of their biology and management following Michener (1974).

Honey bee *(Apis mellifera)*

The honey bee is undoubtedly the best known insect species that contributes most to the pollination of entomophilous crops in Canada (CAPA 1995), but there are both advantages and disadvantages to its use. The honey bee prefers to fly in good weather only. It is thus relatively more reliable as a pollinator as one moves from the more variable, cooler and more inclement weather of spring to the stable, warmer summer season.

Several factors affect the length of time spent by bees on each foraging trip. These include a) the quantity of nectar or pollen available, b) the position and nature of floral nectaries, c) the distance the bees must travel to obtain nectar and pollen, d) weather conditions and e) forager competition. Honey bees may forage up to 13.5 km from their hives and each forager averages 15 to 106 minutes per trip. Usually the foraging distances providing maximum seed set and fruit production is much shorter.

The honey bee is a generalist feeder that visits and pollinates most of the crops grown, yet on a single foraging trip is highly constant to species, making it a reliable cross-pollinator. However, this means that it is not specialised for any particular crop.

Individual honey bee foraging is not random. Each bee makes a restricted number of visits to comparatively small areas of 3- or 6- metre in diameter, which often represent a single plant species. They are fairly constant to a foraging area. However, when the nectar or pollen source begins to fail, bees may extend their foraging area and some individuals wander. Larger foraging areas are found where competition is absent, but smaller areas are associated with intense competition. Competition should result in a more thorough working of all flowers in the foraging area and may cause a more rapid cessation of flowering through setting of seed. As little as 12.5% of the total hive population may forage at any one time. This suggests that even when nectar is easily available, bees spend more time in the hive between trips that they do on the trip itself.

In most areas of Canada, bee producers are constantly challenged by climatic extremes and diseases in order to maintain healthy and sustainable populations for optimum production (CAPA 1995). Many producers are reluctant to move bees into orchards or field crops because of the possible interaction with disease infected colonies or insecticides. In other words, the management of healthy colonies for their survivorship is becoming more and more territorial. However, orchards and field crops depend upon the transportability of pollinators for a productive crop.

Honey bees managed by beekeepers across Canada are primarily those derived from the Italian, Carniolan and Caucasian races. Little comparative evaluation has been made however they have been evaluated for brood rearing, temperament, ability to overwinter, honey production, some aspects of pollination, and more recently resistance to disease and mite pests.

In British Columbia, honey bee colonies are rented for pollination of apple, cherry and pear trees in the Okanagan and Kootenay regions; some minor use is made of honey bees in the pollination of red and white clover. In the Lower Mainland region the major use of honey bees is in the pollination of berries, including raspberry, strawberry, blueberry, and cranberry. The pattern is roughly the same in Atlantic Canada, where two-thirds of the honey bee colonies are rented for the pollination of apple, strawberry, cranberry and lowbush and highbush blueberry.

In Ontario, honey bees are important both as rented and as incidental pollinator of apple, pear and cherry in the Georgian Bay, Lake Ontario, Niagara, Norfolk and Kent regions. Colonies are rented on a small scale for the pollination of strawberries and recently and extensively for field cucumber pollination.

Little use is made of honey bees for pollination in the Prairie Provinces; most of the colonies in this region are employed for honey production and are placed in or near fields primarily for the collection of nectar. A limited amount of honey bee pollination of sweet clover, red clover, sainfoin and rape is carried out, although the demand for bees for hybrid canola pollination is increasing.

Alfalfa leafcutter bee *(Megachile rotundata)*

This bee, among the 25 species of *Megachile* in our fauna, is the most important pollinator of alfalfa in Canada and is increasing in importance world-wide. It can also be used to pollinate many other legume species such as sainfoin, clovers, cicer milkvetch, and birdsfoot trefoil (Richards 1991; Richards and Edwards 1988). With good management the bees can increase alfalfa seed yields as much as 20 fold. Large numbers of leafcutter bees (50,000 to 75,000 per hectare) are needed to pollinate the crop. For this reason, the loose-cell system of leafcutter bee management was developed (Hobbs 1964, 1973; Richards 1984, 1987) . The system places the optimum number of bees on the crop at the appropriate time to obtain a high seed set and an adequate return of viable bees for the following year (Richards 1984).

The loose-cell system enables easy removal of bee cells from laminated, grooved nesting materials made of pine wood or polystyrene, for storage over the winter without destroying the nesting material. The system was developed to control the potential build-up of populations of natural parasites of the bees (cuckoo bees, chalcidoid wasps, blister beetles) and efficient use of cold storage and incubation facilities to synchronise bee emergence with the beginning of flower bloom. The development and emergence of bees can be regulated more easily by using controlled incubation facilities than by relying on field conditions. The techniques to synchronise the emergence of the bees with flowering have been easier to develop than techniques to control the blooming of the crop. The system allows for the easy control of chalkbrood, a potentially serious disease of the bee (Richards 1985).

The alfalfa leafcutter bee is a solitary nesting bee by nature, although it is gregarious. At the nests, each female makes her own nest by cutting, transporting, and placing suitable leaf material in the tunnel to form thimble-shaped cells, collecting provisions of pollen and nectar, and laying eggs in the cells. She has little interaction with other females of either her own or the daughter generation.

The management system that has been devised permits beekeepers to make samples of cells they produce to estimate accurately numbers of cocoons, female bees, parasites and disease. These estimates allow leafcutter beekeepers to improve their beekeeping practices. The estimates also provide quality guidelines when the bees are sold, nationally and internationally.

Bumble bees

Bumble bees (*Bombus* spp.) are important pollinators of native plants and a wide variety of crops. Several characteristics make them useful crop pollinators: a) long tongues; b) ability to forage at low temperatures; and c) ability to harvest pollen from buzz-pollinated flowers (*e.g.* blueberry, cranberry, and tomato). As a consequence of these characteristics bumble bees are most effective as pollinators of crops with long or trumpet-shaped flowers (i.e. red clover, cicer milkvetch), crops blooming during cold weather (i.e. fruit trees), and buzz-pollinated crops. The blossoms of buzz-pollinated crops have anthers that require rapid vibration before they will release their pollen grains. Bumble bees are especially efficient at performing this type of vibrational pollination.

There are about 40 species of bumble bee in Canada with a higher diversity and density found in southern Alberta than in other areas of Canada. The bees produce annual colonies that reach a peak size in mid-late summer of 50-150 workers, depending on conditions and the species. The life cycle begins in spring and overwintered, mated queens emerge and search for suitable nest sites. After a nest site is found the queen collects pollen and nectar and lays her first brood of worker eggs (usually 6-8). About 3 weeks later the first workers emerge and the colony then produces several successive broods of worker over the summer. By mid- late summer, colonies produce new queens and males. The new queens mate and, after spending sometime 'fattening up", dig into the soil to winter. Any remaining workers and males die in the fall.

Bumble bees often are rare in areas of intense agriculture because of pesticide usage, lack of suitable nesting sites and insufficient food plants to sustain the colony over the active season. Wild populations can be encouraged by leaving undisturbed areas around crops such as fence rows that provide suitable nesting sites (e.g. under logs or in old mouse and vole nests). Providing suitable habitat for bumble bees may also increase rodent populations, requiring protection of fruit trees with plastic wraps. Even more important than increasing the number of nesting sites is ensuring adequate food plants. Because bumble bees do not store food for more than a few days, a steady uninterrupted progression of plants over the season is essential to support colonies when crops are not in flower.

Native populations also can be augmented by commercially reared colonies, but these can be expensive, and colonies are vulnerable to wax moths, parasitic bumble bees, skunks, racoons and bears. At present commercially reared bumble bees are too expensive to be used as pollinators of most field crops (Richards and Myers 1997). However, with further research and development including a wider selection of species, it may soon be feasible to use commercially reared bumble bees for pollination of some crops such as cranberry, blueberry, red clover and cicer milkvetch. Commercially reared colonies currently provide excellent pollination of greenhouse crops such as tomato (Eijnde *et al.* 1991; Banda and Paxton 1991; Kevan *et al.* 1991; de Ruijter 1997).

Mason bees

Mason bee species (*Osmia* spp.) are recognised as potential pollinators for diverse crops, including orchard (apple, pear, almond (USA)), vegetable, greenhouse, and field crops. They are one of the most common solitary bees in the more northerly latitudes and higher altitudes. The osmiine bees, unlike other Megachilinae, collect mud, or mud mixed with macerated leaf material, or only macerated leaf material to construct their cells. Generally the bees are solitary yet gregarious. They are univoltine and spend the winter as an adult in a tight cocoon. This adaptation permits the species to begin flight early in the first seasonal warm spell of spring. Their early spring flight, gregarious habitats and their tendency to forage on the most readily available pollen source make them potentially valuable pollinators in early blooming orchards.

The blue orchard bee, *Osmia lignaria propinqua* is distributed across southern Canada. Significant biological characteristics making this species a commercial success are: apple pollination is maximised when 250 female bees are nesting per acre; pollination by this bee continues when honey bees cease flight during inclement weather; pollination is evenly distributed across orchards when nesting materials are evenly distributed throughout the orchards; populations sizes can be increased under intensively farmed orchard systems; exposure to insecticides is minimised because the nesting cycle can be complete during the flowering period; nesting populations can be moved; management systems have been developed for commercial-sized populations; inexpensive but successful control methods have been developed for the more important nest associates; large field-trapped populations have been obtained; and populations have been successfully transported intercontinentally (Torchio 1976, 1982, 1985, 1990; Willis and Kevan 1995).

Other native solitary bees

Most genera of native bees are poorly known biologically and comprehensive population censuses of any bee species are restricted. Most native bees are burrowers, principally in soil, but also in wood and pithy plant stems. Non-burrowing bees incorporate such materials as leaves, soil, pitch and stones in their nests. There are hundreds of species of burrowing bees but they are generally considered a supplement to honey bees where insects are required for crop pollination. Cane (1997) provides a review of the impediments to the management of ground-nesting species. Most species have a short flying season of ca. 3-4 weeks and typically the different genera and species emerge in succession. Associated with this seasonality is a synchronisation of their foraging activity to a limited number of plant species (oligolecty) in flower at that time and which they can access for pollen and nectar. Most of them have short tongues which make them specialist pollinators for native plants. However, *Halictus and Andrena* spp. are known to be common visitors to apple bloom in Nova Scotia and the same genera are recognised as the main pollinators of lowbush blueberry in eastern Canada. Many of the native bees play a very important role in the pollination of native flowers across Canada.

Relevance of pollinator biodiversity to crop pollination

World-wide, about 30,000 plant species are edible and about 7,000 have been cultivated or collected by humans for food at one time or another. Only 300 of these are now widely grown, and just 12 species furnish nearly 90% of the world's dietary energy (calories) or protein. These 12 include rice, wheat, corn, sorghum, millet, rye, barley, potatoes, sweet potatoes, cassavas, bananas, and coconuts (Thurston 1969; FAO 1996). These crops are either wind-pollinated or self-pollinated. Superficially, it appears that insect pollination has little effect on the world's food supply/possibly no more than 1% (McGregor 1976). However, when total animal and plant products are considered, about one-third of the Canadian food diet is dependent, directly or indirectly, on insect-pollinated plants. Production of fruit or seed of some plants depends entirely on insects to move pollen from male to female parts of flowers.

The importance of insect pollinators can be put in perspective by examining total Canadian food production as an example. In 1995, about 68 million ha of land were cultivated. About 45 million ha were devoted to wind- or self-pollinated crops such as grains or rangeland. About 3 million ha were devoted to self-pollinated crops such as rapeseed, flax, beans, peas, soybeans, and peanuts that may receive some benefit from insect pollination. A small improvement in yield or grade can have a large positive impact on profit. The remaining 9 million ha were devoted to fruits, vegetables, and legume crops and are completely dependent on, or produced from insect-pollinated seed. About 11 million ha were summer fallowed. Animal food products such as beef, pork, poultry, lamb, milk, and cheese contribute about half of the Canadian diet. These products are derived in part from insect-pollinated legumes such as alfalfa, clover, or trefoil. Insects also have a major impact on oilseed crops. More than half of the world's diet of vegetable fats and oils comes from rapeseed, sunflower, peanuts, cotton, and coconuts. Many of these plants depend on or benefit from insect pollination.

The agronomic and economic value of bee-effected pollination has been an internationally contentious issue since at least the turn of the century. Attempts to value the pollination activity of bees have ranged from "guesstimates" of no empirical substance, to informed estimates (largely by apiculturists) to a few concerted efforts by economists (Gill 1991; Southwick and Southwick 1992). Estimates by Canadian researchers on the value of pollination to Canadian agriculture have ranged from C $443 million to C$1.2 billion (Winston and Scott 1984; Charest and Hergert 1992; CAPA 1995). Others have estimated Australia's benefits at A$156 million (Gill 1991), USA at US $1.6 billion to US $40 billion (Levin 1983; Robinson *et al.* 1989; Southwick and Southwick 1992), and the European Community at 5000 million ecus

(Borneck and Merle 1989). The estimates have been used to justify continued public financing of honey price support schemes (USA), increase public funding of bee related research and extension programs, enhance the efficiency of the policy making process, and to recognise the contribution beekeepers make to the well-being of society. The estimates are derived primarily for honey bee pollinated crops. Honey bees have often been credited with pollination services that are actually performed by other bee species (Parker *et al.* 1987; Richards 1996; Kevan 1999). There are few estimates of the value of non-*Apis* pollination, and these insects are generally not appreciated. The benefits we derive from native pollinators are believed to be increasing as the honey bee industry experiences continued difficulties from mites, Africanised bees and diseases, and as crops that are better pollinated by bees other than honey bees are grown more intensively.

Even though a general decline in honey bee and native bee populations is occurring across Canada, honey/pollen production for honey bees has remained relatively stable. The annual farm gate value for honey and wax, which had an annual value of $50 million between 1985 and 1989 is estimated at approximately ten times smaller than the value of pollination attributed to honey bees. More of the honey/pollen production occurs across the prairie provinces.

Pressure indices affecting pollinator diversity in Canada

The decline of native bees, both documented and suspected, is causing concern for scientists in many countries, including Canada. This decline has come about through a number of pressure indices (forestry, agriculture, urban, access, utility, harvest, exotic species, pollution, and extraction) as indicated in figure 1. These pressure indices are mainly the result of human activities with more important ones being: pesticide use, air pollution, habitat modification, spread of diseases and parasites, and competition from introduced flower visitors. Interactions between native bees and managed *Apis* species, whether indigenous or not, are the subject of mounting discussion as we increasingly realise the unique pollination requirements of both wild plants and crops. The introduction of managed non-*Apis* species to new areas brings another dimension to these arguments.

Agriculture and Forestry

Recent technological advances in agronomic practices in Canada have focused primarily on improving yield, increasing the number of crops grown, and increasing the area of harvestable crops. At the same time Canadian policy has encouraged the removal of marginal land out of commercial production (*e.g.* Permanent Cover Program) and competitiveness in global economies. These advances have been applied to most crop species. The positive results of these practices are impressive: the quality and quantity of food have increased; food costs have decreased; numerous fresh fruits and vegetables of high quality are available for much longer periods; the quality and types of prepared food products have greatly improved; and, the large labour force once required has been reduced at the same time as crop areas have increased.

Pesticides

Accompanying the technical advances and intensive farming practices, a negative impact on crop pollination and bee populations developed. The dangers associated with pesticides, especially insecticides, and pollinators are well documented and understood, especially with regard to the honey bee. Less understood, and often overlooked is the problem of sublethal effects that reduce longevity, adversely affecting foraging, memory and navigational abilities of some bees (Johansen and Mayer 1990; MacKenzie 1993; Kevan and Plowright 1995). For most pesticides used in Canada there is published information on the toxicity to honey bees (adults), and sometimes other bees. Yet, more effort is needed on the effects of pesticides on other species of pollinators and little to no data exists for immature stages for any bee species. From the few comparative studies made, it is evident that the toxicity of pesticides to honey bees is a poor predictor of the hazards posed to other bee species (NRCC 1981, Johansen and Mayer 1990). The mode of action and route of entry of the pesticides varies among the bee species and is complicated by the lack of standardised testing methods. Recent trends in Canada to reduce the use of pesticides in agriculture (10% less farmland treated between 1985 and 1991) and forestry and to increase education about pesticide-pollinator interactions have gone far to lessen the impact of pollinator poisonings. Certain pesticides, such as aldrin, chlordane and DDT, are no longer used in Canada, although levels of these substances continue to be detected in the environment from current use in other jurisdictions as well as revolatilization from past domestic use. It must be remembered that pesticides are an integral part of integrated pest management practices (IPM) for crop protection in modern agriculture and forestry and will continue to be used for the foreseeable future. Pesticides will continue to affect bee populations.

Most pesticide problems stem from human error such as accidents, carelessness in application, and deliberate misuse despite label warnings and recommendations (Johansen and Mayer 1990). As pesticide applications become more and more regulated and applicators are required to take courses in safety and use before certification, these problems should diminish. With the development of better regional pest forecast maps, pesticide applications timed to pest developmental phenologies, refined pest-crop threshold levels, and increased use of biocontrol agents, there is a potential for reduced pesticide-pollinator interactions. Penalties associated with misuse do not encourage changes in practices. Methods such as not spraying blooming plants or spraying when pollinators are not foraging are common sense approaches to reducing problems associated with pesticide applications (Johansen and Mayer 1990; MacKenzie 1993). Producers are frequently unaware of the impacts of pesticide usage on pest and non-target organisms.

In non-agricultural settings and agroforestry, pesticide issues are more complex because of the wider diversity of flora and pollinators. A well documented example is the use of fenitrothion in eastern Canada where it was sprayed against spruce budworms defoliating forest trees and had negative side effects on pollinators in commercial blueberry fields and on pollinators for several species of native flora (NRCC 1981; Kevan and Plowright 1995). Several different plant species of the forest and forest margins suffered reduced fruit and seed set, which in turn probably impacted wildlife by depriving them of natural quantities of food. Another Canadian example involves mosquito control programmes and major losses to honey and leafcutter bees.The effects on pollinators resulting from other extensive applications of broad-spectrum pesticides against other major pests, such as other forest defoliators, locusts, and grassland herbivores have hardly been investigated.

Habitat modifications

There are three ways that habitat modifications affect pollinator populations: a)modification of food sources, b) modification of nesting or oviposition sites, and c) modification of resting and mating sites. Habitat modifications frequently come about through climate change or pressures associated with the value of agricultural products. The most common means of habitat modifications are through the establishment of monocultures, overgrazing, land clearing, and irrigation. The modification of food sources can be illustrated by examples of the removal of vegetation (mechanically or by herbicides), which provides the pollinators' food when crops are not in bloom, from agricultural areas (Kevan 1991, 1993). Frequently the vegetation that is removed is regarded as unwanted, weedy or in competition with crop plants, yet is invaluable to pollinators and other beneficial insects as a food source. Planting cross-pollinated crop species (*e.g.* alfalfa, apple, melons, blueberry) in large tracts of unbroken land in disjunct areas (monocultures) has artificially created shortages of pollinators available for these crops. The demise of native leafcutter bee populations in Manitoba was documented as being the end result of the modification of their nesting and oviposition sites. Local seed production in fields of alfalfa destroyed nesting sites found in stumps and logs (Stephen 1955). Habitat manipulations (clearing land of trees or shrubs, irrigation practices) associated with agriculture often adversely affect availability of both food sources and nest sites, creating a double problem for native pollinators, especially those that are long-lived such as colonies of bumble bees. Examples can be found in the low diversity of bees found in cranberry bogs of British Columbia (MacKenzie and Winston 1984; MacKenzie 1994).

Much of the ranchland of British Columbia and parts of eastern Canada have resulted from deforestation. Overgrazing, overstocking, and introduced animals (cattle, sheep and llama) are all believed to negatively impact on the pollinator biodiversity and the native flora. The influence of livestock grazing pressure on native plants continues to receive research attention in western Canada as it has in the past (Johnston *et al.* 1971, Willms and Majak, personal communication). However, data are generally lacking to assess the risk to pollinator biodiversity, yet a study by Richards (1995) demonstrated bumble bee diversity and density as well as floral resources were reduced in areas of higher livestock grazing pressure.

Habitat fragmentation has become one of the major threats to plant and animal communities in the Canadian agricultural landscape. The resulting decrease in species diversity and abundance may affect ecosystem functioning (Lawton 1994; Kruess and Tscharntke 1994). Plant-pollinator interactions in particular can be expected to be disrupted by habitat fragmentation (Rathcke and Jules 1993; Didham *et al.* 1996; Steffan-Dewenter and Tscharntke 1997; Kwak *et al.* 1998). Decreases in native bee populations and in commercial beekeeping in agricultural landscapes during recent decades should generally reduce pollination and seed set (Jennersten 1988; Corbet *et al.* 1991). Reduced reproduction success may have important effects on the long term dynamics of plant populations (Bond 1995) including often reduced seed set and lowers genetic variation (Kwak *et al.* 1998). However, entomophilous flowers in temperate areas have diverse, mainly unspecialised pollinator faunas (Ellis and Ellis-Adam 1993), so that a reduced diversity of bees in agroecosystems may be compensated by other pollinators. And long-distance pollinators can make a major contributions to pollen-mediated gene flow in fragmented populations if they revisit the same plant species after changing patches (Jennersten 1988; Kunin 1993).

There is some evidence that ecological attributes of both insects and plants do change systematically in the early years of succession after a disturbance such as ploughing (Corbet 1995). Parrish and Bazzaz (1979) found a change in the predominant pollination system through succession, from open flowers visited by small flies and beetles early in succession to deeper, zygomorphic flowers visited by larger bees in later years. These concepts are relevant to the formulation of set-aside policy, because of the importance of large, long-tongued bees as pollinators for crops and for wild flower populations fragmented as a result of changes in land use.

Habitat modification for pollinators has evoked concern on a broad scale (Janzen 1974). He indicates a vicious cycle of reduced vegetation for pollinators' resources, reduced pollination in the vegetation, the demise of the plant's reproductive success and reductions in seed and fruit set, resulting in the failure of revegetation with the equivalent level of biodiversity as would have otherwise existed. Changes in the frequency and nature of pollinator visits are expected to affect the genetic features of the population, such as the balance between self and cross pollen transfer, but the nature of these changes will depend on the local circumstances (Corbet 1997). Barrett and Kohn (1991) show that the genetic consequences of small population size are poorly known and hard to predict, and the genetic consequences of inadequate pollination are equally unclear.

Pollution

Another factor influencing pollinator diversity and pollination in Canada that has recently been identified is air pollution. Bees and plants tend to be bioaccumulators of heavy metals. Bees are being analysed for their arsenic content in British Columbia as a biological indicator species of air pollution from the smelters in nearby Washington State. Pollen loads collected by honey bees and other bees may even reflect the known concentration of soil-borne heavy metals (Sawidis 1997). Pollen is being suggested as a biological indicator because of its high sensitivity to pollution stress. Metals accumulate on plant surfaces or within tissues as a result of dry deposition or root uptake. Pollen germination and tube growth is very sensitive to toxic compounds and these pollen parameters have been found to provide a far more sensitive method for detecting damage by air pollutants than the production of visible leaf injury or other vegetative symptoms (Masaru *et al.* 1980; Pfahler 1981, Cox 1988).

Exotic species

The Canadian honey bee industry continues to experience pressure from tracheal, *Varroa* and other mite infestations and contamination from several diseases so that the number of colonies available for pollination is becoming alarmingly low. The impact of these pests on colonies of honey bees is well documented, but little information is available on the effects on pollination. Many amateur or small-scale beekeepers may abandon their activities because of the additional complexities of bee management associated with monitoring for mites and diseases and controlling them. The number of feral colonies of honey bees has decreased significantly as mite infestations have become common (Watanabe 1994). Thus, the honey bee industry may not be able to adequately meet the pollination needs of intensive farming, increased area of crops requiring pollination, and of developing greenhouse crops. Closing the Canadian border to imports of honey bees from the USA in 1987 successfully slowed the spread of mites in Canada. This has bought time for Canadian beekeepers and researchers to prepare for these problems and for new control and detection methods to be developed. Save beekeepers still re-establish populations each spring thought queen purchases from New Zealand and Hawaii, however as prices increase and diseases move into these areas it is questionable as to how long these sources will continue to be available. However, in many parts of Canada overwintering technology and skills are making Canadian beekeeping more self-sufficient.

Pests, especially fungal diseases such as chalkbrood, are also important in native bee populations and have required research to understand the diseases and the development of control measures (Vandenberg and Stephen 1982; Goettel and Richards 1991; Geottel *et al.* 1993). Yet the importance of diseases and other associated organism in the regulation of populations of native pollinators is generally unknown (Rust andTorchio 1991).

International concerns are also being expressed that honey bees, Africanised bees, and some other commercially introduced native pollinators (*e.g.* bumble bees and alfalfa leafcutter bees) may not benefit the native biota. They have been shown to displace native pollinators from flowers, may not trigger the pollination mechanisms of the flowers they visit, may force native bees to switch to less profitable resources when they are abundant at the richest patches of flowers, introduce unwanted pests, and instil aggressive interactions with native Apis species (non-Canadian) (Paton 1993; Buchmann 1996; Sugden *et al.* 1996).

Environmental factors

Native bee populations are known to have frequent fluctuations in response to natural factors. These responses are variable within species and are not easily isolated. There has been a tendency to invoke pesticides as culpable in any and all cyclic fluctuations in native bee populations and in the depauperization of solitary bees in agricultural lands. The effects of pesticides is frequently limited to local population perturbations and that, when compared with such environmental factors as weather and the availability of nesting sites, play a minor role in regulating the composition or density of native bee fauna. The effect of weather on populations of many soil nesting solitary bees is well known. Unseasonally heavy rain shortly after peak population emergence may cause surface puddling resulting in drowning of adults in burrows, but also penetrate sealed cells, raising the humidity to levels permitting the ubiquitous soil fungi to displace the developing and mature larvae. Protracted inclement weather (late spring snows, rain) during which flight is restricted is a common cause of population loss. Unusually warm early spring weather (during which emergence of these species occurs naturally or is induced through incubation), when followed by a prolonged cool, wet period, results in starvation of the adult population. Losses suffered at this time of year may remove the species from the local fauna until it is reintroduced or reinvades naturally. Extended cold winter conditions, freeze-thaw events, heavy snows also influence bee populations. It is anticipated that climate change will result in greater numbers of invasive species and that the density and diversity of current species will change across Canada. The Canadian apifauna may become more diverse in response to increased arid regions as species invade northward from the species diverse southwestern United States and adjacent northern Mexico.

Collectively, these problems may have long-term, negative consequences resulting in shortages of honey bee and native bee populations reserved for crop pollination. The continued evaluation and development of management practices for non-*Apis* pollinators will help ensure adequate pollination for a diversity of crops.

Remediation or trends in pollinator biodiversity in Canada

Recommendations for and approaches used to increase the availability of pollinator numbers have varied (Parker *et al.* 1987; Southwick and Southwick 1992; Torchio 1990,1991; Corbet *et al.* 1991; Osborne *et al.* 1991; Williams *et al.* 1991). In Europe, preservation and management of habitats thought suitable for bees' forage or nesting sites have been repeatedly proposed as a method to maintain or increase pollinator numbers (Westrich 1996; Edwards 1996). Enhancing native pollinator populations by habitat management is a potentially cost-effective option that deserves attention, and may become essential if honey bees become less readily available (Corbet *et al.* 1991). Habitat management could be most effective if planned on a scale larger than that of an individual farm, and it therefore requires co-ordination on a regional scale across government levels. For the few crops and many native flowering plant species unsuited to pollination by managed colonies of bees, this is the only viable option. There has been some development in Europe of non-*Apis* species as managed pollinators (Tasei 1975; Krunic and Brajkovic 1991; Heemert *et al.* 1990). In North America, efforts have focused on the development of non-Apis species as managed pollinators for specific crops with significant success for the alkali bee, *Nomia melanderi*, various mason bees, *Osmia* spp. and especially the alfalfa leafcutter bee, *Megachile rotundata* (Richards 1993). There have been proposals for habitat management programs, but little positive action specifically for pollinators, especially in intensive agricultural systems. However, this tendency is changing especially regarding plants (Tepedino *et al.* 1997). Throughout the world, a few other successful programs exist which enhance native pollinator numbers, (i.e. mason bees for apple pollination in Japan (Maeta 1978).

Protected area index

From the view point of wildlife biodiversity, field margins, headlands, fence lines, road, rail, and utility right of ways, public lands, and so forth are important refuges for a wide diversity of pollinators and associated plant species. The value of these areas to agricultural productivity is unknown, denigrated and not researched.

Across Canada there are approximately 3,500 protected areas identified in the National Conservation Areas Database that are managed by some level of government. These include national or provincial parks, conservation areas, or wildlife management areas. In addition the Nature Conservancy of Canada manages an additional 550 protected areas. In total this represents about 8% of Canada's total landmass. Although these areas are fragmented they do represent all major ecoregions of the country and as such may hold habitats suitable for the long-term preservation and sustainability of native pollinators.

CONCLUSIONS

Conservation of honey bees, other managed bees, native bees and other pollinators is an important issue in the global context of agricultural and natural sustainable productivity. It is a curious fact, that although the major pollinators for many crops grown in Canada are known, the quantitative relationships of pollinator populations, activities, and densities with plant and flower density and resultant seed set are largely unknown. Further the breeding systems for many crop species are inadequately know or misunderstood and for native flowering plants almost completely unknown. It is important the researchers expand their horizons to embrace the culture of non-*Apis* pollinators into agriculture. In an era of heightened concern about global environmental sustainability and conservation of biodiversity, the importance of pollination and deleterious affects on it embrace a wide front of interrelated issues. These range through habitat destruction, pesticides, parasitic mites and diseases, competitive interactions with alien species, air pollution and the anticipated threat of climate change causing the demises of various pollinators. The needs for conservation, imaginative approaches to management, and basic biological research, must be fully recognised by biologists, ecologists, agriculturists, and the general citizenry of Canada.

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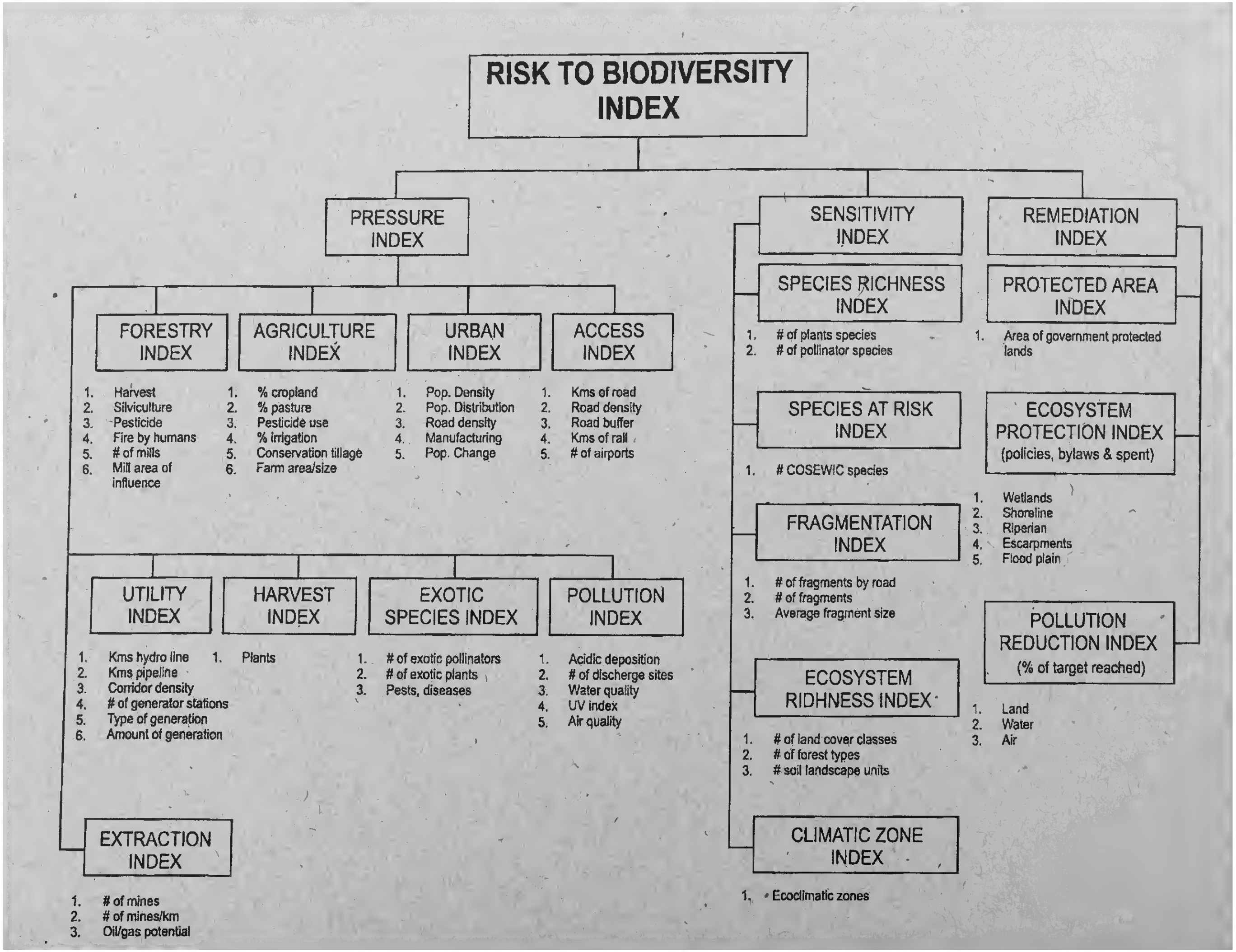
FIGURE 1. Elements of a model to assess risk to pollinator biodiversity (adapted from Rubec *et al.*1992).


RISK TO BIODIVERSITY INDEX
PRESSURE INDEX
FORESTRY INDEX
1. Harvest
2. Silviculture
3. Pesticide
4. Fire by humans
5. # of mills
6. Mill area of influence
AGRICULTURE INDEX
1. % cropland
2. % pasture
3. Pesticide use
4. % irrigation
5. Conservation tillage
6. Farm area/size
URBAN INDEX
1. Pop. Density
2. Pop. Distribution
3. Road density
4. Manufacturing
5. Pop. Change
ACCESS INDEX
1. Kms of road
2. Road density
3. Road buffer
4. Kms of rail
5. # of airports
UTILITY INDEX
1. Kms hydro line
2. Kms pipeline
3. Corridor density
4. # of generator stations
5. Type of generation
6. Amount of generation
HARVEST INDEX
1. Plants
EXOTIC SPECIES INDEX
1. # of exotic pollinators
2. # of exotic plants
3. Pests, diseases
POLLUTION INDEX
1. Acidic deposition
2. # of discherge sites
3. Water quality
4. UV index
5. Air quality
EXTRACTION INDEX
1. # of mines
2. # of mines/km
3. Oil/gas potential
SENSITIVITY INDEX
SPECIES RICHNESS INDEX
1. # of plants species
2. # of pollinator species
SPECIES AT RISK INDEX
1. # COSEWIC species
FRAGMENTATION INDEX
1. # of fragments by road
2. # of fragments
3. Average fragment size
ECOSYSTEM RIDHNESS INDEX
1. # of land cover classes
2. # of forest types
3. # soil landscape units
CLIMATIC ZONE INDEX
1. Ecoclimatic zones
REMEDIATION INDEX
PROTECTED AREA INDEX
1. Area of government protected lands
ECOSYSTEM PROTECTION INDEX (policies, bylaws & spent)
1. Wetlands
2. Shoreline
3. Riperian
4. Escarpments
5. Flood plain
POLLUTION REDUCTION INDEX (% of target reached)
1. Land
2. Water
3. Air

POLLINATION IN AGRICULTURAL LANDSCAPES, A SOUTH AFRICAN PERSPECTIVE

J S Donaldson

ABSTRACT

Pollination represents possibly one of the greatest areas of interaction between natural systems and agricultural systems. A consistent pollination service is one of the key factors supporting agricultural production but land use and farming practices also have a substantial impact on pollinators. The decline of pollinators threatens agricultural production and the extent of this impact has recently been highlighted by the collapse of honeybee colonies. Although the general problem of pollinator decline has been discussed in several books and publications, there is still value in obtaining regional perspectives on the extent of the problem and what is being done about it. In this paper, I review the current situation in South Africa.

INTRODUCTION

The problem of declining pollinator populations and the consequences for agriculture and conservation biology have been highlighted in several recent books and articles (Buchmann and Nabhan 1996; Kearns and Inouye 1997; Allen-Wardell *et al.* 1998). Many of the issues raised by these authors are universal, but there are almost certainly going to be regional differences arising from variation in the pollinator faunas, the natural occurrence of honeybees in some areas, different land use options, and the choice of agricultural crops. In this paper, I review what is known about pollinator decline in South Africa, the possible consequences for agriculture and what is being done in South Africa with regard to pollinator conservation.

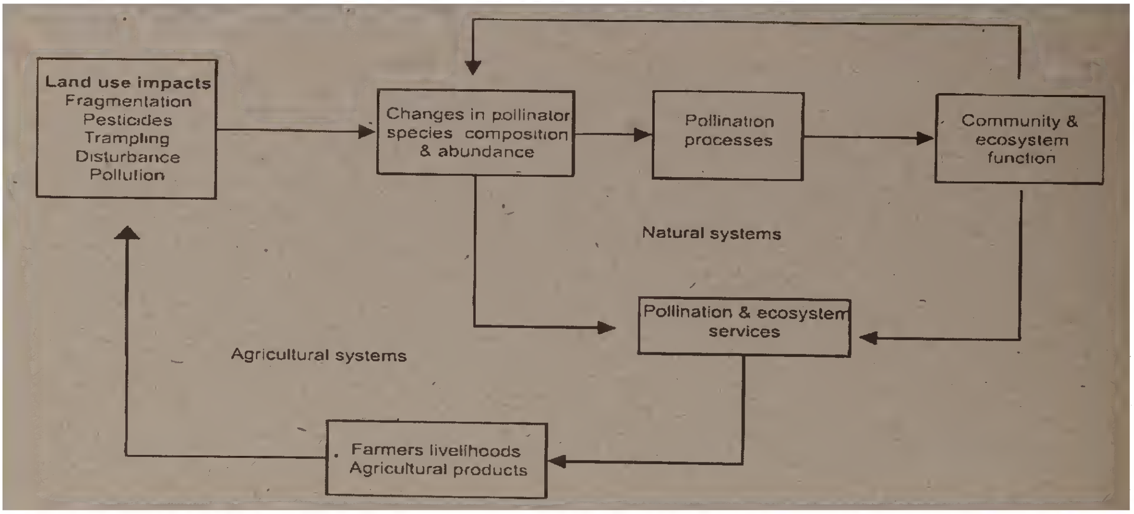
Pollination: a South African perspective

South Africa encompasses a diversity of environments from summer rainfall areas with subtropical rainforests to arid winter rainfall areas with dwarf succulent shrublands (Cowling and Hilton-Taylor 1997). Southern Africa also has an extremely rich flora comprising more than 20 500 species (80% endemics) (Cowling and Hilton-Taylor 1997) and an exceptional diversity of other taxa such as amphibians, reptiles, birds, mammals (Siegfried 1989) and insects (Scholtz and Holm 1985). With such generally high levels of diversity, the species richness of insect pollinators may be expected to follow the general trend. Indeed, Michener (1979) ranked the warm temperate xeric areas of Australia, Chile, and South Africa fourth (out of 10 regions) in terms of relative bee abundance and diversity although they had far fewer species than other warm temperate areas such as the Mediterannean.The dry western parts of South Africa have high levels of diversity and endemism for aculeate Hymenoptera (Gess and Gess 1993) and the Cape Florisitic Region of South Africa appears to be a centre of diversity for long-proboscid fly pollinators that include Tabanidae, Nemestrinidae and Bombyliidae.

Monkey beetles (Rutelinae: Hopliini) are an important group of pollinators that are endemic to southern Africa and Lepidoptera are a diverse group within southern Africa, comprising ca. 8% of the world total (Henning 1985). South Africa therefore has an impressive diversity of insect pollinators that are unquestionably important for native plants and that may be of considerable benefit in agricultural systems.

Pollination services in agriculture represent possibly one of the greatest areas of interaction between natural systems and agricultural systems (Fig. 1). In many instances, the productivity of agricultural landscapes (crops and pastures) relies on natural pollination although production of fruit and seed crops is often enhanced by bringing in additional honeybee colonies (Anderson, Buys and Johannsmeier 1983). Agriculture is also likely to have the greatest impact on native pollinators through the modification and elimination of pollinator habitats and the use of agricultural chemicals (pesticides, herbicides, fertilizers). This is most obvious in transformed landscapes, which accounts for ca. 22% of South Africa's land area, but is also true of the vast tracts of land used for stock farming (*e.g.* Gess and Gess 1993).

FIGURE 1: A diagrammatic representation of the pollinator interaction between natural ecosystems and agricultural systems



Despite the potential importance of the interaction between native pollinators and agricultural systems, a survey of published work on pollination in South Africa (Fig. 2) shows that this interaction has received very little attention. Most research has focussed on descriptions and evolutionary studies of pollination systems in indigenous plants. Considerably less work has been done to determine the effectiveness of different pollinators or the impact of a pollination deficit on fruit set. This is particularly true of published studies of crop plants. In contrast, the majority of studies on threats to pollinators and on pollinator biology have dealt with honeybees, especially within an agricultural context. The trend in research publications leads to two conclusions. Firstly, that there has been relatively little interest in studying the pollination systems of crop plants in South Africa (as opposed to the tremendous interest in pollination of indigenous plants) and secondly, that honeybees have been regarded, almost exclusively, as the prime agents for pollination in agricultural systems. In this respect, the situation in South Africa is similar to that in other parts of the world (Buchman and Nabhan 1996).

Pollinator decline

There has been no comprehensive assessment of pollinator decline in South Africa but there has been ongoing research into factors that have a detrimental effect on pollination. As in other parts of the world, honeybees have received most attention and two threats to honeybee populations have been of particular concern. First, the so-called 'Cape honeybee problem' in which workers of the Cape honeybee (*Apis mellifera capensis*) gain access to the hives of the African honeybee (*A. mellifera scutellata*) and destroy the host colony (Cooke 1993). Beekeepers have lost up to 75% of their colonies annually as a result of the Cape honeybee problem. Second, *Varroa mite* was first recorded from South Africa in 1997 (Allsopp, Govan and Davison 1997) and has subsequently spread to seven of the country's nine provinces (*M. Allsopp* pers com.). The effect on wild and commercial hives is being monitored and there appear to be geographical differences in the response of bees to Varroa that may be related to variation in climate or to different levels of resistance between *A. mellifera capensis* and *A. mellifera scutellata* colonies (*M. Allsopp* pers com.).

FIGURE. 2. The frequency of scientific and semi-scientific publications on topics related to pollination systems and pollinator biology in South Africa. Bars for 'pollinator effectiveness' and 'pollinator limitation' include only papers that dealt specifically with these issues. Publications dealing primarily with plant or pollinator taxonomy were not included.

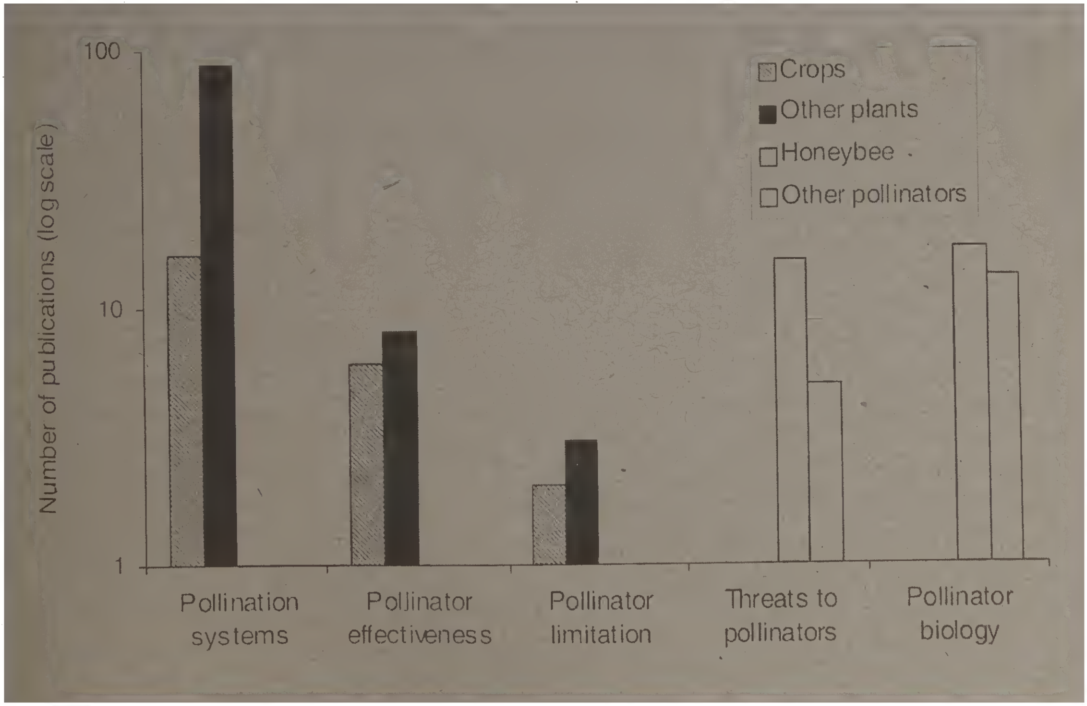


Fig. 2 shows that threats to non honeybee pollinators have hardly been studied at all in South Africa. Nevertheless, the few available studies indicate that landuse practices have probably had the greatest impact on non honeybee pollinators. Habitat fragmentation has been identified, worldwide, as a major cause for the loss of biodiversity (Hobbs *et al.* 1992; Haila *et al.* 1993) including pollinators (Aizen and Feinsinger 1994a,b; Bronstein 1995; Kearns and Inouye 1997). Studies of habitat fragments in wheatlands in the Western Cape Province (Donaldson *et al.* MS) showed that bees were relatively resilient to changes in fragment size and isolation but were affected by changes in habitat related to the process of fragmentation (*e.g.* changes in vegetation cover). In contrast, butterflies were more sensitive to fragment size (R. Bowie unpublished data).

Fragmentation occurs mainly in intensive agricultural systems. However, extensive systems such as stock farming affect vast areas of South Africa (Macdonald 1989) and farming practices in these areas can have a substantial impact on the pollinator fauna (Gess and Gess 1993). Grazing practices can change the availability of plant resources (nest sites, nectar and pollen) and trampling can make areas unsuitable for ground and bank nesting species (Gess and Gess 1993). Different land use practices in the same area can result in different pollinator faunas even in adjacent fields (A. van der Spuy, unpublished data).

Introduced plants have had a devastating effect on natural vegetation in several parts of South Africa. The change in floral composition and vegetation could also have affected the composition and distribution of indigenous pollinators (Rebelo 1987) but this aspect of pollination biology has not been investigated.

Two introduced insects have been regarded as a potential threat to indigenous pollinators. The argentine ant, *Linepithema humile* (Formicidae) has been recorded from *Protea inflorescences* (Paton, 1986; Visser, Wright and Giliomee 1996) and large infestations of *L. humile* resulted in a significant reduction in insect visitors to *Protea eximea* and *Protea nitida* inflorescences. There has also been speculation that the argentine ant would result in a decline in butterfly populations (Henning *et al.* 1997). However, the overall impact of argentine ant on pollinator abundance and diversity is unknown. There is a similar paucity of information on the impact of the yellowjacket wasp, *Vespula germanica* that has invaded parts of the Western Cape province. *V. germanica* may compete for nectar with indigenous wasps (Rebelo 1987) and has been known to exterminate weak honeybee hives in New Zealand (Line, 1965) but it is restricted to parts of the Western Cape and its overall impact is unknown.

In other parts of the world where honeybees have been introduced, there has been concern about the displacement of indigenous bees. Honeybees are indigenous to South Africa but commercial beekeeping nevertheless poses a potential threat to other pollinators because commercial hives may be placed in natural vegetation during periods of peak nectar flow thereby depriving other insects of nectar and pollen resources (Rebelo 1987). The extent of this practice and its impact on non honeybee pollinators has not been evaluated.

Due to the poor performance of honeybees on some crops (*e.g.* tomatoes) there have been several applications to import bumblebees (*Bombus*) into South Africa. The initial applications have been for greenhouse crops where, it is argued, the bumblebees can be contained within an artificial system. However, there is a high probability that bumblebees can escape from greenhouse colonies and there is evidence for *Bombus* species establishing in areas outside their natural range (A. Dafni personal communication). This has the potential to disrupt sensitive pollination systems involving native bees. As a result, the importation of bumblebees has, so far, not been approved. As yet, there has been no assessment of the value of local bees for buzz pollination as an alternative to bumblebees.

Pollination deficit

Pollinator limited fruit set has been has been of concern in both agricultural and natural systems. Pollinator limited fruit set appears to be a common phenomenon among plants in fynbos (*e.g.* Johnson and Bond, 1997) and may explain some of the floral diversity in the Cape Floristic Region (Johnson, 1994). However, there is also evidence for the disruption of pollination due to local extinction of native pollinators (Donaldson *et al.* MS) and one of the challenges to conservation theory has been to identify plants that are most at risk as a result of pollinator decline (Bond 1994). Despite the potential impact of pollinator limitation on fruit set in agriculture, the problem appears to have received less critical experimental and theoretical attention in South Africa. Johannsmeier (1995) listed numerous plants in South Africa where fruit or seed set is dependent on insect pollinators, particularly bees. Among the plants are many crop species where seed or fruit production or quality is increased by the addition of honeybees, *e.g. Brassica napis* var. *oleifera* (oilseed rape), *Cynara scolymus* (globe artichoke), *Eriobotrya japonica* (loquat), *Fragaria x ananassa* (strawberry), *Helianthus annuus* (sunflower), *Persea americana* (avocado), *Rubus* spp. (black- youngberries), *Sinapis alba* (white mustard), *Trifolium* spp. (clover), *Vicia* spp. (vetch), *Vicia faba* (broad bean). The implication is that there is a pollination deficit in these crops unless honeybee colonies are increased at the time of pollination. It is unclear how great this deficit will be if honeybee colonies decline as a result of the Cape honeybee problem or the spread of *Varroa.*

Even with the widespread use of honeybees in South African agriculture, poor fruit set remains a problem for some crops, notably *Mangifera indica* (mango) (du Toit and Swart 1993a; Eardley and Mansell 1994a), *Persea americana* (avocado) (du Toit and Swart 1993b, 1994a; Eardley and Mansell 1993), *Litchi chinensis* (litchi) (Eardley and Mansell 1994b) and other subtropical fruits (du Toit 1990). Although poor pollination may not be the only cause of low fruit set (*e.g.* Thomas, Eicker and Robbertse 1994), it is clear that much further work is needed on the pollination of subtropical fruits (du Toit 1990). Of particular importance in the context of pollinator decline, is to determine the potential for pollination of these crops by native pollinators. Johannsmeier (1995) listed 15 crop species from the Western Cape Province (17% of crops) for which the pollination needs were unknown or for which there was no information. This is likely to underestimate likely pollination problems since much of the pollination data for other crops is derived from areas outside South Africa and does not take local conditions into consideration.

In crops where honeybees do not increase fruit set, other native pollinators may be appropriate. Watmough studied the biology of carpenter bees that may be of particular value for the pollination of crops in the Fabaceae, but there has been little success in developing the agricultural potential of these bees. Nevertheless, Gess and Gess (1994) noted that Xylocopinae, Megachilinae and Masaridae were essential for the successful pollination of rooibos tea (*Aspalathus linearis*, Fabaceae) and that the management of tea plantations needed to promote the abundance of these pollinators. A similar situation probably exists in the case of honeybush tea (*Cyclopia* spp.: Fabaceae) that is now being extensively harvested in parts of

South Africa.

Conservation of pollinator diversity

Until very recently, conservation activity in South Africa focussed almost exclusively on large mammals (Pringle 1982). As a result, the reserve system that comprises ca. 6% of the total land area (Siegfried 1989) was established in areas that suited this particular focus with little reference to other taxa. The current broader focus on biological diversity has highlighted some of the gaps in the existing reserve system. Of particular note for bees and aculeate Hymenoptera is the low level of conservation in areas with high diversity such as the succulent karoo (2.36% included in reserves) and Nama karoo (0.45%). Field sampling at four sites in these areas (Gess and Gess 1993) indicates high levels of species turnover and emphasizes the need for a more representative reserve system.

A more complete reserve system is unlikely conserve all or even the majority of pollinator species. The mosaic of farmland that surrounds reserves must be included in the conservation programme. At present, South Africa has a network of Natural Heritage Sites and private nature reserves that extend the reserve system onto private land. However, a more comprehensive system is required that promotes pollinator friendly land use practices. In this respect, research on the impacts of land use on pollinators is needed to guide conservation actions. Several studies on the impacts of land use on pollinators and other insects have already been undertaken in South Africa (*e.g.* Gess and Gess 1993; Ingham and Samways 1996; Rivers-Moore and Samways 1996; Donaldson *et al.* MS) but more information on appropriate land use practices is needed and existing information must be made accessible to farmers.

In conclusion, if native pollinators are to be conserved because of their value to agriculture, then further work is needed. Firstly we need to identify areas where native pollinators are likely to play an important role in agriculture and, secondly, we need to promote ways of integrating native pollinators with other agricultural activities.

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AFROTROPICAL BEES NOW: WHAT NEXT ?

Connal Eardley

ABSTRACT

Bees are an important group of pollinators and indispensable in agriculture and for maintaining biological diversity. Although indigenous honeybees are used extensively as pollinators in commercial agriculture in Africa, other bees are also important pollinators for both commercial and small-scale farming. Although less abundant they are more effective pollinators of many plants. In the afrotropical region bees appear to inhabit all the different biomes, making them an important reference group for biodiversity studies. Besides, they are an effective indicator group because of their sensitivity to environmental degradation. A detailed knowledge of the systematics of bees is clearly vital for the sustainable use of genetic resources in Africa. There are 129 bee genera in sub-saharan Africa, of which 83 (64%) have been revised since 1965, and 25 (19%) are currently being studied. Of the 73 genera of long-tongued bees in sub-saharan Africa 72 either have been revised or are receiving attention. It is therefore possible to identify most of the long-tongued bees. The short-tongued bees, which are more common and also very important pollinators, are less well known. No systematic research is currently being conducted on 33% (18 of the 55 genera) of the genera. It is imperative that Africa does not lose its expertise in bee systematics, which is pivoted on a few individuals, if advances are to be made in pollination biology.

INTRODUCTION

Bees feed their progeny on pollen and nectar, and some bees also use plant oils. These products are mostly collected from flowers by the bees that utilize them. This behaviour often results in bees pollinating the flowers they visit, which gives them the potential to play a major role in enabling seed production and determining patterns of gene flow in populations of many species of flowering plants. Bees therefore have a strong influence on patterns of diversification and distribution of the species of flowering plants with which they are associated. Flowering plants, however, are an important group of primary producers, and factors affecting their distribution and abundance may have ramifications throughout the communities to which they belong. Whereas some bees visit and pollinate a broad spectrum of flowers, and some flowers are visited by many different pollinator species, other bees and plants appear to be highly specialized resulting in a narrow spectrum of host plants or pollinators. Therefore the ecological role of bees within the community may be disproportionate to their absolute numbers, as either species or individuals. As many agricultural crops depend on pollination for fruit and/or seed production, the maintenance of diverse bee populations in agro-ecosystems is essential for sustainable agriculture.

Indigenous African honeybees (*Apis mellifera* Linnaeus), because of the technology associated with honey production, can be easily moved to agricultural fields in large numbers. This has resulted in honeybees being the most important, possibly the only, commercially managed pollinator in Africa. Although they have the advantage that large numbers can be easily manipulated, they are not efficient pollinators of many crops (Westerkamp 1991; Eardley & Mansell 1996a & b). This is due to their size, method of carrying pollen and reluctance to visit the flowers of certain plant species. Bees that have loosely packed pollen on the hind legs and on the ventral surface of the metasoma appeared to be more effective pollinators than honeybees of litchi, avocado and mango in South Africa (unpublished observations).

An accurate knowledge of the systematics of bees is essential for ecological research aimed at understanding their role in natural communities. Fortunately the systematics of bees has always received a disproportionate high level of attention relative to other groups of Afrotropical insects. This unfortunately has not been accompanied by an equivalent interest in their biology, including pollination biology. Most studies on pollination biology, other than that on the honeybee, have either been descriptive and concerned with interesting insect-plant relationships and not on pollination of agriculturally important plants, or have not been published.

Non-domesticated bees are responsible for much of the pollination of agricultural crops in Sub-saharan Africa, and their population densities are reduced by intensive and indiscriminate farming practices. Evidence of this is in a reduction in the number and diversity of pollinators in avocado, litchi and mango orchards (own observation & M. Mansell, personal communications) and lower seed set in sunflower (A du Toit, personal communication) in some extensively cultivated areas. For commercial crops this necessitates hiring bee-keepers to bring in honeybees. Such resources may not be available, which may result in reduced production. In South African semi-deserts insect-pollinated plants predominant as pasture. The Karoo climax community grasses have largely been replaced with pioneer insect pollinated plants. Insect-pollinated plants also form a major component of Namaqualand's natural vegetation. Current stock farming practices often result in changes in available nesting sites, water, mud and vegetation, which impact negatively on the bee populations that are responsible for much pollination in these area (Gess & Gess 1993). Research on the natural pollinator's biology is vital to prevent these semi-deserts from becoming denuded of vegetation due to a lack of pollinators. This cannot be done without a good knowledge of the systematics of the insects involved, especially bees.

In Africa indigenous honeybees will possibly always be the most important pollinators in commercial agriculture. There is a need, however, to investigate alternative indigenous pollinators to reduce the increasing dependence of agriculture on a single species of pollinator. Recently thousands of *A. mellifera scutellata* Latreille hives were invaded by *A. mellifera capensis* Eschscholtz workers, and infestations of varroa mite, which preys on honeybee larvae, have recently occurred in South Africa. The maintenance of diverse bee populations will reduce this dependence on *A. mellifera* and facilitate the pollination of wild plants, which have numerous associated benefits. These include the prevention/reduction of desertification and soil erosion, maintenance of watersheds and provision of refuges for biological control agents.

Current Systematic Knowledge

There are 128 Sub-saharan bee genera, of which 83 (64%) [66 (67%) for southern Africa] have been revised since 1965, and 24 (33%) are currently being studied. Thus 86% of the Sub-saharan bee genera are either revised or being studied (Appendix 1).

Of the 74 genera of long-tongued bees 73 have either been revised or are receiving attention. *Ctenoplectra*, which requires revision, is a small genus. Therefore it is possible to identify most of the long-tongued bees, several do however require further study. Only the southern African species of *Xylocopa, Amegilla* and *Anthophora* have been revised, *Megachile*, *Chalicodoma* and *Creightonella* require further study to enable their accurate identification.

The short-tongued bees, which appear to be more common and are most probably more important as pollinators due to their size and method of carrying pollen are less well known. No systematic research is currently being conducted on 33% (20 of the 60 genera) of the genera. Further, the revised genera generally comprise few species and those that require revision have many species. A need clearly exists for systematic research on the Sub-saharan short-tongued bees.

TABLE 1. The number of sub-saharan bee genera, per family, that have been revised since 1965, are currently being revised and those for which there is no useful revisory study and which are not currently being studied.

FAMILY	NUMBER OF GENERA				
	Revised whole Sub-saharan Region	Revised only for S. Africa	Being revised Sub-saharan Region	Unstudied	TOTAL
Apidae	30	3	4	1	38
Fideliidae	-	-	2	0	2
Megachilidae	22		12		34
Colletidae	4		2	0	6
Andrenidae	3		1	0	4
Melittidae	11		2	2	15
Halictidae	13	-	1	16	30
TOTAL	83	3	24	19	129

Systematic research should be coordinated to ensure efficient progress. Globally coordinated systematic research will enable phylognetic relationships to be established and facilitate comparison of pollinator scenarios in different zoogeographical regions.

Little information on pollination in Africa has been published. This is partly due to insufficient knowledge on the systematics of certain bee groups, such as the Halictidae and some Megachilidae (the genera that Pasteels [1965] revised require further study), as a number of pollination studies of agricultural significance have been initiated but not completed. Short-tongued bees and megachilids are often major components of such pollinator guilds. Therefore an ability to identify a larger proportion of pollinators is needed to stimulate pollination research. As a large portion of the Afrotropical Apoidea have been revised, relatively little further investment in bee systematics will provide large returns in enabling meaningful research in sustainable agriculture and biological diversity. Comparable systematic knowledge is available in very few other insect groups.

REQUIREMENTS

The needs of pollination biologists, with respect to biosystematic science and services are:

- Easy-to-use keys to families, genera and species
- Automated identification systems
- Distribution data
- Host plant records
- Catalogues and species lists, and
- Readily available literature

Much information is available towards these ends, but is as yet unpublished. Distribution and host plant records for many species are available, but not yet published. Databases of some of the South African collections are being prepared. Catalogues and reference lists have received substantial attention. However, the time taken to complete such long-term projects is a major constraint for potential users, and often leads to a duplication of effort. It is therefore essential to disseminate information before final publication.

SOLUTION

The solution appears to be in electronic media. Identifications can be facilitated by the development of electronic multi-access keys. The publication of information using inexpensive electronic media or the World Wide Web could make information such as catalogues available to users, who can identify errors and omissions, before publication. Existing publications could be placed on the Web for easy access. The electronic publication of new information would free more funds for research.

The Convention on Biological Diversity (CBD) has identified the Clearing-house Mechanism as the vehicle to achieve these objectives. Pollinators are one of two groups that have been identified by Decision III/11 (1996) of the Conference Of the Parties (COP) to the Convention on Biological Diversity, taken during their Third Meeting (COP3) in Buenos Aires, Argentina. Bee systematists have a responsibility to develop an effective global electronic information storage and retrieval system to serve the needs of systematics and pollination biology alike.

BioNET-INTERNATIONAL is one of the bodies recognised in the Darwin Declaration as an appropriate avenue for the development of biosystematic capacity. As the above issues mostly concern the development of such capacity, BioNET-INTERNATIONAL, through its developing country LOOPs (Locally Organized and Operated Partnerships), could be a suitable vehicle for the achievement of this objective.

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APPENDIX 1

The current systematic status of the Sub-saharan bees, including major revisions and specialists currently studying taxa. The Madagascan bee fauna is currently being revised (Pauly *et al.*, 2001) and is not included.

APIDAE		
Acanthomelecta	Revised	Lieftinck 1972
Afromelecta	Revised	Lieftinck 1972
Allodape	Revised	Michener 1975
Allodapula	Revised	Michener 1975
Amegilla	Revised, southern Africa only	Eardley 1994
Ammobates	Revised	Eardley & Brothers 1997
Ammobatoides	Revised	Eardley & Brothers 1997
Anthophora	Revised, southern Africa only	Eardley & Brooks 1989
Apis	Revised	Ruttner, 1988
Braunsapis	Revised	Michener 1975
Ceratina	Being revised	Daly, University of California, Berkley, USA
Cleptotrigona	Revised	Michener 1990

Compsomelissa	Revised	Michener 1975
Ctenoceratina	Revised	Daly 1988
Ctenoplectra	Not revised	
Dactylarina	Revised	Michener 1990
Epeolus	Revised	Eardley 1991b
Eucara	Revised	Eardley 1989
Eucondylops	Revised	Michener 1975
Halterapis	Revised	Michener 1975
Hypotrigona	Revised	Michener 1990
Liotrigona	Revised	Michener 1990
Macrogalea	Revised	Michener 1975
Megaceratina	Revised	Daly 1985
Meliponula	Revised	Michener 1990
Nasutapis	Revised	Michener 1975
Neoceratina	Being revised	Daly
Nomada	Revised	Eardley & Schwarz 1991
Pachymelus	Revised	Eardley 1993b
Pasites	Revised	Eardley & Brothers 1997
Pithitis	Being revised	Daly
Plebeina	Revised	Michener 1990
Protopithitis	Being revised	Daly
Sphecodopsis	Revised	Eardley & Brothers 1997
Tetralonia	Revised	Eardley 1989
Tetraloniella	Revised	Eardley 1989
Thyreus	Revised	Eardley 1991a
Xylocopa	Revised, southern Africa only	Eardley 1983
FIDELIIDAE		
Fidelia	Being revised	Whitehead & Eardley, in press
MEGACHILIDAE		
Afranthidium	Being revised	Michener* & Griswold** 1994 *University of Kansas, Lawrence
		USA, **USDA, Bee biology & Systematics Laborastory, Logan USA Pasteels 1984
Afroheriades	Being revised	Griswold
Afrostelis	Revised	Pasteels 1984
Anthidiellum	Revised	Pasteels 1984
Anthidioma	Revised	Pasteels 1984
Anthidium	Revised	Pasteels 1984
Aspidosmia	Being revised	Griswold
Atropium	Revised	Pasteels 1984
Benanthis	Revised	Pasteels 1984

Chalicodoma	Revised	Pasteels 1965
Coelioxys	Being revised	Schwarz, Ansfelden, Austria Pasteels 1968
Creightoniella	Revised	Pasteels 1965
Cyphanthidium	Revised	Pasteels 1984
Euaspis	Revised	Pasteels 1984
Gnathanthidium	Revised	Pasteels 1984
Haetosmia	Being revised	Griswold
Heriades	Being revised	Griswold
Hoplitis	Being revised	Griswold
Larinostelis	Revised	Michener & Griswold 1994
Icteranthidium	Revised	Pasteels 1984
Lithurge	Revised	Eardley 1988
Megachile	Revised	Pasteels 1965
Noteriades	Being revised	Griswold
Ochreriades	Revised	Griswold 1984
Othinosmia	Being revised	Griswold
Pachyanthidium	Revised	Pasteels 1984
Plesianthidium	Revised	Pasteels 1984
Pseudoanthidium	Revised	Pasteels 1984
Pseudoheriades	Being revised	Griswold
Serapista	Revised	Pasteels 1984
Stelis	Revised	Pasteels 1984
Stenoheriades	Being revised	Griswold
Trachusa	Revised	Pasteels 1984
Wainia	Being revised	Messinger & Griswold
COLLETIDAE		
Calloprosopis	Revised	Snelling 1985
Colletes	Being revised	Kuhlmann, Ahlem, Germany
Scrapter	Revised	Eardley 1996
Hylaeus	Revised, partly	Snelling 1985, excludes Subgenus Deranchylaeus
Nothylaeus	Being revised	Snelling, Los Angeles, USA
Psilylaeus	Revised	Snelling 1985
ANDRENIDAE		
Andrena	Not revised	
Melitturga	Revised	Eardley 1991c
Meliturgula	Revised	Eardley 1991c
Mermiglossa	Revised	Eardley 1991c
MELITTIDAE		
Agemmonia	Revised	Michener 1981

Atrosamba	Revised	Michener 1981
Capicola	Not revised	
Ceratomonia	Revised	Michener 1981
Haplomelitta	Revised	Michener 1981
Haplosamba	Revised	Michener 1981
Meganomia	Revised	Michener 1981
Melitta	Not revised	
Metasamba	Revised	Michener 1981
Promelitta	Revised	Michener 1981
Prosamba	Revised	Michener 1981
Samba	Revised	Michener 1981
Rediviva	Being revised	Whitehead
Redivivoides	Being revised	Whitehead
Uromonia	Revised	Michener 1981
HALICTIDAE		
Acunomia	Revised	Pauly 1990
Afronomia	Revised	Pauly 1990
Austronomia	Not revised	
Crocisaspidia	Revised	Pauly 1990
Eupetersia	Not revised	
Halictus	Not revised	
Lasioglossum	Revised, partly	Pauly 1980
Leuconomia	Not revised	
Lipotriches	Not revised	
Macronomia	Not revised	
Maynenomia	Revised	Pauly 1990
Nomia	Revised	Pauly 1990
Nomiapis	Not revised	
Nomioides	Being revised	Pesenko, Academy of Sciences, St Petersburg Russia
Nubenomia	Not revised	
Pachyhalictus	Revised	Pauly 1989
Pachynomia	Revised	Pauly 1990
Parathrincostoma	Not revised	
Patellapis	Revised	Pauly 1990
Pseudapis	Not revised	
Rophites	Not revised	
Ruginomia	Revised	Pauly 1990
Spatunomia	Revised	Pauly 1990
Sphecodes	Not revised	
Steganomus	Revised	Pauly 1990
Stictonomia	Revised	Pauly 1990

Systropha	Not revised	
Thrinchostoma	Not revised	
Trinomia	Not revised	
Zonalictus	Not revised	

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BRAZILIAN BEE SURVEYS: STATE OF KNOWLEDGE, CONSERVATION AND SUSTAINABLE USE

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ABSTRACT

The understanding of bee communities and their association with particular habitats can prove to be a very useful tool in identifying the vulnerability of these organisms to landscape changes and is also fundamental to assess the potential of bees for sustainable use in agriculture. Data on bee communities have been collected in Brazil for more than thirty years and are mainly bee species lists, information on bee abundance, seasonal and daily activity, and lists of mellitophilous plants. A local picture of community composition and structure can be drawn although proper species identification impedes a detailed analysis and limits comparisons among areas. Our intention here is to present overviews of the information on native bees gathered from surveys on bee communities and discuss the implications of the status of current knowledge to native bee conservation and its potential sustainable use.

INTRODUCTION

The knowledge about Brazilian bees can be obtained from works of the naturalists in the beginning of the century, like Cockerell (1900), Ducke (1906, 1907), Friese (1910), Schrottky (1902), from bee collections, private (Moure 1943, 1944) or in museums; from works on bee biogeography and from bee community surveys (Aguiar 1995; Aguilar 1998; Albuquerque 1998; Albuquerque and Mendonça 1996; Alves dos Santos 1996; Barbosa and Laroca 1993; Bortoli and Laroca 1990, 1997; Brito 1994; Camargo and Mazucato 1984; Campos 1989; Carvalho and Bego 1998; Cure *et al.* 1993; Cure *et al.* 1992; Faria and Camargo 1996; Gottsberger *et al.* 1996; Hoffman 1990; Hakim 1983; Knoll 1985; Laroca 1974; Laroca and Almeida 1994; Laroca *et al.* 1982; Martins 1990; Mateus 1998; Oliveira and Campos 1995; Orth 1983; Ortolan 1989; Pedro 1992, 1996; Pesenko 1978; Primack 1995; Ramalho 1995; Raw *et al.* 1998; Sakagami *et al.* 1967; Schlindwein 1995; Schwartz-Filho 1993; Silva 1998; Silveira 1989; Silveira and Cure 1993; Silveira *et al.* 1993; Silveira and Campos 1995; Sofia 1996; Taura 1990; Wilms 1995; Wittman and Hoffman 1990; Zanella 1991). This information is scattered over different kinds of published and unpublished material, unfortunately, the knowledge on Brazilian bees is lacking a synthesis. Particularly, the understanding of bee communities and their association with particular habitats can prove to be a very useful tool in identifying the vulnerability of these organisms to landscape changes and is also fundamental to assess the potential of bees for sustainable use in agriculture.

Systematic bee assemblage surveys were first carried in the late 60's by Sakagami *et al.* (1967), when a standard sampling methodology was proposed. Basically, bees were netted on flowers or nearby them with limited time spent on each flower. Since then most bee surveys applied this methodology, although authors often mention modifications.

Data produced by these works are bee species lists, information on bee abundance, seasonal and daily activity, and lists of mellitophilous plants. Local pictures of community composition and structure can be drawn, but proper species identification impedes a detailed analysis and limits comparisons among areas. Ramalho (1995) presented a synthesis of available data on Brazilian bee communities pointing out a gradient of species richness for each family according to latitude.

Our intention here is to present overviews of the information on native bees gathered from surveys on bee communities and discuss the implications of the status of current knowledge to native bee conservation and its potential for sustainable use.

We intend to answer the following questions about Brazilian bees' diversity, which we use to suggest some guidelines for a bee conservation policy:

1.How extensive has been the effort to survey bee communities in Brazil's regions and ecosystems?

2.What are the main groups accounting for the alpha diversity in each region?

3.What can surveys in disturbed and undisturbed areas tell us about bee communities?

4.What are the bee-plant potential associations between bees and plants and what are the perspectives of the sustainable use of native bee fauna in agriculture?

The Surveys

In Brazil the interest on systematic surveys started thirty years ago and since then more than 46 studies have been completed. Many of those studies were made by graduate students as dissertation projects.This resulted in a clumped distribution of sampling effort in the states where universities are located. Surveys are often conducted independently by each major academic working group, and are not part of a broader diversity inventory effort or planning. The resulting data frequently remain unpublished, being accessible only from the original dissertations and thesis, usually only available at universities sponsoring the survey. These surveys are snap shots and give us spatially and temporarily restricted information on bee communities. Only in two studies (Siveira and Campos 1995; Wittman and Hoffman 1990) did authors attempt to present data in a larger geographical scale. Monitoring programs have not been established, although three sites in South Brazil have been sampled in different years (Laroca and Orth, this book).

Brazil is a large country ranging from latitudes 5ºN to 34ºS. Many biomes are contained within its frontiers. In order to present data on the distribution of surveys and describe the results we use the classification of Udvardy (Udvardy 1975) of Biogeographical Realms and Provinces cited on the Global Biodiversity Assessment published by the United Nations Environment Programme (Heywood 1995). For each biogeographical realm a description of local vegetation types is provided, in some cases local vegetation may differ from the general description of Udvardy's category. According to this classification, 27.8 % of the surveys were carried out in the Tropical Savannas, 24.1% in Tropical Humid Forests, 31.5% in Subtropical/Temperate Rainforests/Woodlands, 13% in the Temperate Grasslands and 3.7% in Tropical Dry Forest/Woodlands. (See Fig.1)

a) Tropical savanna

The Tropical Savanna realm comprises more than 2 million km^2, and is locally called "cerrados". Many different physiognomies, from open grasslands to woodlands are found, but a floristic identity is recognised. Patches of deciduous or semi-deciduous forests and gallery forests also occur. The cerrado is intensively exploited for agriculture and cattle grazing which has resulted in the loss of around 37% of its original cover (Dias 1994). The bee surveys were conducted in disturbed fragments relatively clumped in the vicinities of the cities and one in high altitude rocky fields (Brito 1994; Camargo and Mazucato 1984; Campos 1989; Carvalho and Bego 1998; Faria and Camargo 1996; Martins 1990; Mateus 1998; Pedro 1992; Raw *et al.* 1998; Rego 1998; Silveira 1989; Pinheiro-Machado in prep.).

b) Tropical Humid forests.

Amazon region

The Tropical Humid forests in Brazil are represented by two major vegetation continuums. One is the Amazonian Forest, a recognised centre of biodiversity world-wide, where not a single bee community survey has ever been conducted. Information about bees from Amazon region are derived from early collections by Ducke (1906) and other such studies on specific groups such as Euglossinae (Oliveira 1995) and Meliponinae (Camargo 1970), among others.

Atlantic Rain Forest.

The other major forest continuum is the Atlantic Rain Forest, which extended originally along the Brazilian Coast from the northeastern to the southern regions of Brazil, and is presently reduced to 9% of its original distribution. The Atlantic Rain Forest comprises the forests on the slopes of the coastal mountains, the vegetation on the coastal sand plains and dunes. This is also an internationally recognised hotspot of biodiversity. The main threats to this formation are due to human occupation. The sampling effort was concentrated on the southern portion of its distribution where habitat disturbances were greatest. In the last decade the bee sampling efforts in the Atlantic rain forest have increased, (Aguilar 1998; Alves dos Santos 1996; Ramalho 1995; Wilms 1995), and new techniques for canopy sampling are being used for the first time.

c) Subtropical/Temperate Rain Forests.

The Subtropical/Temperate rain forest realm is characterised by semidecidous and altitudinal forests located on the Brazilian Southern Plateau. All surveys conducted in these formations were in the Southeast region, the most economically developed part of the country. There are no primary forest left in this region, but there are important secondary growth forests where natural reserves have been established.

d) Tropical Dry Forest/Woodlands.

The Tropical Dry Forest/Woodlands realm is locally called "caatinga" vegetation. This is a vegetation that grows under very irregular pluvial regime and passes through long droughts. It is a habitat with very typical physiognomy and floristics, with characteristically thin, thorny branched, low-lying trees.

e) Temperate grassland.

The last realm is Temperate Grassland, located in South Brazil. A variety of habitats are found in this region. Bee inventories were carried out in 7 different regions (Sazima 1989). These regions comprise the Southern-most distribution of the Atlantic Forest, the *Araucaria* Plateau, deciduous forests, open fields (pampas), disturbed secondary growth subtropical rain forest and coastal plain forests.

Although more than 46 studies may sound like a lot, in a large country like Brazil, this number was not enough to sample uniformly the variety of different landscape and ecosystems. A glance at the map presented in Fig.1 reveals very large gaps in regions of high diversity .The Amazon Forest, the *Pantanal* and the Atlantic Forest between the States of Rio de Janeiro and Espírito Santo are examples.

If one considers the sampled areas based on environmental disturbance, we should find that 63% of the studies were conducted in areas covered with natural vegetation of primary or secondary growth, 10% were in agroecosystems and 27% in urban areas. Unfortunately, around 70% of these natural areas are secondary growth fragments and the other 30% are not pristine areas, but are areas within reserves where man's interference has been minimal. The data highlight the idea that the Brazilian bee communities are in fact still poorly known, based on the hypothesis of loss of diversity associated with habitat disturbance presented in a conservation biology text (Meffe 1994).

The following conclusions are derived from the data presented above. To achieve a sound knowledge on Brazilian bee fauna a general plan of sampling sites is to be proposed. If data necessary to provide an overview of bee biodiversity is to be obtained by academics, a co-operative program between universities and environmental agencies must be established. Data produced should be published or made available in a national database, to allow comparisons, monitoring changes, and avoid undesirable repetitive samplings. Hotspots of diversity should be considered priority areas for sampling and collections at these sites should be encouraged. Collections should be properly housed and arrated in recognised entomological museums.

Bee fauna diversity

Six families, Andrenidae, Anthophoridae, Apidae, Colletidae, Halictidae, and Megachilidae, 42 tribes and 219 genera were found in Brazilian surveys. Anthophoridae accounts for 70 genera, Halictidae for 34, Colletidae for 30, Andrenidae for 30, Megachilidae for 28 and Apidae for 27.

The total number of species accounted by each family in Brazilian bee inventories is not an information that can be promptly assessed. The species list resulting from all bee community surveys sum up more than 3,000 names. Moreover, only 1,000 names correspond to identified species. The rest are species that could not be properly identified (Silveira *et al.*, this book) and many of them probably belong to the same species.

The overview of Brazilian bee diversity based on the surveys of communities produced till now may be subject to some bias. Surveys of regional distribution may have produced underestimates of some groups, depending on their biogeographical distributions.This could be the case of Apidae-Meliponinae known to be richest in species around the latitude 0o (Ramalho 1995).The taxonomic status of the group, meaning how much effort has been put into taxonomic description and revisions, may also have a significant effect on results. Well-studied groups may end up with greater numbers of species than poorly studied ones.Taxonomic revisions may recognise more species in what has been considered a single species. Demographic characteristics of some groups, as low-density populations, or crepuscular habits, may influence the final result depending on the sampling methodology and sampling effort.

Bee community diversity can be estimated in many ways. A simple one is through the *alpha* diversity, or the number of species found in the area. Inventories in Brazil found from 35 up to more than 300 species in single sites.The sites where fewer species were found are in dunes and in caatinga vegetation (see chapters in this book), habitats with very seasonal and harsh environmental conditions as temperature, humidity and wind speed. Harsh environments, otherwise, cannot be immediately assumed to contain fewer species. Michener (1979) has already pointed out that xeric temperate regions are where the greatest diversity of bees is found.The number of species found in surveys carried in dunes and caatingas range from 35 to 41 species. Surveys in coastal islands resulted in 57 and 75 species (Schwartz-Filho 1993). In the continent the number of species obtained is often superior to 100 species for surveys with at least one year of sampling. It is not possible to point out specific sites of greatest species richness based on raw data from surveys because of important differences in collecting methodology and sampling efforts.

Some authors have presented the Shannon-Wienner (H') diversity and evenness indices from their samples, and they range from 2.11 in the caatingas to 4.48 in cerrado fragments and 0.53-0.80 of evenness for studies with one year of sampling. One pattern in bee communities seems to be that there are few species with great abundance and many species with only a few individuals. This pattern still holds if eusocial species are kept aside. However, more detailed studies are needed to confirm this apparent generality for the Brazilian apifauna.

We have attempted to provide a description of bee diversity in the main vegetation types found in the biogeographic realms presented above and point out what groups better explain the diversity of the bee fauna in these macro-regions. For this purpose we counted the number of species presented by authors in each survey, which we used to obtain an average number of species for each taxonomic group for the chosen macro-environment. This was the way we found to avoid recounts of non identified species and a misleading panorama if we used only well identified species.The six families were found in all biogeographic realms, although they have not been present in every survey.

The Tropical Savanna.

We have selected 9 surveys carried on *cerrado* remnant areas (Campos 1989; Carvalho and Bego 1998; Martins 1990; Mateus 1998; Pedro 1992; Rego 1998; Silveira 1989; Pinheiro-Machado in prep). Family rank based on the average number of species shows Anthophoridae with 45.5%, Halictidae with 20.7%, Megachilidae with 18.2%, Apidae with 17.6%, Colletidae with 4.1% and Andrenidae with 1.2%. A total of 32 tribes and 119 genera were found in these 9 surveys. Eight tribes with the greatest number of species account for 70% of the total species. These tribes are Augochlorini (16.1%), Centridini (15.1%), Megachilini (14.0%), Exomalopsini (11.9%), Trigonini (10.5%), Ceratinini (5.4%), Halictini (4.5%) and Eucerini (3.4%).

The genera with the greatest number of species are *Megachile* (ME) with 11.1%, *Centris* with 10.2%, *Paratetrapedia* with 8.2% and *Augochloropsis* with 6.3% of the species. The eight richest genera account for 53.5% of the species richness in Tropical Savannas, and they are, besides those mentioned above, *Epicharis* (5.1%), Augochlora (5.1%), *Ceratina* (3.9%) and *Exomalopsis* (3.6%).

Tropical Humid Forests.

Nine areas of Atlantic Rainforest were selected (2,5,29,30,47,55,56,64,66). The richest family is Halictidae, with 30.9% of the species, followed by Anthophoridae with 30.1% of the species, Megachilidae 14%, Apidae 12.7%, Colletidae 7.7% and Andrenidade 4.2% of the species. Bees' species belong to 32 tribes and 131 genera.

The tribes with more species are Augochlorini (22.8%); Megachilini (12%); Halictini (8.3%), Ceratinini (6.6%), Trigonini (6.3%); Exomalopsini (5.9%), Centridini (4.7%), Hylaeni (4.0%), Eucerini (3.7%), Panurgini (3.6%). These 10 tribes account for 71.6 % of the total species richness.

The genera with more species area *Megachile* (10.1%), A*ugochloropsis* (8.3%), *Augochlora* (7.0%), *Dialictus* (5.3%), *Centris* (4.8%), *Ceratina* (3.9%), *Paratetrapedia* (3.8%), *Hylaeus* (3.9%), *Ceratinula* (3.5%). It is necessary to pick up 9 genera with the greatest number of species to achieve fifty percent of the number of species.

Subtropical /Temperate Rainforests.

Most surveys in this biogeographic realm were conducted in disturbed areas that were originally covered by the Araucaria forests. We based the estimate presented above in 9 surveys, but only one was in natural vegetation remnant (6,8,9,26,30,32,41,42,63). The rank based on the average number of species are 46.1% of the species in Halictidae, 18.3% in Anthophoridae, 12.0% in Megachilidae, 10.9% in Andrenidae, 4.8% of the species in Colletidae , and 4.6% in Apidae. Bees' species belong to 31 tribes and 107 genera.

The six richest tribes account for 79.9% of the species in the samples, which are: Halictini (25.1%), Augochlorini (20.5%), Megachilini, (11.4%), Panurgini (10.1%), Eucerni (6.5%), Ceratinini (6.3%).

The six genera with greatest number of species account for 50.9% of the sampled species. The richest genera are *Dialictus* (21.5%), *Augochloropsis* (9.2%), *Megachile* (8.2%), *Ceratina* (4.4%), *Psaënythia* (4.2%), and *Augochlora* (3.4%).

Tropical Dry Forests.

This biogeographic realm has been sampled only 2 times until now, being each sampling period restricted to one year (Aguiar 1995; Mares 1986). Therefore, data in this particular case should be regarded as preliminary data. The species richness is much more concentrated in Anthophoridae, with 38.8% of the species, Apidae with 17.6% of the species, Megachiliade with 16.5%, Halictidae with 12.9 % of the species, Andrenidae with 8.2% and Colletidae with

5.9% of the sampled species. The bee species found in the caatinga was represented in 17 tribes and 37 genera.

The seven richest tribes account for 76.5% of the total number of species. Trigonini and Megachilini are the richest tribes both with 14.1% of the species, followed by Centridini with 12.9%, and Halictini with 10.6%, Augochlorini with 7.1%, and Eucerini, Panurgini, Exomalopsini with 5.9% of the species each. The genera with more species are *Centris* with 12.9% of the species, *Megachile* with 11.8% of the species, *Dialictus* with 4.7%, and *Exomalopsis* and *Augochlora* with 3.5 % of the species each, and *Ceratina* with 2.4% of the species.

Temperate Grasslands.

Bee species caught at the various habitats from South (Hoffman 1990; Schlindwein 1995; Wittman and Hoffman 1990) belonging to six families are 29.8% Anthophoridae; 25% Megachilidae; 23.3%, Halictidae, 22.7%; Andrenidae 9.5% Colletidae 8.7%; Apidae, 5.9%. Species found in 33 tribes and 95 genera.

The tribes that contribute most to the species richness are Megachilini, with 17.4%, Augochlorini with 17.1% of the species, Eucerini, with 6.1%, Halictini with 5.2%, Ceratinini with 4.7%, Exomalopsini with 4.6%; Melitomini with 4.1% Xylocopini with 4.0%, Trigonini with 3.8% and Centridini with 2.5% of the species. These 10 tribes account for 69.5% of the species.

Fifteen richest genera account for 50% of the number of species. These are *Megachile* (13.9%), *Augochloropsis* (8.0%), *Ceratina* (4.4%), *Augochlora* (4,3%), *Dialictus* (3.4%) and *Psaenyhia* (3,2%), among others.

Taxonomic groups explaining the alpha diversity in the various regions of Brazil are affected by Family species richness. The importance of Augochlorini (*Augochloropsis*) and Megachilini (*Megachile*) is a constant in almost all biogeographic realms, except in the areas of caatingas in the Tropical Dry Forests where Augochlorini is not as well represented as in the other areas. Unfortunately the reduced number of surveys does not allow further discussions.

Comparing savanna like vegetation (cerrados) and rainforest bee fauna it is possible to notice that the species richness in cerrado is more evenly distributed than in rainforests, where Augochlorini has a major role. The increased contribution of Centridini and Exomalopsini for the number of species in the cerrados is an evident difference. The importance of oil collecting species, common in the two above mentioned tribes, has been related to the presence of many species of Malpighiaceae in the cerrados (Ramalho 1995). Ceratinini and Eucerini make a similar contribution to species number in both habitats, while Panurgini is important only in the rainforests sample. Trigonini accounted for a higher percentage of species in the cerrados than in the rainforests, while the contrary is noticed for Halictini.

In the habitats in South Brazil, we can see the decrease in importance of Centridini and Trigonini. Ceratinini and Eucerini are similarly important in percentage of species, although their contributions are larger than in the above mentioned habitats. Panurgini is much more represented in the South than in the other regions so far surveyed. Most samples taken in the Subtropical/Temperate rainforest realm were in urban or suburban areas, and this might be the cause of the great percentage of Halictini species. One forth of the species are Halictini, and the majority of them are *Dalictus*. Megachilini has the greatest percentage of species in the surveys carried in the Temperate Grassland Realm.

It is worthy mentioning that the above presented rank for the number of species per family is not necessarily the same presented by authors in each original work. This could result for many reasons, but one should be highlighted. It is probably related to particular features of sampled habitats, once the heterogeneity in the local scale is enough to result in diverse faunal compositions.

Habitat alteration and bee communities

The very issue in conservation biology is to reveal what are the effects of human activities on the various levels of life is organisation, from species to ecosystem (Primack 1995). The three guiding principles of this science stated by Meffe and Carrol (1994) embrace a) the role of evolutionary processes, b) the idea of a "dynamic and largely non-equilibrium" world and c) the importance of including the human presence in conservation planning.

Habitat conversion to agroecosystems or to urban landscapes may affect bees in many different manners. Habitat loss and population isolation of the bee colonies is easy to picture in these scenarios. Bees are a large group with an enormous potential for a variety of demands that may be more or less affected by habitat changes. The nesting demands, dependence of particular food resource, physiological and behavioural constraints are examples of biological features that can influence the persistence of a particular taxon.

What we know so far about Brazilian native bee biology is far short of placing us in a comfortable position to determine or identify species sensitivity or vulnerability to any sort of human activity. What we can do is to look for clues in the available knowledge to ask new questions and to set some starting hypotheses to be properly tested opportunely.

Bee surveys have been conducted in more or less disturbed areas. The most disturbed areas are cities, where the original cover was not only removed, but in many cases the native plants have been replaced by exotic. Microclimatic changes are severe. Even with this disturbance, some groups were able to persist in cities and others seemed to have increased their relative abundance. Halictidae is the most represented family in samples taken from both urban areas and agroecosystems. But this trend could be challenged as most surveys in the disturbed areas were done in southern Brazil where Halictidae is known to be the most diverse (Eickwort 1969). Some authors (Pedro 1992; Taura 1990) refer to Pesenko's (1978) work to support the idea that Halictidae may be related to disturbed or open areas. The available data in the literature is not conclusive in this way, as for instance Halictidae was the family found most frequently in two areas of well-developed Atlantic Forests (Ramalho 1995; Wilms 1995).

Another novel and interesting approach would be to investigate bees according to their behavioural, morphological and functional perspectives. The effects of habitat change on bees could be more easily detected at a species level that share common demands rather than using a taxon that may embrace bees with differing requirements.

Potential bee plant association

We have looked in all surveys for information about the main flower resources used by bee families in order to highlight groups that could play an important role in bee fauna for sustainable use in agriculture. Not all works present such data. The available data are the proportions of individuals of each bee family that were caught in each plant family. Authors usually present their data as the "main plant families" used by bees. We have established that the main plant families are the ones where most individuals were caught up to 70% of the individuals. Two major biogeographical realms of special interest to conservation issues were considered: the Tropical Savannas and the Tropical Humid Forests. For each biogeographical realm we recorded the number of many surveys that record a bee family that uses a named plant family as a main food resource. So the frequency we refer hereafter is the number of surveys a bee-plant pair appears out of the total number of surveys considered. Six surveys were considered in each biogeographical realm. This number represents the number of surveys that had the information promptly available.

In the Tropical Savannas the most important plant families to Anthophoridae were Malpighiaceae, Asteraceae and Lamiaceae. Apidae frequented the broadest spectrum of plant families, but Malpighiaceae and Asteraceae were the most frequent association. Halictidae also frequented a broad spectrum of plant families, but Asteraceae and Malpighiaceae were the most frequent. Megachilidae is the bee family with the narrowest spectrum of important families. Asteraceae is where more than 50% of all Megachilidae were caught in surveys considered. Leguminosae is the second most frequent pair with Magachilidae. Both Malpighiaceae and Asteraceae were where large numbers of bees in the surveys were found and thus are important sources to all families. If later work surveyed bees down to genera, potential associations could be better envisioned.

In the Tropical Humid Forests Anthophoridae bees were found in Asteraceae and Rubiaceae most frequently as well as in Euphorbiaceae and Leguminosae. Apidae were mainly caught in Asteraceae, Melastomataceae, Sapindaceae and Leguminosae. Halictidae were most frequently associated with Asteraceae, Rubiaceae, and Leguminosae. The most important plant source for Megachilidae was Asteraceae, as it was in the Tropical Savannas, but Megachilidae also frequented Rubiaceae and Leguminosae.

The data presented above are useful in our preliminary approach, which has no intention of being conclusive. We believe that it possible to identify and determine potential associations in a more accurate and precise manner from data that have already been collected and that this could be a starting point for the investigation of how native bees could be better utilised in agriculture.

Constraints to a synthesis of Brazilian Bees Communities

The most evident difficulty is dealing with data on Brazilian bees is finding them. A major setback is that so much data either remains unpublished or takes too long to become available to the public. Consequently, this hinders the development of bee inventory and methodology which raises pertinent questions. If data cannot be exposed to criticisms, the same mistakes will keep reocurring. The limitations of present applied sampling methodology on bees has been known for a long time, but new alternatives or adjustments have not been proposed or discussed.

The common complaint of authors is the difficulty of comparing samples and identifying patterns because of methodological constraints. Silveira and Campos (1995) and Silveira *et al.* (1993) proposed some statistical techniques to improve data analyses from bee inventories. Cure *et al.* (1993) started a discussion on the influence of the sample size on richness estimates. These are problems that need to be addressed.

The important constraint imposed by methodological differences or absence of well-established techniques for dealing with different samples is to the synthesis of knowledge needed to provide an overview of Brazilian bees. This is exactly the problem we faced here. Results can only be presented in a preliminary or partial way. Until much more data are available these problems will persist, as they do throughout the rest of the world.

Another difficulty arises from the description of the habitat were samples were taken. Descriptions are usually partial or incomplete. A very detailed description of the area would include not only the characteristics of the sampled areas but also of the surrounding environment that may influence faunal composition. Even the size of the sampled areas is often not clear. The total area of the landscape unit or the portion that was sampled is to be informed. Curves of species area are useful tools for conservation biologists and are based on this information. Better descriptions of previously sampled sites are needed by botanists and other natural scientists. However, assembling such teams is difficult.

CONCLUSIONS

Much effort has been put into the study of bee communities in Brazil. Nevertheless, because of its continental dimension much is still to be done. Many particular habitats, areas of plant endemism, natural remnants of different vegetation are expected to provide a great contribution to the total diversity of bees in Brazil. Although the state of Rio Grande do Sul, South Brazil, has been surveyed for a long time, sampling in particular habitats can bring out many new species (Oliveira and Campos 1995). Surveys in more pristine areas are lacking.

A co-ordinated effort to provide a complete overview of the Brazilian fauna has already started with the National Biota project, supported by FAPESP (Research Foundation of São Paulo State). The work is carried by University groups as part of a major biodiversity inventory program. The next step to be taken in Brazilian surveys is the establishment of a standard methodology that could be applied effectively in all types of Brazilian habitats to allow comparisons among areas and biodiversity diagnoses. Proper analyses are also needed to assure the data are as useful as possible. Data on populations should be encouraged because such data are the fundamental tool for conservation and management.

The sustainable use of native fauna in agriculture is still poorly investigated. For historical reasons the idea of increasing agricultural production is often associated to more land being cultivated. Greenhouses are probably a costly alternative for a country like Brazil with great expanses of land and economic difficulties. The introduction of exotic pollinators is absolutely not recommended as the local fauna has proven to be rich, both in species and in behavioural and morphological features.

What then, could be said about the use of bee pollinators in agriculture? The studies of communities showed us that even in very disturbed areas bees are found. Because of lack of data from more undisturbed areas and other constraints discussed above, it is not correct to say anything about how great the diversity is except in a few places. But if remnants of native vegetation are maintained in agriculture properties a great deal of bee fauna could be conserved. That is the very same fauna, which has a potential for agriculture use. Experiments are needed to evaluate the impact of the native bee presence and their absence in the production of surrounding agriculture fields.

Stingless bees are easy to manipulate, thus making them an interesting starting group. They have been a well studied ecologically, behaviourally and physiologically. The role of stingless bees for pollination has been questioned, because of their illegitimate behaviour at flowers (Renner and Feil 1993), but no sound evidence exists that they are more opportunistic than useful for plants. Stingless bees can also be used in a very interesting manner for the cause of pollinator conservation. The idea of a bee, for the laymen, recalls the exotic *Apis mellifera.* A huge part of the population does not even know that this is not a Brazilian bee, and that the country is home to a great diversity of bee species. Mares (1986) has pointed out the importance of "people who bring accurate scientific information and explain the importance of conservation programs to the society at large, without which work, society would not support programs that limit free access to resources".The stingless bees are easily kept in experimental boxes and have a good appeal in educational exhibits.

Megachilidae are bees well explored as pollinators in the Northern Hemisphere. The importance is well established. In Brazil, as shown above, Megachilidae bees are a significant part of the biota, and seem to be an interesting alternative to be explored. The importance of other taxa is already known, as Xylocopini bees and Passifloraceae (Sazima and Sazima 1989). The use of these native bees in small properties could have a positive impact on household economy.

The Brazilian bee fauna has an enormous potential for agricultural production enhancement, but the studies and projects must be framed in the Brazilian perspective. The Northern Hemisphere models are probably not the best alternatives, but the lessons are there so that local alternatives and solutions can be pursued. The potential use of bee groups as pollinators in agricultural systems should take into account bee distribution and local bee plant associations. Preliminary data presented above indicate that there may be differences in bee-plant family associations according to the vegetation type or ecosystems the pair occurs.

It is clear from the Brazilian bee literature that we do not have information on communities and population processes, and this should be a warning to the possible negative or positive impacts of native bee population management. Although the use of native bee fauna as pollination services is recommended as opposed to the introduction of exotic pollinators, we shall not forget that even the management of native populations can result in undesirable effects on the total biodiversity.

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FIGURE 1 . Number of bee community surveys carried out in Brazil in each Biogeographical Region (According to Udvardy, 1975). TS =Tropical Savannahs; TG= Temperate Grasslands; TH=Tropical Humid Forests; TD=Tropical Dry Forests; ST=Subtropical/Temperate Rainforest

DIVERSITY OF THE BEE FAUNA OF THE BRAZILIAN CAATINGA

Celso Feitosa Martins

ABSTRACT

This paper discusses the diversity of bees found in the caatinga of Brazil. It compares the population diversity of the caatinga area to other Brazilian ecosystems and the possible reasons behind the differences. Certain endemic species of bees are discussed.

INTRODUCTION

Biodiversity in recent years has become prominent not only as a research paradigm, but also as a popular subject for audience attraction in the media. In spite of this, the current knowledge on the biodiversity of ecosystems as, for example, of the Neotropical region, is still very embryonic. In Northeastern Brazil, particularly in semiarid regions, very little is known about the diversity of several groups of animals and plants.

The ecosystem of the Caatinga occupies 750,000 km^2, approximately 10% of the Brazilian territory. According to Andrade-Lima (1981), there are at least 12 Caatinga types. The areas of the Caatinga are suffering from strong human influence, and the fauna and flora are becoming greatly altered before a good knowledge of the local community structures and their flora and faunal diversity can be gained.

It is known that the mammals and terrestrial vertebrates of the Caatinga, besides having a low diversity also comprise a low percentage of endemic species.

In comparison, the insects represent a larger degree of endemism. This probably reflects, at least partially, the narrower relationship between insects and plants and also as yet unknown historical factors. The oscillations of the standing crop of the biota in an area with low annual precipitation (300 - 800 mm.) highly irregularly distributed in time and space greatly influence the insect fauna of the Caatinga. Many insect species seem well adapted to the long dry periods. Some survival strategies in the Caatinga are prolonged development of larval stages or to enter into a period of diapause or both. Some species adopt nocturnal habits primarily to take advantage of lower temperatures and higher humidity levels (Barrios 1994,1995). Countless examples of specific relationships between insects and plants exist among the Orthoptera, Lepidoptera, Heteroptera and Coleoptera. Among bees, worth special mention is *Ceblurgus longipalpis* (Hymenoptera, Halictidae), an oligolectic bee that forages mostly on the flowers of *Cordia leucocephala* (Boraginaceae) (Aguiar and Martins 1994). Other oligolectic relationships are found between species of *Melitoma* and *Ipomoea* (Anthophoridae), *Bicolletes* and *Loasa rupestris* (Colletidae), and *Sarocolletes* and *Sida galheirensis*

(Colletidae). (Martins 1990 and unpublished data) (Table 1). However, the existing information on the diversity and biology of the insects is still scarce and dispersed, owing mainly to the lack of good collections, extensive and intensive surveys and/or to taxonomic difficulties in the study of some groups (Barrios *op. cit.*).

Regarding bees (Apoidea), recent studies present some interesting data. Martins (1990, 1994), using a standardized methodology to study the relationships between bees and the plants they visit in the Caatinga, found about 15% new and/or endemic species in an arboreous-shrubby Caatinga in the district of Casa Nova, Bahia State.

Compared with other ecosystems (*e.g.* Savanna and Atlantic Wet Forest), the diversity of bees found in the Caatinga is low (Martins 1990, 1994, and unpublished data; Aguiar and Martins 1997; Aguiar 1995). However, similar studies suggest that although the species richness (alpha diversity) is low in each specific area and that different areas present several exclusive species (beta diversity). This suggests high gamma diversity (although lower in comparison with other Brazilian biomes) as proposed by Whittaker (1972) and Schluter and Ricklefs (1993), when all the semiarid regions are considered. These concepts are relevant the study being developed by Zanella (1998). In a preliminary list of the bee fauna of the Caatinga, excluding areas with other biomes within the domain of the Caatinga, Zanella (1998) observed about 180 species, with a high rate of endemism suggested to be about 30% of the collected species.

An interesting group that presents similar species richness as in other ecosystems of opened areas of the Neotropical region is the eusocial Meliponinae. In the surveys and studies of bees in Bahia State (Martins 1994; Martins and Aguilar 1992) and in Paraiba State (Aguiar and Martins 1997; Martins *et al.* submitted), the following stingless bees species were observed: *Melipona asilvae, Melipona subnitida, Melipona mandacaia, Scaptotrigona* sp. n. - group *depilis, Scaptotrigona* sp. n. - group *tubiba, Plebeia flavocincta, Plebeia* spp including spp. n., *Trigona spinipes, Trigonisca pediculana, Trigonisca* sp. n., *Frieseomelitta* sp. n., *Frieseomelitta varia, Partamona* sp. n. aff. *nigrior* and *Lestrimelitta limao.*

Besides the similar species richness to the other biomes of opened areas, several species of Meliponinae of the Caatinga are also likely endemic. Honey and pollen stores of the colonies of many of these species are harvested by honey-hunters and local beekeepers. And because of deforestation, management techniques of natural and agroecosystem resources and other human influences, some of these species (*Melipona* spp.) are already rare and threatened by extinction in some areas (Table 2).

Considering the importance of an endemic fauna adapted to the xeric conditions of the Caatinga, the pollination potential of meliponine bees, honey and pollen production, and consequently relevant role in the sustainable development use of the Caatinga, the preservation and recovery of the ecosystems located in the semiarid region of Northeastern Brazil is urgent. There is much to study and discover about the fauna of the Caatinga and its adaptations to this unique environment.

TABLE 1. Some examples of oligolectic bees and the plant species they visited.

Bee Species	Bee Family	Plant Species	Plant Family
Ceblurgus longipalpis	Halictidae	*Cordia leucocephala*	Boraginaceae
Melitoma-spp	Anthophoridae	*Ipomoea* spp	Convolvulaceae
Bicolletes spp	Colletidae	*Loasa rupestris*	Loasaceae
Sarocolletes sp	Colletidae	*Sida alheirensis*	Malvaceae

TABLE 2. Meliponinae observed in the Caatinga of Bahia and Paraiba State, Northeastern Brazil.

Bee Species	Situation	Endemic
Melipona asilvae	Threatened	*
Melipona subnitida	Threatened	*
Melipona mandacaia	Threatened	*
Scaptotrigona sp. n. – grupo depilis		*
Scaptotrigona sp. n. – grupo tubiba		*
Trigona spinipes		
Plebeia flavocincta		*?
Plebeia spp		*
Trigonisca pediculana		
Trigonisca sp. n.		*
Frieseomelitta sp. n.		*
Frieseomelitta varia		
Partamona sp. n. aff. *nigrios*		*
Lestrimelitta limao		

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BEE DIVERSITY OF THE COASTAL SAND DUNES OF BRAZIL

Blandina Felipe Viana and Isabel Alves-dos-Santos

ABSTRACT

A summary of the bee fauna on the Brazilian coastal sand dunes is presented. The data used in this synthesis come from the results of apifauna surveys undertaken in five sites on the Brazilian coast: 2°30'S, 7°S, 12°56'S, 25°30'S and 30°S. This preliminary synthesis allows an overview of the composition and richness of the bee species in the dune and beach environments along the Brazilian coast.

INTRODUCTION

One of the features of the Brazilian coast is the presence of vast sedimentary sand plains which are the result of the transgressions and regressions of the sea in the Holocene (Araújo and Lacerda 1987). These plains include areas termed beaches, foredunes, dunes, low zones and boundary zone, which differ in the plant cover. This set of environments is termed "restinga". The complexity of the restinga communities increases as far as we are from the ocean.

In spite of their homogeneous appearance the dunes have interdependent micro-environments and several particularities related to their flora, which is constantly under nutritional and hydric stress. The dunes vary in shape and position because of wind changes. but the vegetation is little affected by such changes being easily adapted to the movements of the mobile subtract. There are also extensive zones in which the dunes are fixed due to the presence of trees and shrubs.

The dune belt along the Brazilian Atlantic Coast is not continuous in width and alignment. In Rio Grande do Sul, for instance, the coastal plain is wide, low, and slightly undulating. It is made up of four belts of recent and ancestral dunes, interspersed by "restingas" and lagoons. In other areas one may find high dunes (up to 90m) such as the ones in the NE region, or portions of clipped littoral marked by the presence of bays, like the ones in the northern part of the state of São Paulo.

Except in neighbour wood of restingas and mangroves, over most of their north-south extension the dunes have the Atlantic Rainforest inland to the west. This ecosystem certainly has a strong influence from the fauna and flora of the dunes.

Temperature and relative humidity are usually more constant on the coast during the year because of the direct influence of the sea. This is especially true in tropical zones (0°-

23.5°S). In the south of Brazil, the influence of polar winds (south winds) may bring instability and may cause drastic changes in the temperature and in the precipitation rate in the coastal region. Regional differences may also be found, such as in the north of the state of Rio de Janeiro, near the Paraíba River (22°S) which may present a dry zone with semiarid aspect. The low humidity in this latitude caused by the colder sea water that brings dry air to the coast (the resurgence zone of Cabo Frio).

The Dunes Vegetation

In the initial portion of the dunes (foredunes or pioner zone) there are halophyte (salt tolerant), succulent and creeper plant species. In the limit between the high tides and the dunes, we find a flora that is cosmopolitan to the tropical coast with species of grasses, weeds and shrubs (Ciperaceae, Gramineae, Asteraceae, Convolvulaceae and others) Toward inland the vegetation gets denser and fixed on the sand, generating the fixed dunes with woody plants. In the south coast of Rio Grande do Sul we may find small portions of forest with giant individuals of *Ficus organensis, Erythrina cristagalli, Salix, Myrcia* spp and other species.

Some studies show new species and some endemism of Bromeliaceae, Orchidaceae, and Lameaceae in restinga areas. However, the main vegetation type may be dominated by other groups, with many typical elements of the families Arecaceae, Cactaceae, Araceae, Velloziaceae, Asteraceae and Leguminosae (Caesalpiniaceae, Fabaceae and Mimosaceae) (Britto *et al.* 1993; Araújo and Henriques 1984).

Opposite to what occurs with the dune vegetation in the temperate region, which features many anemophilous and few entomophilous species (Knuth 1896, Gottsberger *et al.* 1988), many of the plant species on the tropical dunes are entomophilous and, more specifically, melittophilous that is, their flowers are visited by Hymenoptera, especially bees. These bees are frequently the pollinators of these plant species, therefore responsible for their sexual reproduction (Gottsberger *et al.* 1988).

The Apifauna of the Dunes

The results of five apifauna surveys carried out or including the coastal dune of Brazil show the diversity of the bees and their importance for the pollination of local vegetation.

In the South of Brazil Alves-dos-Santos (1996 and 1999) found 206 species of bees in the lowland areas in the broad coastal plain of Rio Grande do Sul (30°S/51°W). Of these, 129 species were found exclusively between sea level and 50 meters altitude (in areas of dunes and restinga). Still in the South of Brazil 75 species were recorded in Ilha do Mel, 122 species in Alexandra and 57 species in Ilha das Cobras (Laroca 1974, Schwartz Filho 1993, Zanella 1991, Zanella *et al.*1998). All these localities belong to the coastal plain of the state of Paraná at 25°30'S and 48°30'W.

In the Northeastern Brazil bee surveys were conducted by Gottsberger *et al.* (1988), Albuquerque (1998), Madeira da Silva (1998) and Viana (in prep.) between the latitudes of 2° and 12°S. All showed the presence of less than one hundred species. The large solitary bees of the family Anthophoridae were predominant for they are able to forage under the adverse dry conditions of the dunes.

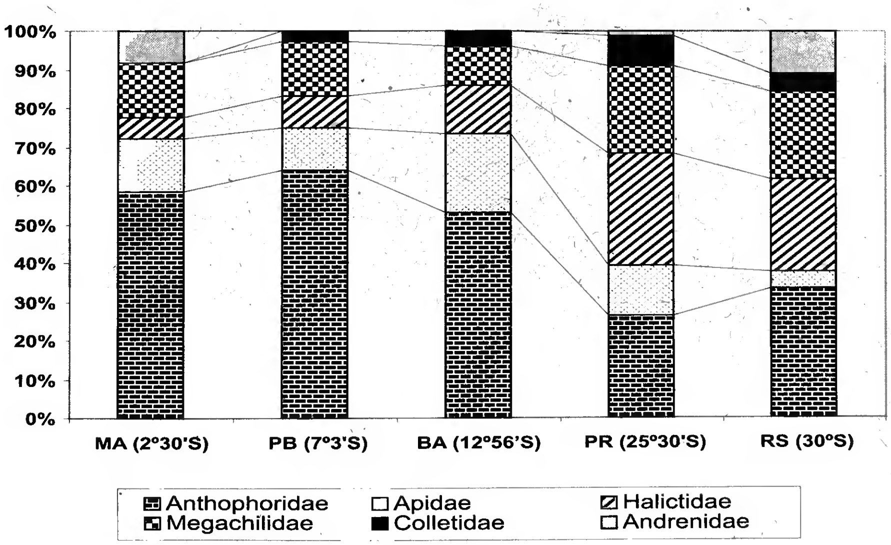
In Maranhão, the two surveyed areas were located near the city of São Luis (2°29'S/ 44°18'W and 2°30'S/ 44°17'W), reaching an altitude of 30 meters above sea level. The climate is hot, semi-humid with well defined dry and rainy seasons, annual mean temperature around 26,7°C and rainfall around 1950mm. Humidity is high almost all year round with an annual mean of about 81%.

In Bahia, the studied area is located in an Environmental Protected Area of the Abaeté Lagoon and Dunes (12°56'S /38°21'W), near Salvador, between 5 and 15 meters above sea level (Viana, in prep.). In Paraíba, the survey was undertaken in the restinga of the Praia de Intermares (7°3'S; 34°50'W), in the municipality of Cabedelo, 10 km from João Pessoa, at an altitude between 0 and 10 m above sea level (Madeira da Silva 1998). The climate in these two localities is hot and humid, with no dry season. Rainfall is highest from March to August. Annual mean temperatures range from 24° to 27°C and annual rainfall is around 2000 mm. umidity has an annual mean of 70-80%.

In Rio Grande do Sul, the surveys were conducted in the north littoral of the state (30°S; 50°-51°W). In Paraná, Zanella *et al.* (1998) surveyed 3 localities in the coastal plain of the state (25° 30'S; 48° 25'W). The climate in these two regions is temperate humid with rain distributed among all months of the year. The temperature in the warmer months is above 22°C and above 3°C in the colder months. Intense rainfall occurs in the summer, reaching 2000mm. In Rio Grande do Sul the relative humidity is higher in the winter (90%) and lower in December (75-85%).

Table 1 shows the list of species in the five localities. It is worth noting that the local bee fauna of Maranhão (São Luís), Bahia (Abaeté) and Paraíba (Cabedelo) are similar in number of species and in frequency of the familiy Apoidea (Fig. 1).

FIGURE 1. Variation in the taxonomic composition of the apifauna of coastal sand dunes of Brazil, summarized by number of species per family.



MA - Maranhão, PB - Paraíba, BA - Bahia, PR - Paraná, RS - Rio Grande do Sul

However, species composition is dissimilar among these areas, in spite of the fact that the vegetation physiognomies are similar. Between Abaeté and Cabedelo = 47%, between Abaeté and São Luís = 31% and between São Luís and Cabedelo = 36% (Sorensen coefficient of similarity). The composition of the Apifauna in these localities is influenced by neighbouring habitats and by the local variation in abiotic factors. It must also be related to the plant species composition, which varies widely at the species level among these areas, as may be seen in table 2. Anthophorinae and Xylocopinae are the two most represented groups in these three localities. According to the authors of these surveys, most species in these groups are local residents with several nests in the areas.

Bees of the tribes Melitomini (mainly in the genera *Ancyloscelis, Diadasina, Melitoma and Ptilothrix*) and Centridini (*Centris* and *Epicharis*) may be typical of open areas and sandy soils (important for their nest construction) in Rio Grande do Sul. Bees of the family Megachilidae are typical of and well distributed in the lowlands mainly in the South of Brazil, whereas this family is not very represented in the Northeastern region (Fig. 1). Halictidae presents a high number of species in south Brazil, and is the most diverse bee family at the coastal plain of Paraná. Andrenidae appears with small number of species in each of these localities, except in Rio Grande do Sul where many bees of the tribe Panurgini were recorded (table 1).

Dispersal of the Species

Because of the large North-South extension of the Brazilian coast, the dunes may serve as a corridor for the movement and dispersal of bee species. However, if there are geographic barriers (physical or thermal), such as the section of the coastal belt by mountains that reach the littoral, or large rivers, their dispersion may be discontinuous.

Because the dunes receive influences from and exchanges with neighbouring ecosystems to the West, some similarity may be expected among the groups on the contact areas or transition zones among the ecosystems.

Surveys undertaken with similar methods of collecting bees on flowers and with the record of different types of ecologically relevant information can result in rich sources of data for comparative studies. Also, similarity analysis of such data can bring some knowledge about the species diversity, relative abundance, dominance and structure of the community, and about the interactions among bees and plants and the partition of resources among the Apoidea.

For a complete biogeographic analysis of the Apoidea distribution on the dune ecosystem, a comparison between the bee fauna and the plants which are important for their survival in different latitudes would be interesting. Although 5000 km of the Brazilian coast are occupied by "restingas" and dunes, the flora and fauna of these ecosystems are still little studied.

The dunes are the most fragile environment among all ecosystems on the coast. The deleterious effects of human activities such as the rapid construction of houses and buildings, the taking away of sand, building roads and streets, commercial facilities and car traffic are marked in this environment. We provide our data from the fire sites as a record of what has been found. Clearly, much work and analysis is required to fully place our findings in this context of biogeography and conservation.

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Table 1. Bee species of coastal sand dunes in Brazil

Bee family	Bee species	MA (2°30'S)	PB (7°3'S)	BA (12°56'S)	PR (25°30'S)	RS (30°S)
ANDRENIDAE						
PANURGINAE						
CALLIOPSINI	*Acamptopoeum prinii* (Holmberg, 1884)	x			x	x
	Callonychium petuniae Cure & Wittmann, 1990					x
	Callonychium sp. 1					x
	Callonychium sp. 2					x
	Cephalurgus anomalus Moure & Lucas de Oliveria, 1962				x	
PANURGINI	*Anthrenoides meridionalis* (Schrottky, 1906)					x
	Anthrenoides micans Urban, 1995					x
	Panurgillus flavitarsis Schlindwein & Moure 1998					x
	Panurgillus hamatus Schlindwein & Moure 1998					x
	Panurgillus minutus Schlindwein & Moure 1998					x
	Panurgillus pereziae Schlindwein & Moure 1998					x
	Parapsaenythia paspalis (Schrottky, 1909)					x
	Parapsaenythia puncticutis (Vachal, 1909)					x
	Parapsaenythia serripes (Ducke, 1908)					x
	Protomelliturga turnerae (Ducke, 1907)	x				
	Psaenythia annulata Gerstaecker, 1868					x
	Psaenythia bergi Holmberg, 1884					x
	Psaenythia chrysorrhoea Gerstaecker, 1868					x
	Psaenythia collaris Schrottky, 1907					x
	Psaenythia demissa Holmberg, 1923					x
	Psaenythia quadrifasciata Friese, 1908					x
	Psaenythia sp. 2					x
OXAEINAE						
OXAEINI	*Oxaea austera* Gerstaecker, 1868					x
	Oxaea festiva Smith, 1854	x				
COLLETIDAE						
COLLETINAE						
COLLETINI	*Colletes petropolitanus* Delatorre, 1896			x	x	
	Colletes punctatissimus Schrottky, 1902					x
	Colletes rufipes Smith, 1879					x

Bee family	**Bee species**	**MA** **(2°30'S)**	**PB** **(7°3'S)**	**BA** **(12°56'S)**	**PR** **(25°30'S)**	**RS** **(30°S)**
PARACOLLETINI	*Bicolletes leucostoma* (Cockerell, 1917)					x
	Cephalocolletes isabelae Urban, 1995					x
	Hexantheda petuniae					x
	Hexantheda perissomera					x
	Niltonia virgilli Moure, 1964				x	
	Perditomorpha sp. 3					x
	Tetraglossula bigamica (Strand, 1910)					x
DIPHAGLOSSINAE						
CAUPOLICANI	*Ptiloglossa pretiosa* (Friese, 1898)					x
HYLAEINAE						
HYLAEINI	*Hylaeus* sp1		x			
	Hylaeus sp.1				x	
	Hylaeus sp.2				x	
	Hylaeus sp.3				x	
	Hylaeus sp.4				x	
	Hylaeus sp.5				x	
	Hylaeus sp.6				x	
	Hylaeus sp.7				x	
	Hylaeus sp.8				x	
	Hylaeus sp.9				x	
HYLAEINI	*Hylaeus* sp.10				x	
	Hylaeus sp.11				x	
XEROMELISSINAE	*Chilicola (Stenocelis) faviscapis* n. sp.			x		
HALICTIDAE						
HALICTINAE						
AUGOCHLORINI	*Augochlora (Augochl.) amphitrite* (Schrottky, 1909)				x	
	Augochlora (Augochlora) caerulior Cockerell, 1900				x	x
	Augochlora (Augochlora) dolichocephala (Moure, 1941)					x
	Augochlora flavipes n. sp. Moure, n.p.			x		
	Augochlora (Augochlora) cf nitidior					x
	Augochlora (Augochlora) aff. pyrgo				x	
	Augochlora obscuripes n. sp. Moure, n.p.			x		
	Augochlora (Augochlora) sp. 1				x	
	Augochlora (Augochlora) sp1		x			
	Augochlora (Augochlora) sp 2				x	
	Augochlora (Augochlora) sp 3				x	
	Augochlora (Augochlora) sp. 4					x
	Augochlora (Augochlora) sp 4				x	
	Augochlora (Augochlora) sp 5				x	
	Augochlora (Augochlora) sp 10					x
	Augochlora (Augochlora) sp 11					x
	Augochlora (Augochlora) sp. nov.					x
	Augochlora (Oxystoglossella) morrae (Strand, 1909)				x	

Bee family	Bee species	MA (2°30'S)	PB (7°3'S)	BA (12°56'S)	PR (25°30'S)	RS (30°S)
	Augochlora (Oxystoglossella) esox (Vachal, 1911)					x
	Augochlora (Oxystogl.) semiramis (Schrottky, 1910)					x
	Augochlora (Oxystoglossella) thalia Smith, 1879					x
	Augochlora (Oxystoglosella) sp. 4					x
	Augochlora (Oxystoglossela) sp. nov.					x
	Augochlora sp. 8					x
	Augochlorella sp.1				x	
	Augochlorella sp.	x				
	Augochlorella ephyra (Schrottky, 1910)				x	x
	Augochlorella michaelis (Vachal, 1911)				x	x
	Augochloropsis acis (Smith, 1879)					x
	Augochloropsis anisitsi (Schrotkky, 1908)					x
	Augochloropsis callichroa (Cockerell, 1900)			x		
	Augochloropsis caerulans (Vachal, 1903)					x
	Augochloropsis cleopatra (Schrottky, 1902)					x
	Augochloropsis cupreola (Cockerell, 1900)				x	x
	Augochloropsis cloera Moure, 1940				x	
	Augochloropsis cyanea (Schrotkky, 1901)					x
	Augochloropsis luderwaldti Moure, 1940				x	
	Augochloropsis multiplex (Vachal, 1903)				x	x
	Augochloropsis notophos sp1 (Vachal, 1903)		x			x
	Augochloropsis pandrosos (Schrotkky, 1909)					x
	Augochloropsis sympleres (Vachal, 1903)					x
	Augochloropsis terrestris (Vachal, 1903)					x
	Augochloropsis (Paraug.) euterpe (Holmberg, 1886)					x
	Augochloropsis (Paraug.) sparsilis (Vachal, 1903)					x
	Augochloropsis sp. 1				x	
	Augochloropsis sp 1			x		
	Augochloropsis sp. 2				x	
	Augochloropsis sp. 2				x	
	Augochloropsis sp. 4				x	
	Augochloropsis sp. 5				x	
	Augochloropsis sp. 6				x	
	Augochloropsis sp. 7				x	
	Augochloropsis sp. 8				x	
	Augochloropsis sp. 9				x	
	Augochloropsis sp. 10				x	
	Augochloropsis sp. 11				x	
	Augochloropsis sp. 12				x	
	Augochloropsis sp. 14					x
	Augochloropsis sp. 15					x
	Augochloropsis sp. nov.					x
	Halictus loureroi (Moure, 1941)					x

Bee family	**Bee species**	**MA (2°30'S)**	**PB (7°3'S)**	**BA (12°56'S)**	**PR (25°30'S)**	**RS (30°S)**
	Neocorynura (Neocorynura) atromarginata (Cockerell, 1901)				x	
	Neocorynura (Neocorynura) pseudocaccha (Cockerell, 1901)				x	
	Neocorynura sp.1				x	
	Neocorynura sp.2				x	
	Neocorynura sp.3				x	
	Pereirapis sp.				x	
	Paroxystoglossa jocasta (Schrottky, 1910)					x
	Pseudaugochloropsis graminea (Fabricius, 1804)				x	x
	Pseudoaugochloropsis pandora (Smith, 1853)	x		x		
	Temnosoma sp.				x	
	Thectochlora alaris (Vachal, 1904)				x	x
HALICTINI	*Agapostemon semimelleus* (Holmberg, 1884)				x	
	Coenohalictus incertus (Schrottky, 1902)				x	
	Dialictus (Chloralictus) opacus (Moure, 1940)		x	x	x	x
	Dialictus (Chloralictus) sp. 1				x	
	Dialictus (Chloralictus) sp. 2				x	x
	Dialictus (Chloralictus) sp. 2					x
	Dialictus (Chloralictus) sp. 3				x	
	Dialictus (Chloralictus) sp. 3					x
	Dialictus (Chloralictus) sp. 4					x
	Dialictus (Chloralictus) sp. 4				x	
	Dialictus (Chloralictus) sp. 5					x
	Dialictus (Chloralictus) sp. 5				x	
	Dialictus (Dialictus) sp. 2					x
	Dialictus (Rhynchalictus) rostratus (Moure, 1947)					x
	Pseudagapostemon (P.) arenarius (Schrottky, 1902)					x
	Pseudagapostemon (P.) brasiliensis Cure, 1989					x
	Pseudagapostemon (P.) pruinosus Moure & Sakagami, 1984					x
	Sphecodes sp.				x	
MEGACHILIDAE						
ANTHIDINAE						
ANTHIDINI	*Anthidium manicatum* (Linnaeus, 1758)				x	x
	Dicranthidium arenarium Ducke, 1907	x		x		
	Dicranthidium luciae Urban, 1992			x		
DIANTHIDINI	*Anthodioctes* sp. 1				x	
	Anthodioctes sp. 3				x	
	Epanthidium confusum (Smith, 1879)				x	x
	Epanthidium tigrinum (Schrottky, 1905)		x		x	x
	Hypanthidium flavomarginatum (Smith, 1879)				x	x
	Hypanthidium sp1		x			
	Larocanthidium emarginatum (Urban, 1997)		x			

Bee family	**Bee species**	**MA (2°30'S)**	**PB (7°3'S)**	**BA (12°56'S)**	**PR (25°30'S)**	**RS (30°S)**
MEGACHILINI	*Coelioxys (Acrocoelioxys) australis* Holmberg, 1886					x
	Coelioxys (Cyrtocoelioxys) quaerens Holmberg, 1903					x
	Coelioxys (Glyptocoelioxys) vidua Smith, 1854					x
	Coelioxys (Melanocoelioxys) tolteca Cresson, 1878					x
	Coelioxys (Rhinocoelioxys) zapoteca Cresson, 1878					x
	Coelioxys sp.1				x	
	Coelioxys sp.2				x	
	Coelioxys sp.3				x	
	Coelioxys sp.4				x	
	Coelioxys sp.5				x	
	Coelioxys sp.6				x	
	Coelioxys sp.7				x	
	Megachile (Acentrina) apicipennis Schrottky, 1902					x
	Megachile (Acentrina) moureana Mitchell, 1930					x
	Megachile (Acentrina) nigropilosa Schrottky, 1902					x
	Megachile (Acentrina) pampeana Vachal, 1909					x
	Megachile (Acentron) bernardina Schrottky, 1913					x
	Megachile (Acentron) lentifera Vachal, 1909					x
	Megachile (Acentron) limae Schrottky, 1913					x
	Megachile (Acentron) sp.1					x
	Megachile (Acentron) sp.1				x	
	Megachile (Archimegachile) sp. 1					x
	Megachile (Austromegachile) corona Mitchell, 1930				x	
	Megachile (Austromegachile) oligostticta Moure, 1955				x	
	Megachile (Austromegachile) trigonaspis Schrotkky, 1913				x	
	Megachile (Austromegachile) susurrans Haliday, 1836					x
	Megachile (Austromegachile) sp. 1				x	
	Megachile (Austromegachile) sp.2				x	
	Megachile (Austromegachile) sp.3				x	
	Megachile (Austromegachile) sp. 4				x	
	Megachile (Austromegachile) sp. 5				x	
	Megachile (Chaetochile) golbachi Schwimmer, 1980					x
	Megachile (Chrysosarus) sp. 1				x	
	Megachile (Chrysosarus) sp. 2				x	
	Megachile (Chrysosarus) sp. 3					x
	Megachile (Dactylomegachile) affabilis Mitchell, 1930				x	
	Megachile (Dactylomegachile) sp.1				x	
	Megachile (Grafella) crotalariae Mitchell, 1930					x
	Megachile (Leptorachis) aetheria Mitchell, 1930				x	x
	Megachile (Leptorachis) angularis Mitchell, 1930					x
	Megachile (Leptorachis) atritegulis Moure, in litt.					x

Bee family	Bee species	MA (2°30'S)	PB (7°3'S)	BA (12°56'S)	PR (25°30'S)	RS (30°S)
	Megachile (Leptorachis) cf beniensis Cockerell, 1927					x
	Megachile (Leptorachis) paulistana Schrottky, 1902				x	x
	Megachile (Leptorachis) tenuitarsis Schrottky, 1902					x
	Megachile (Leptorachis) sp1	x				
	Megachile (Leptorachis) sp2	x				
	Megachile (Leptorachis) sp. 4					x
	Megachile (Leptorachis) sp. 5					x
	Megachile (Leptorachis) sp. 6					x
	Megachile (Melanosarus) brasiliensis Dalla Torre, 1896 RS					x
	Megachile cf (Melanosarus) sp. 1					x
	Megachile (Neomegachile) sp.				x	
	Megachile (Neomegachile) sp. 1					x
	Megachile (Prionepist.) tuberculifera Schrottky, 1913					x
	Megachile (Pseudocentron) curviceps Smith, 1853				x	
	Megachile (Pseudocentron) electrum Mitchell, 1930					x
	Megachile (Pseudocentron) framea Schrottky, 1913					x
	Megachile (Pseudocentron) nudiventris Smith, 1853				x	x
	Megachile (Pseudocentron) pyrrogastra Cockerell, 1913				x	
	Megachile (Pseudocentron) terrestris Schrottky, 1902				x	x
	Megachile (Pseudocentron) sp. 1				x	
	Megachile (Pseudocentrum) sp1	x				
	Megachile (Pseudocentrum) sp2	x				
	Megachile (Pseudocentron) sp. 2				x	
	Megachile (Pseudocentrum) sp3	x				
	Megachile (Pseudocentron) sp. 3				x	
	Megachile (Pseudocentron) sp. 4				x	
	Megachile (Pseudocentron) sp. 10					x
	Megachile (Ptilosarus) sp.				x	
	Megachile (Sayapis) dentipes Vachal, 1909		x			x
	Megachile (Sayasis) obdurata Mitchell, 1930					x
	Megachile (Tylomegachile) orba Schrottky, 1913				x	
	Megachile (Willinkella) anthidioides Smith, 1853				x	
	Megachile (Willinkella) apicipennis Schrottky, 1902				x	
	Megachile (Willinkella) sp. 1				x	
	Megachile sp 1		x			
	Pseudocentrum (Pseudocentrum) leucomelaena n.sp.			x		
	Pseudocentrum (Pseudocentrum) leucosera n.sp.			x		
	Pseudocentrum (Pseudocentrum) xanthosera n.sp.			x		
ANTHOPHORIDAE						
ANTHOPHORINAE						
	Centris (Centris) aenea Lepeletier, 1841	x	x	x		

Bee family	Bee species	MA (2°30'S)	PB (7°3'S)	BA (12°56'S)	PR (25°30'S)	RS (30°S)
	Centris (Centris) caxiensis Ducke, 1907		x	x		
	Centris (Centris) flavifrons Fabricius, 1775	x	x	x	x	
	Centris (Centris) leprieuri Spinola, 1841	x	x	x		
	Centris (Centris) nitens Lepeletier, 1841		x	x		
	Centris (Centris) spilopoda Moure, 1969	x	x	x		
	Centris (Centris) varia (Erichson, 1948)				x	
	Centris (Hemisiella) sp1	x				
	Centris (Hemisiella) sp. 1					x
	Centris (Hemisiella) nigripes Friese, 1899					x
	Centris (Hemisiella) tarsata Smith, 1874	x	x	x	x	
	Centris (Hemisiella) trigonoides Lepeletier, 1841		x	x		
	Centris (Heterocentris) analis Lepetier, 1841				x	
	Centris (Melanocentris) atra Friese, 1899				x	
	Centris (Melanocentris) dorsata Lepeletier, 1841				x	x
	Centris (Melanocentris) fluviatilis Friese					
	Centris (Melanocentris) obsoleta Lepeletier, 1841					x
	Centris (Paracentris) burgdorfi Friese, 1900					x
	Centris (Paremisia) fuscata Lepeletier, 1841	x	x	x		x
	Centris (Paremisia) proxima Friese, 1899					x
	Centris (Paremisia) pulchra n.sp.			x		
	Centris (Paremisia) similis Fabricius , 1804				x	
	Centris (Ptilopus) sponsa Smith, 1854			x		
	Centris (Xanthemisia) lutea Friese, 1899			x		
	Epicharis (Anepicharis) dejeani Lepeletier, 1841				x	
	Epicharis (Xanthepicharis) bicolor Smith, 1854		x	x		
	Epicharis (Xanthepicharis) nigrita Friese, 1900			x		
	Epicharis sp.1				x	
CTENIOSCHELINI	*Mesocheira bicolor* (Fabricius, 1804)				x	
	Mesonychium asteria (Smith, 1854)	x	x			
	Mesonychium littoreum Moure, 1944			x		x
ERICROCIDINI	*Mesoplia rufipes* (Perty, 1833)	x			x	
	Mesoplia regalis (Smith)	x				
	Mesoplia sp 1		x			
	Mesoplia sp 1			x		
	Mesoplia sp 2			x		
EUCERINI	*Florilegus (Euflorilegus) festivus* (Smith, 1854)		x			x
	Florilegus (Euflorilegus) fulvipes (Smith, 1854)					x
	Florilegus (Euflorilegus) riparius Ogloblin, 1955					x
	Florilegus similis Urban, 1970		x	x		
	Gaesischia (Gaesischia) fulgurans (Holmberg, 1933)					x
	Gaesischia (Gaesischia) nigra Moure, 1948					x
	Gaesischia (Gaesischia) sparsa Brethes, 1910					x
	Gaesischia (Gaesischia) trifasciata Urban, 1968					x
	Melissodes (Ecplectia) nigroaenea (Smith, 1854)					x

Bee family	Bee species	MA (2°30'S)	PB (7°3'S)	BA (12°56'S)	PR (25°30'S)	RS (30°S)
	Melissodes (Ecplectia) sexcincta (Lepeletier, 1841)				x	
	Melissoptila (Comeptila) paraguayensis (Brethes, 1909)					x
	Melissoptila (Ptilomelissa) aureocincta Urban 1966				x	
	Melissoptila (Ptilomelissa) bonaerensis Holmberg, 1903					x
	Melissoptila (Ptilomelissa) claudii Urban 1998					x
	Melissoptila (Ptilomelissa) cnecomala (Moure, 1944)					x
	Thygater (Thygater) analis (Lepeletier, 1841)				x	x
	Thygater (Thygater) paranaensis Urban, 1967					x
EXOMALOPSINI	*Exomalopsis analis*	x				
	Exomalopsis aureopilosa Spinola, 1853					x
	Exomalopsis sp.1				x	
	Exomalopsis sp.2				x	
	Exomalopsis sp.3				x	
	Exomalopsis sp.4				x	
	Lanthanomelissa (L.) goeldiana (Friese, 1899)					x
	Paratetrapedia melanpoda Moure, 1948					x
	Paratetrapedia sp.1				x	
	Paratetrapedia sp.2				x	
	Paratetrapedia sp.3				x	
	Paratetrapedia sp.4				x	
	Tapinotaspis (Tapinotaspoi.) pernigra (Schrottky, 1920)					x
	Tapinotaspis (Tapinotaspoi.) tucumana (Vachal, 1904)					x
	Tapinotaspoides sp.				x	
MELITOMINI	*Ancyloscelis apiformis* (Fabricius, 1793)	x				x
	Ancyloscelis sp.				x	
	Ancyloscelis fiebrigi (Brethes, 1909)					x
	Ancyloscelis gigas Friese, 1904					x
	Ancyloscelis turmalis Vachal, 1904					x
	Ancyloscelis ursinus Haliday, 1837					x
	Diadasina distincta (Holmberg, 1903)					x
	Diadasina riparia (Ducke, 1907)					x
	Diadasina sp	x				
	Melitoma segmentaria (Fabricius, 1804)	x				x
	Melitoma sp.				x	
	Melitoma sp. 1					x
	Ptilothrix fructifera (Holmberg, 1903)					x
	Ptilothrix plumata Smith, 1853	x				
	Ptilothrix relata (Holmberg, 1903)					
RHATHYMINI						
TETRAPEDINI	*Tetrapedia diversipes* Klug, 1810					x
	Tetrapedia rugulosa Friese, 1899					x

Bee family	**Bee species**	**MA** (2°30'S)	**PB** (7°3'S)	**BA** (12°56'S)	**PR** (25°30'S)	**RS** (30°S)
NOMADINAE						
ISEOPEOLINI	*Leiopodus* sp.				x	
	Psilepeolus sp. nov.					x
	Trophocleptria sp.				x	
NOMADINI	*Nomada* sp.				x	
PROTOEPEOLINI	*Nomadinae* (gen. nov. / sp. nov.)					x
XYLOCOPINAE						
CERATININI	*Ceratina asunciana* Strand, 1910					x
	Ceratina correntina Schrottky, 1907					x
	Ceratina (Calloceratina) chloris (Fabricius, 1804)				x	x
	Ceratina (Crewella) asuncionis Strand, 1910					x
	Ceratina (Crewella) maculifrons Smith, 1844	x			x	x
	Ceratina (Crewella) paraguayensis (Schrottky, 1907)		x			x
	Ceratina (Crewella) rupestris (Holmberg, 1884)					x
	Ceratina (Crewella) sp. 1		x		x	
	Ceratina (Crewella) sp. 2				x	
	Ceratina (Rhyzoceratina) stilbonota Moure, 1941					x
	Ceratina (Rhyzoceratina) volitans Schrottky, 1907					x
	Ceratina sp. 1				x	
	Ceratina sp.2				x	
	Ceratina sp. nov.					x
	Ceratinula pirifera n.sp.			x		
	Ceratinula sclerops (Schrottky, 1907)					x
	Ceratinula transcincta n.sp.			x		
	Ceratinula sp1		x			
	Ceratinula sp1	x				
	Ceratinula sp. 1				x	
	Ceratinula sp. 2				x	
	Ceratinula sp2		x			
	Ceratinula sp2	x				
	Ceratinula sp. 3				x	
	Ceratinula sp. 4				x	
	Ceratinula sp. 5				x	
	Ceratinula sp. n.	x				
XYLOCOPINI	*Xylocopa (Megaxylocopa) frontalis* (Olivier, 1789)	x	x	x	x	x
	Xylocopa (Neoxylocopa) augusti Lepeletier, 1841					x
	Xylocopa (Neoxyloc.) brasilianorum (Linnaeus, 1767)				x	x
	Xylocopa (Neoxylocopa) carbonaria Smith, 1854	x				
	Xylocopa (Neoxylocopa) cearensis Ducke, 1910	x	x	x		
	Xylocopa (Nanoxylocopa) ciliata Burmeister, 1876					x
	Xylocopa (Neoxylocopa) grisescens Lepeletier, 1841		x	x		
	Xylocopa (Neoxylocopa) nigrocincta Smith, 1854			x		x
	Xylocopa (Neoxylocopa) orthogonaspis Moure	x				

Bee family	**Bee species**	**MA** **(2°30′S)**	**PB** **(7°3′S)**	**BA** **(12°56′S)**	**PR** **(25°30′S)**	**RS** **(30°S)**
	Xylocpa (Neoxylocopa) suspecta Moure & Camargo, 1988		x	x		
	Xylocopa (Schoenherria) varians (Smith, 1874)					x
	Xylocopa (Schoenherria) macrops (Lepeletier, 1841)				x	x
	Xylocopa (Schoenherria) muscaria (Fabricius, 1775)	x	x			
	Xylocopa (Schoenherria) prov. subcyanea Pérez, 1901			x		
	Xylocopa (Stenoxylocopa) artifex Smith, 1874					x
	Xylocopa (Xylocospila) bambusae Schrottky, 1902					x
APIDAE						
APINAE						
APINI	*Apis mellifera* Linnaeus, 1758	x	x	x		x
BOMBINAE						
BOMBINI	*Bombus (Fervidobombus) atratus* Franklin, 1913				x	x
	Bombus (Fervidobombus) brasiliensis Lepeleiter, 1836				x	
	Bombus (Fervidobombus) morio (Swederus, 1787)			x	x	x
EUGLOSSINI	*Euglossa cordata* (Linnaeus, 1758)	x	x	x		x
	Euglossa cyanozoma (Dressler, 1982)				x	
	Euglossa sp.1				x	
	Eufriesea surinamensis (Linnaeus, 1758)	x				
	Eulaema (Apeulaema) nigrita Lepeletier, 1841	x	x	x	x	
	Eulaema meriana flavescens Friese, 1899			x		
	Euplusia dentilabris Mocsäry, 1897				x	
	Euplusia hatchbachii Moure				x	
	Euplusia mussitans Fabricius, 1787			x		
	Euplusia violacea					x
MELIPONINAE						
MELIPONINI	*Melipona marginata* Lepeletier, 1836				x	
	Melipona marginata obscurior Moure, 1971					x
TRIGONINI	*Cephalotrigona capitata* (Smith, 1854)				x	
	Frieseomellita doederleini (Friese, 1900)			x		
	Frieseomellita silvestri languida Moure, 1989			x		
	Mourella caerulea Friese, 1900					x
	Nannotrigona testaceicornis Lepeletier, 1836				x	
	Oxytrigona tataira (Mueller, 1874)				x	
	Partamona helleri				x	
	Plebeia droryana (Friese, 1900)				x	
	Plebeia remota (Holmberg, 1903)				x	
	Plebeia emerina (Friese, 1900)					x
	Scaptotrigona xanthotricha Moure, 1950				x	
	Scaura latitarsis (Friese, 1900)				x	
	Tetragonisca angustula (Smith, 1863)				x	
	Trigona fulviventris guianae Cockerell, 1910				x	
	Trigona fuscipennis Friese, 1900				x	

Bee family	Bee species	MA (2°30'S)	PB (7°3'S)	BA (12°56'S)	PR (25°30'S)	RS (30°S)
	Trigona spinipes (Fabricius, 1793)		x	x	x	x
	Trigonisca sp 1			x		
Number of bee species		**42**	**36**	**49**	**164**	**187**

Table 2. Bee plants species of coastal sand dunes in Brazil

Plant family	Plant species	MA (2°30'S)	PB (7°3'S)	BA (12°56'S)	PR (25°30'S)	RS (30°S)
ACANTHACEAE	*Justicia brasiliana Roth*					x
ALISMATACEAE	*Echinodorus grandiflorus (Cham. et Schlecht.) Micheli*					x
AMARANTHACEAE	*Alternanthera philoxeroides (Mart.)Griseb.*					x
	Philoxerus portulacoides St.Hil.					x
AMARYLLIDACEAE	*Crinum Habranthus salsum Rav.*				x	
ANACARDIACEAE	*Anarcardium occidentalle L.*		x			
	Schinus terebinthifolius Raddi.				x	
	Tapirira guianensis Aubl			x	x	
APIACEAE	*Eryngium nudicaule Lam.*					x
APOCYNACEAE	*Catharanthus roseus (L.) G. Don*				x	
	Forsteronia leptocarpa Hoker et Arnot				x	
	Mandevilla funiformis (Vell) K. Schum.			x		
	Temnadenia stellaris (Lindl.) Miers				x	
ARACEAE	*Anthurium longipes Schott*			x		
ARECACEAE	*Allagoptera brevicalyx M. Moraes*			x		
	Syagrus romanzoffianum Cham.				x	
ASCLEPIADACEAE	*Ditassa blanchetti Decne*			x		
	Oxypetalum banksii Roem. & Schult.				x	
ASTERACEAE	*Acanthospermum australe (Loefling) Kuntze*				x	
	Achyrocline satureioides (Lam.)DC.				x	x
	Aspilia pascaloides Griseb.					x
	Ageratum conyzoides L.				x	
	Baccharis cassinifolia DC.				x	
	Baccharis dracunculifolia DC.				x	
	Baccharis erioclada DC				x	
	Baccharis pseudovillosa Teodoro					x
	Baccharis semiserrata DC.				x	
	Baccharis trimera (Less.) DC.				x	
	Baccharis sp 1				x	
	Baccharis sp2				x	
	Baccharis sp 3				x	
	Baccharis sp 4				x	
	Bidens pilosa L.				x	
	Centratherum punctatum Cassini				x	

Plant family	**Plant species**	**MA** (2°30'S)	**PB** (7°3'S)	**BA** (12°56'S)	**PR** (25°30'S)	**RS** (30°S)
	Conocliniopsis prasiifolia (DC) K & R			x		
	Conyza sp. 1				x	
	Conyza sp. 2				x	
	Elephantopus mollis H.B.K.				x	x
	Erechthites valerianaefolia (Wolf)DC.					x
	Emilia sonchifolia (DC) Benth.				x	
	Enhydra sessilis DC				x	
	Erechthites valerianaefolia (Wolf)DC.				x	
	Eupatorium betonicaeforme Baker				x	
	Eupatorium inulaefolium H.B.K.				x	
	Eupatorium vautherianum DC				x	
	Eupatorium sp. 1				x	
	Eupatorium sp. 2				x	
	Eupatorium sp.3				x	
ASTERACEAE	*Eupatorium sp.4*				x	
	Hypochoeris rosengusti					x
	Mikania campanulata Gardner				x	
	Mikania micrantha H.B.K.	x			x	x
	Mikania nitida (DC) King & Robinson			x		
	Mikania sp. 1				x	
	Mikania sp. 2				x	
	Mikania sp. 3				x	
	Noticastrum gnaphalioides (Bak.) Cuatr.					x
	Orthopappus augustifolius (Sw.) Gleason				x	
	Pluchea sagittalis (Lam.)Cabr.					x
	Porophyllum ruderale (Jacquin) Cassini				x	
	Pterocaulon alopecuroideum DC.				x	
	Senecio brasiliensis (Spreng.) Less.				x	x
	Senecio crassiflorus (Poir.) DC.					x
	Senecio leptolobus DC.					x
	Senecio sp				x	
	Solidago microglossa DC				x	
	Spilanthes decumbens (Smith)A.H.More					x
	Spilanthes stolonifera DC.					x
	Stilpnopappus scaposus DC			x		
	Symphyopappus cuneatus DC				x	
	Tagetes minuta L.				x	x
	Vernonia arenaria Mart.	x		x		
	Vernonia beyrichii Lessing				x	
	Vernonia cognata Lessing, L.					x
	Vernonia constricta Matzenbacher et Mafioleti					x
	Vernonia edmundoi Barroso			x		
	Vernonia flexuosa Sims.					x
	Vernonia tweediana Baker					x

Plant family	**Plant species**	**MA** (2°30'S)	**PB** (7°3'S)	**BA** (12°56'S)	**PR** (25°30'S)	**RS** (30°S)
	Vernonia scorpioides (Lamarck) Persoon				x	
	Vernonia sp.1				x	
	Vernonia sp.2				x	
	Wedelia paludosa DC				x	
	Wulffia baccata (Lf.) O. Kuntze	x				
BIGNONIACEAE	*Arrabidaea brachypoda (DC) Bur.*					
	Jacaranda puberula Cham.				x	
	Tabebuia elliptica (dc.) SANDW.		x	x		
BORAGINACEAE	*Cordia curassavica DC.*				x	
	Cordia verbenacea DC.					x
	Heliotropium clausenii Dc.		x			
	Heliotropium polyphylium Lenn.	x				
BROMELIACEAE	*Aechmea sp*			x		
	Hohembergia ramageana Mez		x			
BURCERACEAE	*Protium bahianum Daly*			x		
	Protium heptaphylum (Aubl.) March.	x				
	Protium icicariba DC March			x		
CACTACEAE	*Cereus pernanbucensis Hort. Wuerzb ex Pfeiffer*		x			
CAESALPINIACEAE	*Cassia occidentalis L.*					x
	Chamaecrista (Cassia) hispidula Vahl. Irwin & Barneby	x				
	Chamaecrista flexuosa (L.) Greene	x				
	Chamaecrista ramosa (Vog.) I & B var ramosa		x	x		
	Moldenhawera nutans Queiroz & Allkin n. p.			x		
CALYCERACEAE	*Acicarpha spathulata R. Br.*				x	
	Acicarpha tribuloides Jussieu					x
CAPPARACEAE	*Capparis flexuosa L.*		x			
	Dactylaena microphylla Eichl			x		
CLUSIACEAE	*Kielmeyera argentea Choisy*			x		
COMBRETACEAE	*Laguncularia racemosa Gaertner f.*				x	
	Terminalia catappa L.				x	
COMMELINACEAE	*Commelina elegans H.B.K.*				x	
	Commelina cf. Virginica L.	x			x	
CONVOLVULACEAE	*Evolvulus sp*			x		
	Ipomoea cairica (L.) Sweet				x	x
	Ipomoea litoralis (L.) Choysi	x				
	Ipomoea longicuspis Meissn.				x	
	Ipomoea mauritiana Jacq.	x				
	Ipomoea pes-caprae (L) R. Brow	x			x	
	Ipomoea sp.1				x	
	Ipomoea sp.2				x	
	Ipomoea sp.3				x	
	Merremia dissecta (Jacq.) Hall.				x	
	Merremia aegyptia (L.) Hallier	x				

Plant family	Plant species	MA (2°30'S)	PB (7°3'S)	BA (12°56'S)	PR (25°30'S)	RS (30°S)
CRUCIFERACEAE	*Lepidium virginicum L.*				x	
CURCUBITACEAE	*Cucurbita pepo L.*				x	
CYPERACEAE	*Carex sp*				x	
	Cyperus sesquiflorus (Torrey)Mattf.et Kükenth.					x
	Fimobristylis sp.				x	
ERICACEAE	*Agaristha revoluta (Spr.) DC*			x		
	Rhododendrom sp. 1				x	
ERIOCALACEAE	*Eriocaulon modestum Kunth*					x
EUPHORBIACEAE	*Croton glandulosus L.*				x	
	Croton cf. helichrysum Baillon					x
	Croton migrans Casaretto					x
	Dalechampia scandens L.		x			
	Euphorbia gymnnoclada Boiss.			x		
	Phyllanthus niruri L.				x	
	Ricinus communis L.				x	
FABACEAE	*Adesmia latifolia (Spreng.) Vogel, L.*					x
	Acosmium bijugum (Vog.) Yakovl			x		
	Canavalia maritima Piper				x	
	Canavalia rosea L.	x				
	Centrosema brasilianum (L.) Benth	x	x	x		
	Centrosema coriaceum			x		
	Centrosema pubescens Benth	x				
	Centrosema virginianum (L.) Benth.					x
	Centrosema sp	x				
	Clitoria cajanifolia Benth	x				
FABACEAE	*Crotalaria mucronata Desv.*				x	
	Crotalaria pallida Ait.		x			
	Crotalaria retusa L.	x				
	Desmodium adscendens (Sw.) DC.				x	x
	Desmodium incanum DC.				x	
	Desmodium sp.				x	
	Galactia jussiaeana H.B.K.	x				
	Indidigofera hirsuta L.	x				
	Indigofera suffruticosa				x	
	Macroptilium atropurpureum Urb	x				
	Poecilanthe itapuana GP Lewis			x		
	Sesbania punicea (Cav.)Bentham					x
	Sophora tomentosa L.		x			
	Stilosanthes viscosa Sw			x		
	Stylosanthus viscosa Swartz				x	
	Swartla apetala Raddi var. subcordata Cowan			x		
	Tephrosia cinerea (L.) Pers.		x			
	Vigna halophila (Piper) Maréchal, Mascherpa & Stainier			x		

Plant family	Plant species	MA (2°30′S)	PB (7°3′S)	BA (12°56′S)	PR (25°30′S)	RS (30°S)
	Vigna luteola (Jacq.)Benth.				x	x
	Vigna peduncularis (Kunth) Fawa et Rendle		x			
	Zornia curvata Mohl.	x				
GRAMINAE	*Echnoclea crus-galli L.*				x	
	Paspalum conjugatum Berg.				x	
HUMIRIACEAE	*Humiria balsamifera (Aubl) St. Hil. var. parvifolia (Juss) Cuatr*			x		
ICACINACEAE	*Emmotum affine Miers*			x		
KRAMERIACEAE	*Krameria bahiana B B Simpson*			x		
LAMIACEAE	*Eriope blanchetti (Benth) R Harley*			x		
	Glechon marifolia					x
	Hyptis fasciculata Benth.				x	
	Hyptis lacustris St. Hill ex. Benth.				x	
	Hyptis mutabilis (Rich) Briquet					x
	Marsvianthes chamaedris (Vahl.) Ktze.				x	
	Marsypianthes hyptoides Mart. Ex Benth	x				
	Ocinum cf. selloi Bentham					x
LAURACEAE	*Aiouea saligna Meissner*				x	
	Cassytha americana L.		x			
	Ocotea notata Miers			x		
LECYTHIDACEAE	*Gustavia augusta L.*	x				
LILIACEAE	*Cordyline terminalis (Kunth)*				x	
	Hypoxis decumbens L.				x	
LORANTHACEAE	*Strutanthus flexicaulis Mart.*			x		
	Struthanthus polyrhizus Mart.			x		
LYTHRACEAE	*Cuphea branchiata Koehne*			x		
	Cuphea calophylla Cham. et Schlecht.				x	
	Cuphea flava Spreny		x			
	Cuphea mesostemon Koehne				x	
MALPIGHIACEAE	*Byrsonima gardneriana Juss.*		x			
	Byrsonima coccolobifolia (Spreng.) Kunth			x		
	Byrsonima microphylla A. Juss			x		
	Byrsonima sericea DC			x		
	Stigmaphyllon paralias A. Juss			x		
	Stigmatophyllum ciliatum Lam.				x	
	Tetrapterys sp	x				
MALVACEAE	*Hibiscus pernambucensis (Bertoloni) Johnston*				x	
	Hibiscus sp				x	
	Malvaviscus arboreus Cav.				x	
	Pavonia cancellata Cav.	x				
	Sida carpinifolia L.f.				x	x
	Sida cordifolia L.				x	
	Sida rhombifolia L.				x	x
	Sida sp				x	

Plant family	Plant species	MA (2°30'S)	PB (7°3'S)	BA (12°56'S)	PR (25°30'S)	RS (30°S)
	Urena lobata L.				x	
MELASTOMATACEAE	*Comolia ovolifolia DC Triana*			x		
	Leandra australis (Cham.) Cogn.				x	
	Pterolepis aglomerata Rottb&Mig.				x	
	Pterolepsis edmundoi Brade & Markgraf			x		
	Tibouchina clavata (Persoon) Wurdack				x	
	Tibouchina gracilis (Bonpl.) Cogn.					x
	Tibouchina multiceps Cogn.				x	
	Tibouchina pulchra Chamisso				x	
	Tibouchina sellowiana (Cham.)				x	
	Tibouchina urvilleana (DC:) Cogn.				x	x
MELIACEAE	*Melia azedarach L.*					x
MIMOSACEAE	*Abarema filomentosa (Benth) Piltifer*			x		
	Inga edulis Mart.				x	
	Mimosa diplotricha Wrigth	x				
	Mimosa somnians Humb. & Bonpl. Ex. Willd		x			
MYRTACEAE	*Calycolpus legrandii Mattos*			x		
	Eugenia pistaciifolia DC			x		
	Myrcia sp1			x		
	Myrcia sp2			x		
	Myrcia panniculata (H.B.K.) Kz. Et Chb.		x			
	Psidium cattleayanum Sab.				x	
	Psidium guayava Raddi				x	
OCHNACEAE	*Ouratea rotundifolia (Gardn.) Engl.*			x		
ONAGRACEAE	*Ludwigia caparosa (Camb.) Hara*					x
	Ludwigia elegans (Camb.) Hara					x
	Ludwigia leptocarpa (Nutt.) Hara					x
	Ludwigia longifolia (DC.)Hara					x
	Ludwigia peploides (Kunth) Raven					x
	Ludwigia peruviana (L.) Hara					x
	Ludwigia suffruticosa L.				x	
	Ludwigia uruguayensis					x
PAPILIONACEAE	*Erythrina crista-galli L.*					x
PASSIFLORACEAE	*Passiflora edulis Sims*			x	x	
	Passiflora foetida	x				
	Passiflora jileki Wawra				x	
PHYTOLACACEAE	*Microteca scabrida Urban*					x
POLYGALACEAE	*Polygala cyparissias St. Hilaire & Moquin*	x			x	
	Polygala laureola St. Hil. & Moq				x	
	Polygala monticola H.B.K.	x				
	Polygala psomophila Chod. & Hub.			x		
	Polygala sp			x		
POLYGONACEAE	*Antigonon leptotus Hook & Arn*				x	

Plant family	Plant species	MA (2°30'S)	PB (7°3'S)	BA (12°56'S)	PR (25°30'S)	RS (30°S)
	Coccoloba arborescens (Vell) How.		x			
	Coccoloba cordifolia Meier			x		
	Coccoloba ramosissima Wedd			x		
	Polygonum punctatum var. aq Elliot				x	x
PONTEDERIACEAE	*Pontederia lanceolata L.*					x
PORTULACACEAE	*Talinum sp.*	x				
RHAMNIACEAE	*Rhamnus sp.*				x	
ROSACEAE	*Rubus urticaefolius Poir*				x	
	Rubus rosifolius Sm.				x	
RUBIACEAE	*Alibertia sp*			x		
	Borreria cymosa Cham. & Schlecht.			x		
	Borreria latifolia Schum				x	
	Borreria verticillata (L) G F W Meye	x	x	x	x	
	Borreria sp			x		
	Chiococca alba (L.)				x	
	Diodia apiculata (R.et S.) Schum.					x
	Diodia radula (R. et S.) Cham. et Schlecht.				x	
	Guettarda platypoda D C		x	x		
	Mitracarpus discolor Miq.		x			
	Richardia brasiliensis Gomez.				x	
	Rudgea villiflora K. Schum.				x	
	Tocoyena sellowiana (Cham. Et Schlecht.) K. Schum		x			
RUTACEAE	*Citrus medica L.*				x	
SAPINDACEAE	*Cardiospermum integerrimum Radlk*			x		
	Dodonaea viscosa (L.) Jacquin				x	
	Paullinia trigonia Vell.				x	
	Pseudima fritescens Radlk.	x				
SAPOTACEAE	*Manilkara salzmanni (DC) H J Lam.*			x		
SCROPHULARIACEAE	*Bacopa tweedii (Benth.) Parodi*					x
	Achetaria ocynoides C.et S.Wetts				x	
	Scoparia dulcis L.		x			
SMILACEAE	*Smilax campestris Griseb.*				x	
SOLANACEAE	*Physalis neesiana Sendtn.*				x	
	Solanum cf. Micrathum Britton.	x				
	Solanum paludosum Moric		x			
	Solanum paniculatum L.		x			
	Solanum sisymbriifolium Lam.					x
	Solanum stagnale Moric			x		
STERCULIACEAE	*Waltheria cinerescens St. Hil.*			x		
	Waltheria indica L.		x			
SYMPLOMEACEAE	*Symplocus sp*				x	
THEACEAE	*Ternstroemia sp*			x		

Plant family	Plant species	MA (2°30'S)	PB (7°3'S)	BA (12°56'S)	PR (25°30'S)	RS (30°S)
TILIACEAE	*Triumfetta semitriloba L.*					
TURNERACEAE	*Turnera melochioides Camb. Var. arenaria Spruce ex. Urb.*	x				
TURNERACEAE	*Turnera ulmifolia L.*	x	x			
VELLOZIACEAE	*Vellozia dasypus L B Smith*			x		
VERBENACEAE	*Glandularia selloi (Spreng)Tronc.*					x
	Lantana camara L.			x	x	
	Stachytarpheta cayennensis (L.C.Richard)Vahl				x	
	Verbena montevidensis Spreng.					x
	Vitex cymosa Benth			x		
	Vitex megapotamica					x
VIOLACEAE	*Hybanthus sp*				x	
ZINGIBERACEAE	*Hedychium coronarium Koenig*				x	
Number of bee plant families and plants visited by bees		**22/33**	**21/29**	**39/66**	**44/140**	**26/62**

Table 3. Number of bee species per family found in the Brazilian dunes.

Bees \Costal sand dunes	MA (2°30'S)	PB (7°3'S)	BA (12°56'S)	PR (25°30'S)	RS (30°S)
Anthophoridae	21	23	26	43	61
Apidae	5	4	10	21	9
Halictidae	2	3	6	48	46
Megachilidae	5	5	5	37	41
Colletidae	0	1	2	13	9
Andrenidae	3	0	0	2	21
Total	**36**	**36**	**49**	**164**	**187**

BEE POLLINATORS INTRODUCED TO CHILE: A REVIEW

Luisa Ruz

ABSTRACT

This paper describes and analyzes the various bee species that over the years have been introduced into Chile for pollination purposes, and have colonized different geographical areas of the country. It calls attention to the need for evaluation of the impact of each species in its new Chilean envinronment, and also emphasizes that studies of ecological consequences should be conducted prior to planned bee introductions anywhere.

INTRODUCTION

Numerous countries have improved their orchard and crop yields by using and managing colonies of *Apis mellifera* L., but, in some cases, better results have been obtained working with more specialized bees to pollinate alfalfa, clover, and tomatoes. Information about the subject has been documented by an extensive literature by numerous authors, which will be analyzed here only to the extent necessary for explaining particular situations relevant to those in Chile.

In Chile, several bee species have been introduced for commercial purposes to increase the yield of seeds, as well as to improve production or increase the quality of fruits in tree orchards and cultivated crops. The history of these pollinators is described and analyzed in this paper. Especially important is the need to find out the current status of these pollinators since they were introduced.

This review concentrates on specialized literature that covers the *Apis* and non-*Apis* pollinators introduced into Chile mainly over the last 35 years. *Apis mellifera*, which will also be discussed, became established in the early 19th century.The analysis of the bee pollinators focus on: 1) their distributional spread after their establishment; 2) the probable environmental impact they may have achived over the years; 3) their pollination success on target or non – target plants; 4) prospective needs for a modified legislation concerning the introduction of foreign bees; 5) an educational approach about the problem at various levels; 6) the need for more studies to evaluate risks of foreign introductions.

An important goal for this presentation is also to promote a discusion about the potential impact of the introduced bee pollinators , which should be studied previous to the introductions being planned.

Bee Introductions: An Historical Overview

Apis mellifera - Concern over bee introduction for pollination purposes began in Chile more than one hundred years ago with *Apis mellifera*, the bee species most easily managed and widely distributed over the world. It was established in Chile in 1848, and since then, has been commonly used to improve pollination and as a valuable honey producer.

Fruit trees such as apple , apricot, peach, plum, pear, and avocado, have shown increased fruit set by placing honey bee hives near the flowering plants. Honey bees can also be directed to target crops. By using chemical attractants, as proposed by Jay (1986), the bees are attracted to some crops and this promotes cross-pollination to set seeds.

In Southern Chile, spraying with Beeline and lavander on *Rubus idaeus* (raspberries) had no positive effects on the fruit characteristics (Neira *et al.* 1994), but BeeScent increased the number of visits and time spent on raspberry flowers by honey bees (Neira *et al.* 1997). In other studies, the use of Beeline and Beescent in pear orchards increased the number of visiting bees, but no differences in fruit set resulted (Neira *et al.* 1996) . In central Chile, however, better results have been obtained using a product (C 598) on Fuerte avocado cultivars. Applications of this product increased the fruit set by 40 % (Apablaza 1981).

The number of hives used to increase pollination by bees in crops has been based mainly on the experience of other countries, and varies according to: flowering time, number of flowers, floral color and structure, nearby orchards, floral rewards and other factors. Avocado flowers, among the trees mentioned above, are on of the least attractive to the honey bee according to Vithanage (1990), even though he states, studies in Australia, the honey bee plays a leading role in avocado pollination, and that providing three hives per hectare at flowering time significantly improved fruit set.

Flowers of the raspberry in southern Chile were visited by the following insect taxa in addition to *A. mellifera* as reported by Neira *et al.* (1997): 4 species of Coleoptera, 7 species of Diptera and 11 species of Hymenoptera, most of them bees (Apoidea). Two species of bumble bee were reported; the native *Bombus dahlbomii* and the introduced *B. ruderatus*. In addition, 7 species of solitary bee; *Manuelia gayi* and *M. postica* (Anthophoridae), *Cadeguala albopilosa* and *C. occidentalis* (Colletidae), *Corynura chloris*, *Ruizantheda proxima* and *Dialictus* sp. (Halictidae) were reported.

In the desert region of northern Chile, Pampa del Tamarugal, *A . mellifera* is one of the few species that might play an important role in the pollination of mesquite (*Prosopis*) (Toro *et al.*1993). Studies looking at feral and managed colonies indicated that they transport the pollen mostly from *P. tamarugo*. The presence of pollen on the head and sternal area of the individuals makes them potentially good pollinators of this plant species (Toro *et al.* 1992). Honey bees, however, because of their careful and slow movement amoung flowers of the same inflorescence, are less efficient than the native bee, *Centris mixta* (Anthophoridae), which rapidly explores a greater number of flowers (Toro *et al.* 1993). The introduction of honey bees for commercial apiculture into this particular geographic region does not seem to be advantageous. A low percentage of individuals from either feral or managed colonies carry complete loads of pollen on their corbicula (Toro *et al.* 1992). In addition, honey bees in this area of the country may be detrimental to native bees that pollinate *Prosopis*, by competing for the limited food resource (Toro 1986a).

Colonies of *A. mellifera* have also been introduced to Quillagua in northern Chile. More than ten years ago, before their introduction into this region, the insect fauna collected in alfalfa fields showed a high species diversity in relation to the size of the area . Some of the species were native bee pollinators responsible for seed production. More recent field observations in this area at the same time of the year indicated that plots of alfalfa where no production of seeds was observed, were visited almost exclusively by honey bees (Ruz, personal observations). As a result of this new situation, several questions can be raised: Does this mean that there is competition between honey bees and native bees? If not, why are native bees not visiting, nor pollinating the alfalfa now? Do the local farmers who encouraged the honey bee introduction to that area have the required undertanding of bee behaviour and its relation with the flowering plants? And, how do environmental conditions affect this behaviour?These are all are questions that need to be answered.

Differences in bee diversity have also been observed in other geographic areas of north central Chile, depending on the presence or absence of honey bees. In Incahuasi, a small isolated area close to La Serena where honey bees are not present, *Geoffreae decorticans* (Papilionaceae) is pollinated by several species of native bees (Anthophoridae,Colletidae and Halictidae). In locations near larger towns, however, the same plant species is visited only by the European honey bee.

Most of the Chilean desert areas already mentioned, are isolated and small, maintain a very few insect fauna and are not invaded by species from other regions.This is an important fact, because it is possible easy to detect changes in the ecosystem when they occur, and evaluate the impact that any foreign species may have when introduced into a new environment .

Some authors have reported that honey bees are poor pollinators when foraging in alfalfa and red clover crops (Bohart 1952; Westerkamp 1991).

Westerkamp (1991) explains that honey bees are poor pollinators because colonies are long-lived and are not adapted to any species of flower. Innate behaviour does not exist, so foragers have to learn how to handle the flowers through trial and error. After learning they prefer to reach the nectar in the shortest way possible, without contacting the plants reproductive elements so becoming inefficient pollinators. On the other hand, the nectar collecting-bees "learn" to avoid tripping flowers, but trip 7 to 85 % during the learning process (Tucker 1956). Trial and error, at least during this period apparently would favour pollination, and as Roubik (1989) notes "a good pollinator is often one that makes mistakes". Considering this fact, it would be important to use a significant number of new colonies for alfalfa pollination (McGregor 1976) . This is one of the most effective strategies used to pollinate crops with honey bees.

Observations made by Bohart (1952) in Utah indicate that in alfalfa, most honey bee nectar gatherers "steal" the nectar from deep nectaries by perforating the corolla without tripping the pollination mechanism. They are poorly equipped to be efficient pollinators. Alfalfa pollen is not its preferred food source of honey bees so pollination may occur, but only if they are present in great numbers. Similar situation have been described by Macfarlane and Griffin (1985) for honey bees visiting red clover in New Zealand.

Native bees, on the other hand, trip most of the flowers when visiting the plant for pollen so they are more effective pollinators. But if they have to work large fields, there would be insufficient numbers to provide adequate pollination. Only a few species of bees are known to increase their populations rapidly (Bohart 1952).

As stated by Cane (1997), honey bees are the most versatile pollinators available to agriculture. However, they still have several morphological, behavioural, phenological and nutritional limitations, which are not shared with native bees (reviewed in Parker *et al.* 1987; Free 1993). On the other hand, despite the fact that non-*Apis* bee species may be superior pollinators to honey bees for some crops, only a few of them are managed for agricultural pollination. A greater understanding of the factors controlling gregarious nesting in ground-nesting bees would facilitate the management of such bees as promising agricultrural pollinators (Cane 1997). The problem, however, is that wild bees are not numerically abundant to be reliable working in crops with many flowers (Torchio 1990). Several factors, such as pesticides, climatic conditions, loss of nesting sites, and others, may affect unmanaged populations of native bees, as well as honey bees in agricultural settings.

Management strategies for non-*Apis* bees are urgently needed .

Non-*Apis* Pollinators

According to Torchio (1995), some apiculturists (Levin 1986; Robinson *et al.* 1989) and others, have overestimated the value of honey bee pollination, treating estimated figures as factual data, and stating that honey bees account for at least 80% of all insect pollination. These studies have not been based on quantitative comparisons of pollination efficacy among bee species. Robinson *et al.* (1989), on the other hand, although recognizing the potential value of native bees as pollinators, states that they are not dependable because their population densities vary greatly from year to year . This assertion is strongly criticized by Torchio (1995), who states that there is no equity making comparisons between the intensively managed honey bees and the complexity of unmanaged native bees, and that only after this equity is established, comparisons based on scientific evidence could be made.

Wild bees are indeed an alternative for crop pollination. Some species have been successfully managed for commercial pollination; *Megachile rotundata* (Megachilidae) is a bee of European origin, accidentally introduced to the United States, and *Nomia melanderi* (native species in the United States) and some species of *Bombus* (Bohart 1970) are examples.

Megachile rotundata - Historically in Chile, there was no production of alfalfa for seeds, except in small cultivated plots in the northern part of the country, where *A. mellifera* was poorly pollinating the flowers. Alfalfa fields found from low altitude to over 3000 m are mainly cultivated for hay to feed cattle, however, they do produce seeds as the result of being pollinated by bees other than honey bees (Ruz, personal observations). Seed production in this plant is highly dependent on efficient pollinators (Bohart 1957) .

The introduction of *M. rotundata* in 1963, and then massively in 1971 from the United States, has increased the efficiency of pollination in alfalfa (Arretz and Aracena 1975). Stephen (1972) has stated that alfalfa fields in the United States pollinated only by honey bees produced a seed set of 760 kg/ha, while those pollinated by *M. rotundata* produced 1.398 kg/ha.

This bee species, in spite of its potential as an efficient pollinator, was not very successful at the beginning of its introduction to Chile. The populations were seriously affected by parasites, such as *Monodontomerus* and *Tetrasticus* (Hymenoptera) families, dermestids as

Trogoderma, and several others, all introduced with the bee nests from the United States (Arretz 1973). Another important parasite was detected 13 years after the first introduction. It was probably already present in Chile parasitizing some Cecidomidae and native Tephritidae (Arretz *et al.* 1989). Parasites were one of the main mortality factors, affecting the colonization of *M. rotundata*, especially at immature stages. In addition, climatic conditions and pesticides sprayed on alfalfa have increased mortality. After a few years, nevertheless, *M. rotundata* definitely became established near Santiago, but population densities have remained low. At present, seed -growers that have re-established new stocks of bees apparently make good profits growing alfalfa for seed but information about productivity or rearing bees is not available in the country.

The impact and spread of *M. rotundata* in Chile, since its introduction has not been evaluated. Its colonization seems to have been slow, however, a new record for the range of distribution has been found by us (Ruz and Monzón, in preparation) in Chincolco (lat. 32° 33'S and 71° 70'W), a valley located at 150 km north of Santiago, and in the nearby area, El Sobrante where large populations were established. Recently, the area was sampled again (H. Monzón, personal communication), but only a few individuals were found, probably as a a result of a dramatic drought throughout most areas of Chile.

Bombus ruderatus - A similar situation related to alfalfa has been observed for red clover *Trifolium pratense*, the main small-legume seed crop in Chile. This plant is also poorly pollinated by honey bees, but is preferred as a food resource by the long-tongued bumblebee, *Bombus ruderatus*.

The florets of red clover have a deep corolla and the sparsely produced nectar is hidden. Sufficient pollination occurs with strong pollen-collecting bee populations during the flowering time of the legume. However, pollen-collecting by bumble bees declines over the season, which is a negative factor for later flowering varieties (Arretz and Macfarlane 1986).

Bombus ruderatus, a reliable pollinator of red clover (Gurr 1974), was introduced to Southern Chile in 1982 from a New Zealand stock (Arrets and Macfarlane 1986) with the purpose of obtaining higher yield of seeds. This bumble bee is polylectic, since does not only visit red clover, but also crops like cranberries, raspberries, and a variety of weeds, among which one of the most important is *Echium vulgare*, an introduced plant where *B. ruderatus* have been observed in great numbers, especially at high altitude in Icalma, X Region, approximately at 1.500 m (H.Toro, personal communication). Also, *B. ruderatus*, since its introduction near Malleco, has spread toward the north to Chillán (H.Toro, personal communication) and to the south to Puerto Montt.

Echium vulgare is very attractive to honey bees and distributed from Santiago to Malleco (Hoffmann 1995) often being present near red clover fields (R.Rebolledo, personal communication). According to Herrera (1996), introduced crop plant and weed species are often opportunistic, they obtain benefits from local pollinators, achieving pollination and setting seeds, even after being separated geographically from their habitual pollinators. This explanation applies exactly to *E. vulgare* in Chile.

The fact that *B. ruderatus* does not particularly prefer red clover may imply that it is favouring the reproduction and spread of the weed instead of increasing seed production of the legume, which was the objective of its introduction. This hypothesis, however, needs to be proved and data must be gathered to be quantified. Populations of *B. ruderatus* have apparently decreased over the last two years, perhaps affected by altered climatic conditions (G.Pérez, personal communication). However, their range has expanded. Likewise, populations of our native bumblebee *B. dahlbomii* have notably decreased (Rúz, personal observation), but this fact may or may not be the result of the presence of *B. ruderatus*. So studies to evaluate this situation are much needed.

Bees reported pollinating red clover in Chile are: *A. mellifera, B. dahlbomii*, and the few species of solitary colletid bees: *Diphaglossa gayi, Cadeguala occidentalis* and *Colletes cognatus*, the first two species being typical generalists from central Chile. These solitary bees, however, because they are ground nesting, may not be ideal for large-scale pollination management (Arretz and Macfarlane 1986). Macfarlane (1985) also mentioned that other visitors of red clover in Chile are Anthophora paranensis, *A. incerta* and *Centris chilensis* (Anthophoridae). Anthophoridae are more likely to be efficient pollinators because of their preference for red clover flowers. However, their distribution may be restricted and have been found to visit red clover only in central north Chile, not in the southern regions (Macfarlane 1985).

Bombus terrestris - A more recent bee introduction to Chile is *B. terrestris*, whose colonies were commercially imported from Israel (E. López, personal communication) and Belgium (M.Beeche, personal communication). Several countries have already introduced this species, which has proved to be an efficient pollinator, thus increasing the yields of tomatoes grown in green houses.

Colonies of *B. terrestris* have been reared commercially since 1988 in the Netherlands (Hughes 1996) for greenhouse tomato pollination after first trying honeybees for the same purpose (de Ruijter *et al.* 1988). Although Ruijter (1996) recognizes that introducing organisms into new areas is a risk, he also states that based on earlier studies, so far, no drastic changes in the abundance of the different bumblebee species have been observed. The importation of *B. terrestris* to Chile was authorized in 1998, by the Servicio Agrícola y Ganadero (SAG) in Chile, according to the International Rules established in the "Behaviour Code for the importation and liberation of exotic agents for biological control", and as part of the international policies practiced by the Food and Agriculture United Nations Organization and accepted by FAO. The same regulations have been applied to all the species introduced previously (M.Beeche, personal communication), which must be fulfilled by the importers before a species introduction can be authorized.

Colonies of *B. terrestris* were distributed to different localities from north to central Chile. Some preliminary evaluations of its effect as a pollinator of different varieties of tomatoes have been conducted in greenhouses in Quillota, in central Chile. Positive results were obtained under some conditions, with higher yields using bumble bees compared to tomatoes treated with hormones (López and Garay 1998a, 1998b).

Some of the imported colonies are now freely working in the field (E.López, personal communication), so in the future their behaviour, as well as their spread and the potential populations of honey bee effects on populations of other species should be investigated. In Israel, *B. terrestris* has proven to be very invasive, causing reduction in honey bees, and various solitary bees. The bumble bees seem to have favorable adaptations, such as tongues of variable length amoung indiviuals in a colony and ability to work in unfavorable weather (Dafni and Shmida 1996). Dafni and Schmida (1996) also observed that this species may have displaced other bees by depletion of nectar in the early morning. In addition, solitary bees were almost entirely excluded from some plants, being physically chased away by *B.terrestris.*

In New Zealand, according to Wratt (1968 *B. terrestris. B. ruderatus and A. mellifera* compete when foraging in large numbers, and when their activities coincided in two crops adjacent to each other (one of red clover and the other of alfalfa). In red clover, the number of *B. ruderatus* decreased with increasing temperature because of increased competition from honey bees. The latter were collecting pollen and probably pollinating this crop, but were totally ineffective as pollinators on alfalfa, on which they were robbing nectar by side entry. On the other hand, *B. terrestris* foraged on alfalfa by top entry only, and it was the only species among the 3 that gathered pollen from the crop. Because *B. terrestris* can also gather and rob nectar from red clover, it proves to be a versatile pollinator, and it may work better on either crop if they are grown separately, in different localities. Red clover can be an alternative source of nectar when adjacent to alfalfa so jeopardizing alfalfa pollination.

Bombus impatiens - *B. impatiens* is a species of bee from eastern North America used for greenhouse tomato pollination. Although information exists about the importation of *B. impatiens* by some seed growers (M.Beeche, personal communication), the details on the reasons of this introduction were not available. The present state of this bumble bee in Chile is unknown. More data needs to be gathered.

DISCUSSION

Introduction of any foreign species into new environments is evidently a risk; it may affect the interactions of the pre-existing animal species, or the reproductive systems of plants. In Chile, there is an increasing interest in importing bees of commercial value, as in the case with bumble bees. There is also a constant desire to introduce honey bee colonies into areas with native insects already well adapted to native vegetation, without the proponents having any real knowledge of the effects of such introductions.

Studies considering native bees related to the polination of cultivated crops have not been done, except those of Toro *et al.* (1993) and these proceedings, where *Centris mixta* was noted as the main pollinator of *Prosopis tamarugo* in Northern Chile.

A discussion about the introduction and development of apiculture in arid and semiarid regions of Chile has been given by Toro (1986a). Even though his argument is mainly theoretical, the problems indicated are likely to occur. They are based on biological principles that need to be kept in mind. Honey bees may compete with the native *C. mixta*, which would mean alteration to the native vegetation in terms of pollination, as well as to non-*Apis* bee behaviour.

It seems that, among bee pollinators, it would be difficult to asses the degree of competition. However, according to Toro (personal communication) it is possible to distinguish two different levels at which competition may exist: 1) adult bees, which feed primarily on nectar, would be more competitive if they are social versus solitary because the former store this provision. Nectar is renewed through the day, but may be depleted by social bees, preventing the solitary natives from using this food resource. 2) larvae feeding on pollen gathered by the adults should be those competing for this resource.This situation would be more stressful for some native solitary bees, especially oligolectic species, which feed on pollen from only a few plants, particularly under severe environmental conditions.

Some explanations of the possible consequences for specializing on plants after the displacement of oligolectic bees by generalists are given by Toro (1986a) and these proceedings. His reflexions, in general , agree with those of Corbet (1997) who discussed the problem extensively through several questions to point out to the importance of pollinators in species preservation, conservation and ecosystem stability. More research on pollination of native plants and a better knowledge of honey bee interactions with native bees should be conducted in Chile and elsewhere. Most contributions on the subject of crop pollination in Chile refer only to honey bees increasing yield not the possible ecological consequences that their introduction into new areas may have produced.

In Chile, crops like red clover are associated with solitary bees, as previously mentioned. The effect of *B. ruderatus* on these native bees after its introduction on the target plant, however, has never been evaluated. Social bees, in contrast to solitary ones, are born "knowing" much less about their resource environment, because it is generally not predictable in terms of whole colony requirements (Heinrich 1976) .Thus, they exploite a variety of plants through the season. This social and generalist behaviour may negatively affect the foraging of the more specialized solitary bees and a displacement of at least some of them may occur. In the long-term , if this situation happens, a decrease or a loss of bee diversity would result. The presence of *B. terrestris* in Israel, as noted above, has already caused a decrease on native bee populations as a clear example of what might happen in Chile, too. More attention and care to these important issues should be considered in the future before new introductions are approved. Authorization for importing biological material, such as bee pollinators, should not only be determined by the presence or absence of parasites or other noxious agents, but also based on biological studies and consultation by specialists. Regulations should include these aspects as well.

In Canada and the United States, the introduction of foreign bumble bees is prohibited and only local species are reared (Ruijter 1997). Even trans-continental movements are strongly discouraged. *B. terrestris* was imported to Japan from Belgium in 1991 for tomato pollination There it was succsessful in producing high-quality fruits (Iwasaki 1995) but it's escape has caused problems of hybridization with native species. More recent laboratory studies conducted on reared colonies of native Japanese bumble bees indicate, however, that there is no significant differences in the pollination efficiency of *B. terrestris* and the natives *B. hipocrita* and *B. ignitus* (Asada and Ono 1997). This fact suggests that with no ecological risk, the Japanese bumble bee should have been used instead of the imported *B. terrestris* (Asada and Ono 1997).

In Chile, the native *B. dahlbomii* has not been well studied to be managed in crop pollination. Nevertheless, recent preliminary research has been conducted to evaluate the effect of this bumble bee species as pollinator of cultivated tomatoes. The result of this study indicated a high number of flowers visited by this native bumble bee, and a significant increase of the tomato seed production (Wagner and Estay 1998). *B. dahlbomii* may prove to be a good alternative to be used in crop pollination, without environmental risk.

B. dahlbomii also needs to be evaluated from the view point of its abundance, which apparently has decreased over time. This bumble bee species was common but today, at least in central Chile, it is rarely seen. Its abundance has also decreased in the South. The factors affecting the populations of this species need elucidation.

In regard to *B. terrestris*, which has been recently introduced into Chile, we do not know how it is going to behave in cases where it is not confined to greenhouses. If feral individuals start new colonies they may increase their distributional range to southern areas where two other species of *Bombus* are already present, one of them the native *B. dahlbomii.* Because all three bee species are polylectic, several questions arise. What flowering plants would be preferred by each one and which would be more or less efficiently pollinated? Will they compete with for food resources? Will they partition the available resources? Will the introduced species really visit the target plants they are suppossed to pollinate ? Where do the native solitary bees fit in this scheme? Considering that *B. terrestris* is a versatile pollinator, what will happen to *M. rotundata* when interacting with it on alfalfa crops in central Chile?

These are not easy questions, but they need to be answered. Research programs should be conducted in this respect. Educational programs should also be available at the primary and high school level, as well as to the general public. Young people should get the appropriate knowledge to protect and conserve our natural and sometimes unique flora and fauna. Introductions of foreign organisms should be avoided, and if introduced, the possible implications should be known. Farmers should also be educated on this subject. The Department of Agriculture should readily provide active support for such programs and scientific institutions, such as entomological societies, should also be greatly involved .

The diversity of native bees in Chile is poorly known, judging from the large number of new species recently described (Toro, 1986b), and actions should be taken to conserve and preserve these species. We should be alert to any possible change that may threaten our environment . Through bee surveys conducted over the last 30 years, it has been possible to detect how bee abundance and diversity has systematically decreased, especially near coastal areas in central Chile. Several factors may be involved in this process, and human activity is apparently one of the most important. Wild areas have been used for human needs, nesting sites of bees have been destroyed and, native vegetation eliminated. What were refuges for native insects have been replaced by roads and buildings. Such environmental changes have negatively influenced the bee diversity and abundance.

Habitat fragmentation in Chile has become one of the major threats to plant and animal communities in both natural and agricultural landscapes. Plant-pollinator interactions can be expected to be disrupted (see Steffan *et al.* 1997).

Pesticide applications in Chile are another possible cause of the decrease in the wild insect pollinators. Pesticides seriously affect bees when foraging on flowering plants, and produce important effects on their populations as illustrated by Kevan and Plowright (1995), Kevan *et al.* (1998) and Kevan (1999). The effect of pesticides on native bees in Chile should also be evaluated .

In short, more ecological studies and control measures for conservation and preservation of the species diversity in ecosystems of Chile are urgently needed to protect our native vegetation and the apidological fauna for pollination purposes.

CONCLUSIONS

The introduction of foreign pollinators has been documented as hazardous by researchers from other countries, the decline in diversity of native pollinators as one of the major consequences. Another in the possibility of introduced bumble bees pollinating non-target plants, such as weeds, so favoring the reproduction of undesirable vegetation. This experience should be taken into consideration in Chile, because several wild bee species which seem to be efficient pollinators may be seriously affected. In spite of knowing about these negative effects, there is a strong pressure from farmers to introduce several species of *Bombus* into Chile to pollinate cultivated plants in greenhouses.

In Chile, there is an urgent need to focus research studying the native bees at the specific level, and their role as pollinators both in native vegetation and cultivated crops. This would help better understand the impact of the already introduced bees and their interactions with native species.

Further studies and evaluation of the effects of introduced bees must be made in chile in order to preserve the diversity in the environment.

Governmental agencies, such as agriculture services (sag in Chile), should add complementary rules to implementation of the present regulations in order to avoid authorizations for introduction of foreign pollinators without previous biological studies of potential environmental impact.

Educational Programs, at every level, are necessary to keep people aware of the real needs we have for the conservation and preservation of our natural ecosystem.

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DIVERSITY AND ABUNDANCE OF WILD BEES IN A MIXED FRUIT ORCHARD IN CENTRAL MEXICO

Carlos H. Vergara

ABSTRACT

The low diversity of bee pollinators sampled from a fruit orchard in the Central Plateau of Mexico is the direct effect of agricultural practices that has occurred in the region for the last 2,000 years. The bee species abundance has a log normal truncated distribution. The reasons for these patterns are discussed and recommendations for future research are given.

INTRODUCTION

Traditional Mexican fruit orchards are special types of agroforestal systems characterized by high biodiversity and richness, similar to that of natural ecosystems (Gómez-Pompa 1990). A particular type of fruit orchard is found in the Central Plateau of Mexico. In these orchards fruit tree species of Eurasian origin, such as apples, pears and peaches are planted intermingled with annual native crops, such as pumpkin, squash, gourds, and several species of beans.

There is no information on the pollinators of these fruit orchards, except for the work of Búrquez and Sarukhán (1980) on the pollinators of wild and cultivated populations of scarlet beans (*Phaseolus coccineus*). Dramatic declines in managed and feral honey bees have been reported for the US., Mexico and Canada (Allen-Wardell *et al.* 1998), but data on the status of wild invertebrate pollinators are lacking. This fact precludes the assessment of a suspected pollinator loss, which has been documented in other parts of the world.

Biodiversity measures have been used to assess the effects of habitat perturbation on different animal communities. For example, Nestel *et al.* (1993) found that the diversity of soil Coleoptera belonging to nine families was greater in shaded than in unshaded coffee agroecosystems in Veracruz (Mexico) and that scarabeid beetles were strongly affected by the degree of forest perturbation. Kevan *et al.* (1997) found that blueberry fields in New Brunswick, Canada, unaffected by the pesticide feniotrothion fitted well to the log-normal model of species diversity and abundance, whereas affected fields did not fit the same model.

This study presents information on the diversity and abundance of the species of bees, both native and the introduced *Apis mellifera*, found as floral visitors of cultivated exotic and native plants and weeds present in a fruit orchard in the Central Plateau of Mexico.

METHODS

STUDY SITE. The study was carried out in a mixed orchard located in Huejotzingo, Puebla at N19°10′02″ W98° 23′27′. The climate in the study area is transitional between the semi-alpine climate prevalent in the Sierra Nevada (Popocatepetl-Ixtaccihuatl volcanoes) and the temperate climate of the Valley of Puebla, with summer (May-October) rains, cool summers, an average annual temperature of 15.7°C and annual rain fall of de 868.2 mm (García 1981; INEGI 1993).

Plants

The plants observed during the study are grouped under three categories:

Fruit trees

Criollo varieties of *Prunus domestica* (plum), *Prunus persica* (peach), *Pyrus malus* (apple), *Pyrus communis* (pear) which are introduced species, and the native *Prunus serotina* (capulín).

Native Cultivated annuals

Phaseolus vulgaris (Common bean), *Phaseolus coccineus* (scarlet runner bean) and *Cucurbita pepo* (squash).

Native Weeds

Simsia amplexicaulis, Bidens odorata (acahual blanco), *Lopezia racemosa* (perita), *Dalea leporina ,Sycyos deppei* (chayotillo) and *Viguiera* sp. (acahual).

Bee Censuses

Bee censuses were performed on all plant species during 1995 and 1996, according to the following protocols:

Introduced fruit trees

Once a week, during the blooming season of each species 10-minute censuses were carried out every hour from 9:00 through 18:00, on observation quadrants of 0.4m x 0.7 m.

Census dates for each of the tree species were as follows:

Prunus domestica (plum): March 7-March 28 (4 censuses)
Prunus persica (peach): October 19-March 19 (23 censuses)
Pyrus malus (apple): March 7-April 10 (6 censuses)
Pyrus communis (pear): March 7-March 19 (3 censuses)
Prunus serotina (capulín): December 7-February 12 (11 censuses)

Native Cultivated Annuals

Phaseolus vulgaris :Ten minute censuses were carried out every hour from 8:30 to 15:30 on 6 groups of 4 plants each, selected at random. The observations were performed twice a week during 5 weeks from June 18 to July 23.

Phaseolus coccineus : the same methodology described above for P. vulgaris was used. Censuses were performed between June 11 and July 23.

Cucurbita pepo : censuses were carried out on 12 plants selected at random, twice a week during 7 weeks form June 21 to August 13. Ten-minute censuses were repeated every hour from 8:30-12:30, when the flowers closed.

Weeds

Ten censuses were carried out on weeds: Three on October 15, 19 and 31, 1995 and seven on October 13, 16, 19, 22, 25, 28 and 31. On each of the dates indicated above all five weed species were surveyed. Ten-minute censuses were carried out every hour on 0.7m x 0.7 m quadrants. Every quadrant contained flowers of only one weed species.

Voucher specimens of the bees observed as flower visitors were collected, pinned and deposited at the Entomological Collection of the Universidad de las Américas-Puebla. These specimens were determined to species by Dr. R. W. Brooks, Natural History Museum, University of Kansas. Bees of the genus *Hesperapis* were determined by Dr. Roy R. Snelling, Department of Entomology, Natural History Museum of Los Angeles County.

Data analysis

A list of species was compiled and, together with the number of individuals surveyed, used for further calculation of Shannon diversity indexes at three levels: general, for bees found on all plants; by plant category (trees, cultivated annuals and weeds) and by plant species. The Shannon Index (H´) was calculated using equation 1:

$$H' = -\Sigma\, p_i \ln p_i \qquad \text{(Eq. 1)}$$

where p_i is the proportion of individuals found in the ith species.

Species abundance and diversity

Species abundance data, expressed as octaves, were plotted against number of species per octave to describe graphically the distribution of the abundance of species.

The overall distribution of species abundance was fitted to a truncated log normal model, following Magurran (1988).

DISCUSSION

The species richness (number of species) found for the orchard studied here, could be regarded as low, since the site is located within the altiplano sur region, considered by Ayala *et al.* (1993) as the second most diverse area in Mexico, after the xeric regions of the Mexican deserts. This apparent lack of diversity may be explained by the fact that agriculture has been practiced in the region for at least the last 2,000 years, and there are no remnants of the original vegetation in a very extensive area around the study site. Deforestation and agricultural practices such as tillage, probably limit the availability of nesting sites both for soil nesting and plant nesting bees. Expected soil nesting genera are either underrepresented, as are the cases of *Colletes*, which is represented only by two species in the sample, and *Andrena*, represented by 3 species, or absent like *Mexalictus*, *Deltoptila.* and *Hylaeus*, The same situation occurs with the plant nesting species, with only one species of *Megachile*, and *Osmiinae* and *Anthidium* not represented. On the other hand, Paragapostemon that is an endemic monotypic genus, is well represented and, contrary to previous conceptions (Roberts and Brooks 1987), females of *P. coelestinus* visit and collect pollen from a variety of plants, including plum and three species of weeds. Also, females are active during the daytime and not infrequently found, at least in the study area. Although the nesting biology of *P. coelestinus* is unknown, it is likely a soil nesting species.

An undetermined number of bee species could have been overlooked during the censuses due to several reasons. Different species of small bees, especially *Lasioglossum*, *Heterosarus*, and to some extent, *Perdita* , are very difficult to tell apart, even upon examination of dead pinned specimens under the microscope.

Also, the survey was carried out during daytime and no matinal or crepuscular species were recorded.

Despite all the limitations of the methodology used, even if the total number of species recorded were to double the actual number recorded the diversity is not as high as that of other studies carried out in small areas in Mexico (Godínez 1992).

When all the bee species are taken together, the species abundance distribution fits a truncated log normal distribution. Bearing in mind that the results presented here represent sampling of only one season, obtaining this type of distribution was expected. The interesting observation is that when bee species abundance distribution is split into three components, according to the type of plants visited, none of the components can be fitted to a particular type of abundance distribution. These facts suggest that the bee community found in the orchard studied functions as a unit only when all the flowering plants present in the area are considered. Since most of the bee diversity (20 species in total, 16 of which exclusively visit weeds) was found visiting the weeds the role of these plants in maintaining the diversity in this type of agroecosystem is extremely important.

Long term comparisons between the bee fauna of orchards as the one studied here, abandoned orchards and areas of preserved vegetation in the same area will provide information on the potential bee species richness of a given landscape, and on the decline in diversity associated with the agricultural practices practiced in that area.

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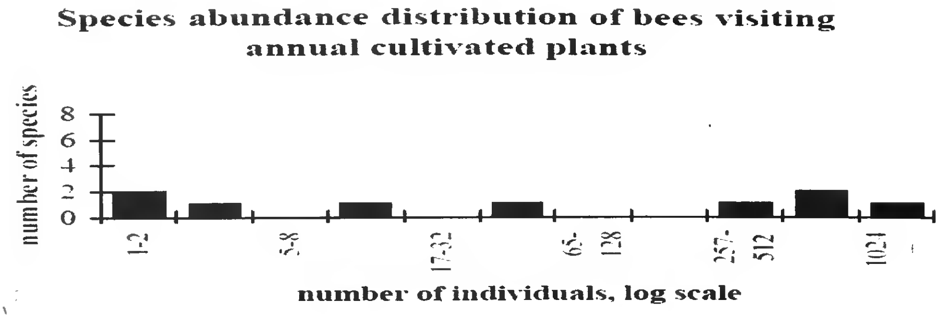
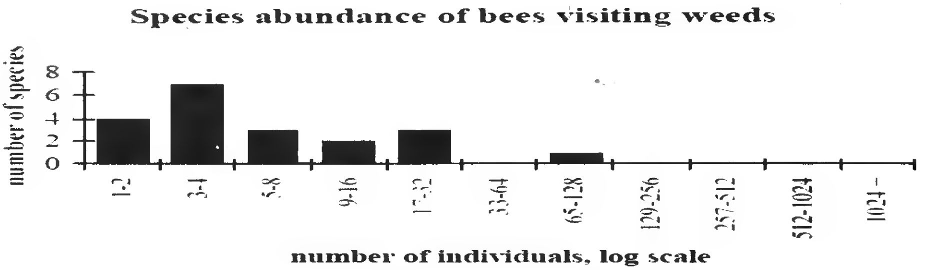
RESULTS

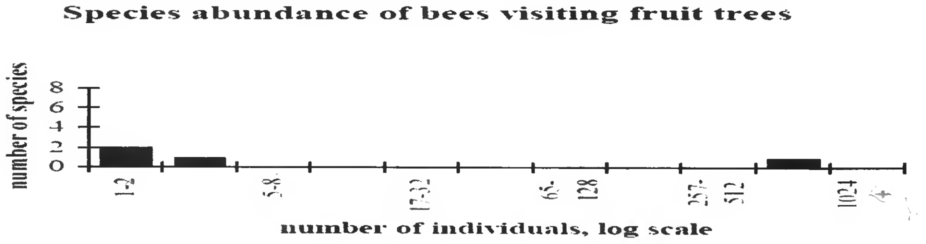
Fig. 1 shows histograms representing the distribution of species abundance for the three plant categories. Only the species abundance distribution for all plants pooled fits a truncated log normal, and is described by this model at a probability of $P \cong 0.75$ ($X^2 = 4.96$; 8 d*f*).

Table 1 shows the list of 28 bee species found as floral visitors of the 14 plant species surveyed during the study. For each bee species, the numbers of individuals observed visiting each plant species is given.

FIGURE 1. Species abundance distribution histograms for each of the plant categories and for all plants pooled.


Species abundance distribution of bees visiting annual cultivated plants


Species abundance of bees visiting weeds


Species abundance of bees visiting fruit trees

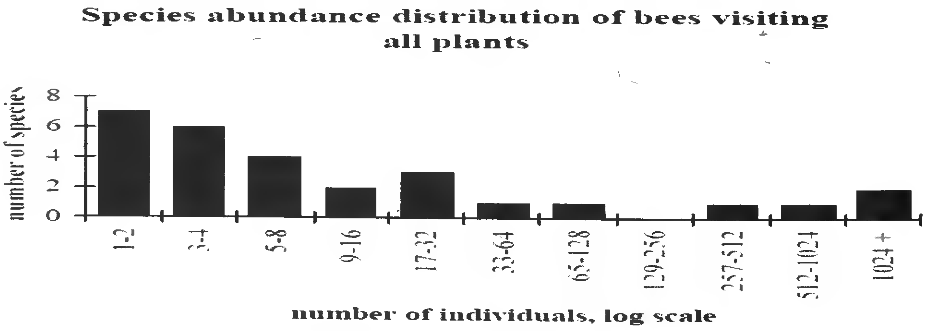

Species abundance distribution of bees visiting all plants

TABLE 1. Bee counts for all plant species.

				CULTIVATED ANNUALS						FRUIT TREES				WEEDS						
				Pear	Apple	Plum	Peach	Capulin		Runner Bean	Common bean	Squash								
			Total of bees	*Pyrus communis*	*Malus domestica*	*Prunus. domestica*	*Prunus persica*	*Prunus serotina*	**Trees total**	*Phaseolus coccineus*	*Phaseolus vulgaris*	*Cucurbita pepo*	**Annuals Total**	*Simsia amplexicaulis*	*Bidens odorata*	*Lopezia racemosa*	*Dalea leporina*	*Sycyos deppei*	*Viguiera sp.*	**Weeds Total**
COLLETIDAE Colletinae	Colletes	*Bombiformis*	20															20		20
		Colletes compactus	2											2						2
ANDRENIDAE Andreninae	Andrena (Callandrena)	*zerifera*	2												2					2
		Andrena (Celetandrena) vinnula	3											3						3
		Andrena sp.	7				1		1					5	1					6
		Megandrena sp.	4											1				3		4
	Panurginae	*Heterosarus (Pterosarus) sp. 1*	3											2	1					3
		Heterosarus (Pterosarus) sp. 2	1												1					1
		Heterosarus (Pterosarus) sp. 3	3											3						3
		Heterosarus (Pterosarus) sp. 4	1												1					1
		Perdita sp.	4											2		1			1	4
		Protandrena sp.	3											2	1					3
HALICTIDAE	Halictinae	*Lasioglossum (Lasioglossum) sp.*	1							1			1							
		Lasioglossum (Dialictus) sp.	1							1			1							
		Paragapostemon coelestinus	20				4		4					6	1				9	16
		Halictus ligatus	1					1	1											
MELITTIDAE	Dasypodinae	*Hesperapis (Disparapis) n. sp.*	90											47	15			1	27	90
MEGACHILIDAE	Megachilinae	*Megachile sp.*	7												1			6		7
APIDAE	Anthophorinae	*Anthophora marginata*	11											2		1	6	2		11
		Peponapis pruinosa	1147									1147	1147							
		Thygater sp. 1	281							215	66		281							
		Thygater sp. 2	709							409	81	219	709							
		Thygater sp. 3	27											18					9	27
		Xenoglossa fulva	41									41	41							
		Centris sp.	10							10			10							
	Apinae	*Apis mellifera*	1680	48	29	197	512	73	859	335	54	415	804			17				17
	Bombinae	*Bombus ephippiatus*	6															6		6
		Bombus pennsylvanicus	7							2	2		4						3	3
		Total	**4092**	48	29	197	517	74	865	973	203	1822	2998	93	24	19	6	38	49	229
		Number of species	**28**	1	1	1	3	2	4	7	4	4	**9**	12	9	3	1	6	5	20
		H'	**1.55**	0.00	0.00	0.00	0.06	0.047	0.047	1.14	1.13	0.97	1.37	1.68	1.43	0.41	0.00	1.37	1.20	2.21

THE HISTORICAL BACKGROUND OF THE DOMESTICATION OF THE BUMBLE- BEE, *BOMBUS TERRESTRIS*, AND ITS INTRODUCTION IN AGRICULTURE

Hayo H.W. Velthuis

ABSTRACT

The history of breeding bumble bees, including the application of *Bombus terrestris* as a pollinator in greenhouse crops, is briefly reviewed. Much knowledge had to be accumulated before large-scale breeding became possible. In the case of *B. terrestris*, a bottleneck for commercial breeding has been the production of young queens in sufficient numbers to meet the demands of a rapidly increasing market for colonies. The example shows that the successful exploitation of an as yet unutilised resource may have all the characteristics of a gold-rush, including devastating consequences for natural environments.

INTRODUCTION

In the discussions on sustainable development it is generally agreed that nature still harbours large numbers of organisms potentially and directly important for mankind. Their profitable use is only awaiting the discovery of their value, or the formulation of the way they should be multiplied. Concerning the more than 20,000 species of bees, there is the recognition that almost all have a certain role in pollination, leading to the production of seeds and fruits, and that the various morphological differences among these species (such as in their body size, the absolute and relative tongue length) are related to a certain degree of specialization for the rather varied flower types.

In the design of agricultural systems this diversity of bees does not play any role. Except for a few species, these bees are not cultivated, their natural nesting sites are neither protected nor respected and in fact, pollination by such "wild" species is taken for granted as long as sufficient pollination occurs. If pollination is unsatisfactory, a generalist pollinator, most often the honeybee, kept in managed colonies, is brought to the site, and if pollination then occurs to the desired degree, this measure is considered to solve the problem. Why pollination was or became unsatisfactory seems to have been and continues to be an unimportant question.

The future use of the many undiscovered pollinators depends on the establishment of methods to breed them in the necessary quantities. The time needed for such a development is generally underestimated. Furthermore, breeding is only part of the way towards the successful use of such a new pollinator. In this regard I like to illustrate this using the bumble bee, *Bombus terrestris*, as an example. This species has become a valuable pollinator in intensive farming since 1988, when it was introduced in the greenhouse production of tomatoes in The Netherlands and Belgium, but it had already been studied and reared in laboratory settings for some decades.

I distinguish the following four aspects of the process: 1. learning how to breed the bee; 2. the search for an application; 3. towards application and wide acceptance of the new method; 4. international aspects of the dissemination of the new technology.

Early rearing attempts

The first accumulation of knowledge about breeding necessarily involves hobbyists, who, by sheer interest, devote their time to naturalistic observations. A prominent person with respect to the breeding of bumble bees in general was F.W.L. Sladen, who published his experiences in 1912. He collected incipient colonies or solitary queens after their hibernation, and put them in nest boxes of various designs. He observed that interactions among queens, or of workers placed in the box together with a queen prior to the start of her egg laying, increased the probability of success. He used workers of those species that start a colony early in spring to stimulate the queens of species that end their hibernation later in the season. He considered the major problems for the domestication of the bumble bees to be the control of their mating and of their hibernation. It is of interest, that by the word domestication he did not think of any practical application.

Sladen's recommendations were followed by others, who added their own techniques. Among them were H.-H. von Hagen (1975) and E. von Hagen (1986), who described their 30 years of experiences of breeding more than 15 species of Central European bumble bees. A brief summary of the earlier applied studies was given by Bornus (1975); and also Free and Butler (1959) mention the earlier breeding experiments. Part of these concerned the dimensions and design, the contents and the localities of nest boxes placed in the field to attract young queens in their search for a suitable nesting site. Extensive studies along these lines were also made at the Polish Research Institute, Pulawi. Here caged plots of 1 m2 were provided with a nest box. Each cage contained flowering *Lamium album*, a noted food plant for various bumble bee species. On suitable days in spring, young queens of various species, and which just had emerged from their hibernation sites, were captured and placed in the cages. The presence of abundant food resources and the carefully selected nest box, differing according to the species, made the queens start breeding (Bilinski 1976). The method was rather successful, but quite labour-intensive. In this case breeding was undertaken to rear colonies for the pollination of alfalfa and red clover, and a major problem was the production of mature colonies synchronised with the blooming period of these plants.

Laboratory breeding technology

The next step was the breeding of bumble bees under laboratory conditions, which involved the development of appropriate feeding methods. This was most successful in pollen storing species, such as *B. terrestris, B. lucorum, B. hypnorum*, and some of the American species (see Plowright and Jay 1966). Pollen harvested from honeybee colonies, using pollen traps at the entrance, proved to be excellent, provided the pollen was not dried (Ribeiro *et al.* 1996). The pollen could be stored in a freezer, and could be given in small quantities or even in bulk, without losing its attractivity or its nutritive value. Sugar water, in concentrations of about 50% w/w, proved to be an excellent substitute for nectar.

However, under laboratory conditions, queens apparently need to be stimulated in order to start breeding. Species that naturally start breeding under the ambient temperatures characteristic of early spring, needed to be placed in climate rooms with temperatures of 28°C, and, in addition, needed to be placed in pairs. Much of the present-day techniques have been developed or combined by P.-F. Röseler, who only in 1985 published in full the results of his 20 years of experience. He developed the technique of having the queens mated, initially by letting them fly at the appropriate age in his rearing room together with a few drones. From this the mating cages of today were developed. After mating, he placed each queen in a small vial, together with a piece of humidified filter paper, and stored them in a refrigerator at about 5°C, to simulate hibernating conditions.

While Röseler followed Sladen in placing two queens together, Ptacek (1985, see his 1990 paper) used worker honeybees to stimulate the onset of egg laying. In a sense, his method also goes back to Sladen, who used workers of another bumble bee species for the purpose. Ptacek also followed Zapletal (1966, see Ptacek 1990), who gave a piece of honeycomb to queens in which he offered them a sugar solution. Ptacek noted the queens, as long as they were alone, to be rather restless on this honeycomb, but they became quieter if accompanied by honeybee workers. As a consequence, they started breeding. For queens emerging early in spring, honeybee workers are more readily available than bumble bee workers, which made the method attractive for occasional breeding attempts. Furthermore, if two queens of the same species are placed together, they generally will become aggressive towards each other, with the consequence that often one of them will be killed. The use of honeybees, therefore, had certainly advantages at that stage of the technical developments.

In our own laboratory the attempts at breeding bumble bees started in 1974, and initially we adopted the techniques of Röseler, beginning in early spring with field-caught queens of B. terrestris, placing two queens together in the nest box. However, once continuous breeding became possible, we changed to adding young, adult bumble bee workers or male cocoons to a single queen. This had the same activating effect on the queen, and the advantage that more cages could be put up when a few queens were available.

Another important discovery made by Röseler was that the obligatory hibernation period of queens could be circumvented by giving them, after a successful mating, a CO_2 narcosis. This allowed breeding throughout the year. The method has been widely used in the commercial breeding that developed soon after.

In our laboratory, however, we preferred a more natural hibernation. Already Zapletal (1961) had placed mated queens in boxes partly filled with loose, moist peat, and Ptacek (1985 in 1990) tried to imitate the natural hibernaculum by drilling holes in a piece of wood, in which queens could be placed after they were deactivated by cooling them in a refrigerator. Pouvreau (1970) offered to queens, flying in a greenhouse, a heap of moist peat dust, and these queens dug themselves into it. Under natural conditions, a few days after mating, queens had already sought a hiding place for the winter. In our own system we borrowed from these methods. Plastic boxes, containing a layer of 10-15 cm of peat dust, are placed underneath the mating cages. Most queens dig themselves a hole in this substrate, and become inactive. A few days later the box, covered with a plastic foil, can be placed in a cold room (Duchateau 1985). Within two months the queens can be reactivated, but longer periods of hibernation are equally well possible.

There are several advantages of this hibernation method over the CO_2 narcosis method. In the first place, after CO_2 narcosis, queens may produce males among their first and second brood. Such early investment in males is a lost one, because males do not help the further development of the colony. This irregularity may also influence the pattern of colony development. Second, queens stored in the cold room can be used at a time most suitable for the breeder or experimenter. It needs to be said, however, that there is still a difference with natural conditions, in that in nature queens hibernate for periods of up to 8 months, a length of time most of them do not survive in the cold room. Mortality rates in relation to natural hibernation conditions are not known.

The application and wide acceptance

The importance of bumble bees, especially the long-tonged ones, has been recognised for more than a century, especially for the pollination of red clover and alfalfa. For this reason in the 19th century some species were introduced into New Zealand, and in Europe Hasselrot (1960) and Holm (1960, 1966) studied the attraction of several species to nest boxes, partly for the same purpose. Long-tonged bees are pocket making species, which are more difficult to breed (Griffin et al, 1990) than the pollen storers; it is to the latter group that *B. terrestris* belongs. In pollen storers, the foragers deposit the collected pollen and nectar in special receptacles, or in old cocoons, from which the nurse bees take it to feed the larvae. In pocket makers, however, the collected pollen is brought directly to a pocket at the base of the cell containing the larvae. These bumble bees do not transport to the larvae the pollen which the breeder provided somewhere near the brood. Unfortunately, *B. terrestris* has a relatively short tongue, and is not a pollinator for deep flowers like red clover and alfalfa.

In my imagination, our *B. terrestris* cultures were promising for applications in agriculture. I discussed these possibilities with a number of colleagues, some of whom were less optimistic (e.g. Röseler, 1979) than I was. With the help of the Directors of the Ambrosiushoeve, the Dutch research Institute for Beekeeping (Ir. Mommers, and later his successors Ir. Pettinga and Dr. van Heemert), I tried to find a greenhouse crop that was hand-pollinated, and where the relatively high costs of breeding bumble bees could compete with high labour costs. In 1982 this led to a study of pollination in *Primula*, where, apart from the expenses of hand pollination in the production of hybrid seeds, the strong tendency of the development of allergy among the workers made such a study rather attractive (Velthuis and Cobb, 1990).

Around 1985 Dr. R. de Jonghe, a Belgian veterinarian with interest in bumble bee taxonomy and an experienced breeder, made his first observations on the value of *B. terrestris* for the pollination of tomatoes. He placed bumble bees in a greenhouse in the southern part of Holland. The grower trusted him, to the later great delight of both of them. The grower got record prices for his produce in the market. Soon after, tomato growers in that area became aware of the value of insect pollination. The next year we received a busload of growers in our laboratory, where they hoped to see how easy it was to breed bumble bees. Many queens were collected by them, placed in nest boxes and treated carefully; probably none of the queens ever laid an egg. Also beekeepers, supposing breeding bumble bees would not be very different from rearing honeybees, attempted to take part in the rapidly developing breeding industry. Dr. de Jonghe started his company Biobest; in The Netherlands it were Bunting Brinkman, Koppert Biological Systems, and several smaller companies that initiated activities. Within a few years in the Low Countries there was hardly a tomato grower left that still used pollination through artificial vibration.

Why was it that the first attempt to pollinate tomatoes through the help of this bumble bee led to such a rapid change? I see three main factors. Firstly, there was much competition in the market, and only the better quality tomatoes fetched a satisfactory price. Bumble bee pollinated tomatoes were of distinctly better quality compared with fruits obtained through artificial vibration, and, during the first years, the grower that used bumble bees got away with the best prices. Secondly, bumble bees did their work at a much lower price compared to the labour costs of artificial vibration. Furthermore, the technology for biological control of insect pests on greenhouse tomatoes was already fully developed by Koppert.

Using bumble bees for pollination implies refraining from insecticide treatments. The availability of biological control agents made it easier for the growers to make the change. Up to the introduction of bumble bees in the greenhouse, this biological control system was only used by a few growers, because checking the crop regularly for developing insect pests needs more attention than following a strict scheme for preventive spraying.

After the tomatoes, other greenhouse products followed. Most prevalent is the use of bumble bees in sweet pepper production, where an upper quality category of product had to be added as a a result of insect pollination.

Why was it, that our questioning of agricultural specialists for hand-pollinated crops that could profit from bumble bee pollination never led to the idea that tomatoes could be worth testing? I think the answer lies in the fact that there was already a method that did lead to a satisfactory fruit set, and that there was a surplus production, leading to often low prices for the growers. There was no need to produce more, and quality aspects of natural pollination were never thought of. The differences in taste of field-grown tomatoes and those from the greenhouse were attributed to differences in the amount of sunshine, leading to a juicier product with higher sugar contents in those summer-grown tomatoes coming from open fields. Juiciness and sugar concentration are also dependent on fruit physiology, and, in turn, this physiology is influenced by the degree of seed set, which was not considered before.

Problems at the start of commercial breeding

It probably needs no explanation that with the rapidly increasing demand for bumble bee colonies, the commercial breeders had difficulties in producing the large amount of colonies requested. In the laboratory, where answers to specific biological questions concerning the development of colonies, or of individuals within the colony, are sought, the failure of a number of queens to produce a colony is not very much a matter of concern. In commercial breeding, however, this success rate is a very important matter, and needed to be improved. The larger companies, therefore, invested in the finer details of the activation of queens, and each company developed its own improvements, which, up to the present, are carefully kept secret from the competitors on the market.

A second problem was in the fact that bumble bee colonies appear to produce males in much larger numbers than they do young queens (Duchateau and Velthuis 1988; Bourke 1997). Many colonies do not produce queens at all, and therefore, obtaining home-bred sexuals for a new generation of colonies often posed problems. To compensate, the southern parts of Europe became favorite places to collect queens. Especially from populations that produce colonies in winter, such as *B. terrestris sassaricus*, queens were collected in great numbers. This mass collection grew to such an extent that public reactions in these countries followed, and some countries prohibited the activity.

Why this male-biased reproduction occurs is still unexplained, but a recent analysis of our laboratory breeding of the last years, in which several hundred of colonies are included, indicates that it might be a consequence of a number of environmental factors (Duchateau *et al.* unpublished). In many breeding situations these environmental conditions might not be optimal for obtaining equality in the investments in the two sexes.

Furthermore, initially colonies from self-bred queens appeared to be weaker than those from field-collected queens. One explanation for this could be that it is an effect of inbreeding. We therefore started a study on inbreeding, and could demonstrate that sex is regulated in the same way as in many other Hymenoptera (Duchateau *et al.* 1994), i.e. through a series of alleles at a sex locus, and that homozygosity for this gene leads to diploid males instead of diploid workers. This indicated that, in the mating phase, care should be taken to select queens and males from different colonies, to avoid such rapid inbreeding effects. Fortunately, diploid males are almost unfertile (Duchateau and Mariën, 1995), and in case they should occur in the breeding system, their low reproductive success would eliminate any consequence of their appearance.

From the point of view of nature conservation, it is most enjoyable that also the commercial breeders nowadays rely largely on their own production of queens and males for the next generations. This circumvents the escalation of the conflict concerning mass collection of mated queens in the field. At the same time, the possibility of such conflicts might be a warning for future introductions of new pollinators: if there would be an economic success without a sufficiently developed breeding technique, the balance of the invention would soon skip to the negative side.

International aspects

The success of bumble bee pollination did not remain a secret of the Low Countries. Large scale exportation of colonies to other countries, within and outside Europe, soon took place. This brought a new kind of problem. Ideally, each country should breed the colonies it needs, using local populations to start with. This would avoid spreading bumble bees from one area to others. Geographic populations probably are genetically different, and mixing them would probably lead to unwanted local hybridization. Furthermore, moving bumble bees would have the possible consequence of the introduction of bumble bee parasites and diseases in places where they do not occur naturally. Governmental strictness stimulated the breeding companies to start breeding locally, like in Irael, where *B. terrestris* is native; in N. America species from that continent, *B. impatiens* and *B. occidentalis* (for use at the eastern or western side of the Rocky Mountains respectively) were selected as alternatives. In Turkey, however, a country that once provided the breeders with large numbers of very early queens, governmental restrictions so far made it impossible to revolutionise its tomato industry.

However, there are several reasons why the local production of colonies is not an ideal situation from the point of view of the breeding industry, as long as it concerns relatively small geographic areas, such as in Europe. In the first place because tomatoes and sweet pepper are not cultivated year-round in any country, and a local breeding centre therefore would face unemployment for part of the year. Producing colonies centrally, in combination with transportation to countries where the growing season for the plant to be pollinated is different, has big economic advantages. It allows the bumble bee breeder to invest in specialization of his personnel. Production costs become lower, as the breeding becomes more efficient.

The international market for the agricultural product demands for equal chances, and therefore growers in countries where bumble bees are not naturally available, seek importation of this pollinator. This is the case in Australia and some Latin American countries. In Japan the government stimulates the development of breeding techniques for local bumble bee species, but in the meantime allows importation of *B. terrestris* from Europe. In Australia the government prevented importation of bumble bee colonies. Pollination by large carpenter bees of the genus *Xylocopa* was proposed (Hogendoorn, personal communication), but in the meantime *B. terrestris* has already accidentally reached Tasmania (Semmens *et al.* 1993).

CONCLUSIONS

The example of the introduction of *Bombus terrestris* in greenhouses demonstrates, that the breeding technology necessarily has to be developed sufficiently before the application can be made. Otherwise, the use of a new pollinator will lead to permanent, excessive robbing of natural populations.

If one of the arguments for nature conservation is that in this way potential benefits can be safeguarded, then there should also be the possibility for scientific and hobbyist researchers to study the biology of the organisms occurring in that reserve, without asking any argumentation concerning utility. Only in that way the body of knowledge can be built on which future applications depend.

Improvements in production technology are measured in economic values only. New technologies, therefore, are only accepted by farmers if there is already such an economic perspective. Without such perspective, experiments on the biological possibilities of the use of a new pollinator are difficult to arrange, and meet skepticism. Even in the case of the Dutch tomatoes, it took years before they were advertised using the bumble bee as a symbol for low pesticide loads. Apparently, such a quality aspect did not belong to the aims of the industry.

Finally, the bumble bee example has shown that there were considerable problems in communication, between scientists, policy makers, and farmers, because most probably each group had, and still has, a different set of goals.

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Session III

Methodology for Pollinator Diversity and Abundance

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MONITORING: AN ESSENTIAL TOOL IN BEE ECOLOGY AND CONSERVATION

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ABSTRACT

Our research group has used several methods to monitor solitary bees in the wildlands of California and Costa Rica. In this paper we review these methods, the questions that directed them, and the usefulness and limits of the methods for current and future studies. The simplest methods are presented first, followed by the more complex methods. We emphasise that monitoring to record trends in pollinator frequencies over time requires a thoughtful and well-designed plan. We also propose that these trends must be accompanied with associated ecological information in order to assist in their interpretations. These interpretations become important if and when decision-makers attempt to use pollinator trends and associated ecological information for land management planning that includes protection and enhancement of pollinators. Biologists must also become more actively involved in promoting awareness and implementing plans to conserve these vital biological elements.

INTRODUCTION

Several recent reports strongly suggest that numbers of crop pollinators around the world are declining, consequently, diminishing yields of some crops (Banaszak 1995; Buchmann and Nabhan 1996; Nabhan and Buchmann 1997; Allen-Wardell *et al.* 1998). The problem also extends to wildlands where numbers of pollinators of native flora may also be declining to levels where reproduction of an unknown number of plant species is or maybe negatively affected (Janzen 1974; Cuddihy and Stone 1990; Royte 1995; Frankie *et al.* 1997). There are ample reasons to believe that these reports are offering the first warnings of more serious future problems as more pollinator nesting/immature habitats and wild floral resources are destroyed by ever-increasingly human development.

The above reports are mostly anecdotal, and thus at this time it is difficult to find hard, convincing evidence to begin taking the necessary steps to reverse the apparent decline in pollinators. Implementing such action requires much more biological information from a variety of researchers who are just now beginning to ask new questions about pollinator diversity and ecology; how to quantitatively monitor pollinators over long periods; reasons for their fluctuations and decline; how to protect and conserve them; how to convince decision makers to take action; and how far should biologists go in promoting pollinator conservation.

In this paper we are concerned with the issue of pollinator monitoring, more specifically with bees. With the exception of honeybees in agricultural (crop) pollination research, the scientific literature on bee pollinator monitoring is extremely sparse (Banaszak 1980; Dafni 1992; Kearns and Inouye 1993; Strickler *et al.* 1996; Frankie et al 1997, 1998). It is our belief that to make informed statements about pollinator trends for bees or for other pollinators in an area over time, there must be good monitoring data available.

Our research group has been developing and testing a variety of bee monitoring methods since 1972, although most of these studies were not designed specifically to assess trends in pollinators and their frequencies through time. The goals of this paper are to:

- Review bee monitoring techniques used by our research group in California and Costa Rica.
- Review monitoring results, analyses, and interpretations of selected case studies.
- Offer biological, socio-economic, and political perspectives on findings.

Study Sites

California. Six study sites were chosen in 1987 for bee monitoring studies in northern California. Three of these were in the San Joaquin valley in grassland-wetland and riparian habitats. Two were in central coastal inland mountains and one was in the southern Sierra Nevada foothills. The latter three sites each contained several diverse habitat types, ranging from grassland, to chaparral, to oak-woodland, to oak-gray pine forest. Details on the vegetation and habitats of all six sites are found in Frankie *et al.* (1998).

Costa Rica. Various study sites were used from 1972-present in the seasonal dry forest in and around the towns of Bagaces and Liberia in the Province of Guanacaste in northwestern Costa Rica. The main habitat types used were dry deciduous forest, riparian forest, savanna, mesic forest, regenerative forest, oak forest, oak riparian forest, and human-disturbed dry deciduous forest. These habitats are described in detail in Frankie *et al.* (1988, 1997).

Types of Monitoring

We have been systematically monitoring bees in Costa Rica since 1972 and in California since 1987. Several approaches and methods have been used for monitoring, depending on the questions or hypotheses posed. Each method was field tested several times prior to collection of the first data set. Usefulness and limits of data generated from each method are discussed. The studies reviewed below are presented in order of the simplest first (based on objectives and methods used) followed by more complex studies.

The first four of five monitoring types described here are based on collections and/or visual counts (or observations) of bees at flowers of selected host plants. Several basic conditions had to be met before these collections were made, which helped to standardise the methodology.

The conditions:

- Weather must be favourable for bees. Warm, sunny, no-wind days are optimal; breezy days are tolerated however. In California, daily high temperatures have to be at least (20° C) or higher; in Costa Rica they have to be (29° C) 85°F or higher. Further, days having high versus low pressure systems are preferred.

- Selected plant species should flower each year; avoid supra-annual flowering species.

- Selected plants must be in full flower.

- Large flowering individuals (trees) or patches of shrubs, herbs, etc. are selected for monitoring over small and/or isolated plants/patches.

- Monitor at time of day when plant is known to attract greatest number of visitors; that is, when floral resources are plentiful.

- Note type floral resource(s) sought by bees on selected plant species; that is, pollen, nectar, oil, etc.

The fifth monitoring type is based on trap-nesting data and is described later.

Monitoring Types

A: Monitoring Bees at Flowers

Concept 1: Monitoring from selected plant species that attract a wide variety of bees.

Questions posed:

- What is the diversity in guilds of bees on selected plant species that are known to attract a wide variety of bees?

- Are elements (taxa) of bee visitor guilds missing (or rare) at particular sites or times?

This simple method, which requires little preliminary field work, provides immediate information on which bee species are present or absent at any given time at a particular site. It is accomplished by collecting bees from flowers with an aerial net. With only modest field experience one can identify and select plant species that attract a variety of visitors from those that attract limited visitor diversity.

This is a useful method for making quick qualitative assessments of bees on plants to determine presence, relative abundance, or absence of species in an area. It is also a good method for comparing bee species diversity between areas and through time. In the latter case, it is necessary to standardise numbers of plants sampled, method of sampling, time frame used, size of aerial net, etc. (See Concept 3 below).

Examples of highly attractive bee plants in California and Costa Rica are as follows:

California: *Wizlizenia refracta*; about 30 bee species known to visit flowers. *Marrubium vulgare*; about 25 bee species visit flowers.

Costa Rica: *Andira inermis*; up to 70 bee species visit flowers (Frankie *et al.* 1976). Dalbergia retusa; up to 60 bee species visit flowers. *Cassia biflora*; up to 30 bee species visit flowers.

Concept 2: Monitoring plant species that attract only selected bee taxa.

Question posed:

- Are known selected bee taxa present in an area where host plant is found?

This is also a simple method; however, it requires background knowledge and experience with given plant species and the specific bee taxa they attract. Once plant species and their limited pollinator guilds are identified, these systems can be useful for monitoring selected bee species. As with Concept 1 Monitoring, these plants can provide immediate qualitative information on presence, relative abundance, or absence of very specific bee species in an area (see also Thorp and Leong 1995). If the collections are systematically made and quantified, results on given plants can be compared spatially with other plants in adjacent areas, or compared through time on the same plants (see Concept 3 below).

Examples of these plant species and their specific bees are as follows:

California: *Cordylanthus rigida* attracts almost exclusively *Bombus californicus* and Megachile angelarum

Costa Rica: *Byrsonima crassifolia* attracts primarily bees of the genera *Centris, Epicharis* and *Paratetrapedia* (Anthophoridae). *Licania arborea* attracts primarily bees of the family Halictidae. *Miconia argentea* attracts primarily stingless bees and a very few small anthophorid bee species. *Tabebuia ochracea* and *T. rosea* attract primarily bees in the genus *Centris* (Anthophoridae).

Note: With the exception of *C. rigida, B. crassifolia* and *Tabebuia* species, honeybees are also common visitors to the above plant species.

Concept 3: Monitoring selected plant species for assessing diversity and frequency of bee species through time.

Question posed:

- What is bee species diversity and frequency on selected plant species (individuals) over more than one season?

This method requires considerable background work and experience and a quantifiable sampling technique. Further, in many cases, it requires that the same individual plant (in the case of trees) or patches (in the case of shrubs) be used. Thus, the prerequisites for using this approach are more restrictive than the previous two methods. The results, however, can be more useful for suggesting statistically significant trends in changing bee composition and bee frequency once baseline guild data have been established.

We are currently using this method to assess changing bee compositions and frequencies through time on two plant species in Costa Rica. These are *Cassia biflora* (Caesalpinaceae) and *Andira inermis* (Fabaceae). Only the case of *A. inermis* and its bees will be considered here as we have more data collected on this species over a longer time period.

The first systematic bee collections were made in 1972 from several trees of *A. inermis* along a roadside planting just south of the town of Liberia (Frankie *et al.* 1976). At that time the area around the trees was in the process of being developed for diverse agricultural uses, and there was still considerable native vegetation and habitat, even though it was fragmented. The bees were again systematically sampled in 1996 from the same stand of trees after 24 years had elapsed (Frankie *et al.* 1997). On the second occasion, greater attention was paid to land developments that had occurred over the 24-year period and to sampling from trees that were marked for future sampling. In 1972 about 70 bee species were collected from trees of *A. inermis*. By 1996, only 28 species were recovered and their frequencies were substantially lower (Frankie *et al.* 1997). More specifically, the average number of total bees collected on a single tree in 1972 for a half hour period was 824±SD210; in 1996 it was only 92±SD59, which represented an overall decline of slightly more than 90% of the bees (see also Frankie *et al.* 1993).

Increased agricultural development over 24 years in the area around the *A. inermis* trees, resulting in less native habitat and vegetation, is believed responsible for the sharp decline in bees. Further, introduction of non-native plant species, more frequent fires (all human-caused), and a more simplified agroecosystem have undoubtedly contributed to the reduction in bees (Vinson *et al.* 1993). The same trees at this site will continue to be monitored in the future years, in part to insure that the differences are not a result of annual variation (casual sampling on the Liberia trees during the interim years, however, suggested that it is a result of a steady decline (Frankie *et al.* 1993)).

With this type of systematic monitoring, a wide variety of new questions can be asked once a data base is established. For example, we observed that despite careful monitoring on each *A. inermis* tree, there were considerable differences in bee composition and frequency among sample trees. When the data were analysed to look specifically at this difference, it was observed that some trees were highly attractive to Africanised honeybees (AHB) and some were not; and, some had little attraction to any bees. Using Chi-square tests, we determined that there were statistically different proportions between AHB) and large native bee taxa (esp. *Centris* and *Epicharis*) on individual trees, suggesting that intraspecific variation in floral rewards appears to occur commonly in this tree. Examining conspecific trees that were growing side by side and had significantly different bees visiting their flowers further supported this observation. Intraspecific variation in floral rewards is suspected in the same forest in *Tabebuia rosea* (Frankie *et al.* 1983a) and in *Caesalpinia eriostachys, Dalbergia retusa, Gliricidia sepium*, and *Myrospermum fructescens* (all in Fabaceae) (see also Frankie and Haber 1983).

Concept 4: Monitoring wide range of plant species in a specific area to assess how bee species partition floral resources seasonally and spatially.

Questions posed:

- What bee species are probably the most important pollinators of given bee plants?

- How can systematic monitoring at flowers be used to assess potential competition between honeybees and native bees for floral rewards?

These kinds of questions require at least a season of pilot field research in an area to acquire experience on the bee taxa present and their relative frequencies on numerous representative plant species. With this experience an appropriate non-destructive monitoring program can be initiated that will be suitable for any plant species and its bees. In California and Costa Rica we have used the following scheme and replicated it up to a dozen times to assess bee type and frequency of visitation to a plant. We marked off a 2x2m square of flowering foliage and recorded numbers of bees that visit flowers in that specific space for 2 minutes. From replicated observations, we have determined low, medium, and high frequency visitation rates of solitary bee species versus honeybees. The only prerequisite for this study is the knowledge of all the families (and some genera) in an area and a strong personal sense of concentration and focus. A tape recorder can be used to assist in recording bee visits, especially when visitation is high and several bee species are present.

Results to date have been informative and provide evidence that honeybees (African and European) are apparently selective in taking floral resources that are also attractive to native bees. Honeybees have a range of preferences and definite non-preferences. After several years of monitoring in California and Costa Rica, the amount of overlap observed between native bees and honeybees approximates 40% in both areas, most subsites of which is a lower percentage than originally expected. A few California subsites have slightly higher percent overlap values, and that may be due, in part, to the high numbers of extant exotic weed species. Surveys of visitation frequencies of bees (see above methodology) on "bee flowers" were conducted to determine percent and level of overlap; that is, simultaneous visits or visits at different times by both honeybees and native bees to the same plant species. In the overlap cases, frequency of visitation may be rare, low, medium or high, depending on the plant species. Furthermore, honeybees may be spatially and temporally partitioned in an area, which may greatly reduce the potential for competition between native bees and honeybees, regardless of their monitored visitation frequency. Much work remains before we will know if honeybees and solitary bees regularly compete, sometimes compete, or coexist at our study sites.

B. Monitoring Bees in Trap Nests

Concept 5. Trap-nest monitoring for selected bee species in any given area.

Questions posed:

- What is diversity and frequency of cavity-nesting bees in an area?
- What are habitat nesting preferences for selected cavity-nesting bees in an area?
- What are changes in bee species composition and frequency through time in given areas?

This type of monitoring to answer most of these questions requires considerable preparatory field work, usually more than a year. In Costa Rica and California, two and three years, respectively, were required to determine; i) hole sizes that would attract extant cavity-nesting bees; ii) placement of trap nests in the most and least preferred habitats; iii) numbers of trap nests (or blocks of trap nests) to be used to sample common and occasional cavity nesters and; iv) length of trap nest season and intervals for periodic trap nest changes. After a season or two of this preparatory work, the first data sets can be gathered to answer the first question on bee diversity and relative bee frequency (Frankie *et al.* 1988; Thorp *et al.* 1992).

In the case of the second question on nesting habitat preference, two years of trial field work are desirable. In Costa Rica, we tested habitat preference for *Centris* species in several dry forest habitats in 1986, after two years of preparatory work (Frankie *et al.* 1988). Data were systematically collected and quantified in 1986 during the entire nesting season for six *Centris* species.

The results of trap-nest collections are best analysed using generalised linear models because the response variables are not continuous or normally distributed. For some questions the response variable is a discrete count (numbers of bees) with a Poisson error structure for which a Poisson regression is most appropriate. Other questions are best addressed with the data in the form of a proportion of used versus unused nesting holes, which has a binomial error structure and suggests a logistic regression. We have used several different statistical packages for these analyses: GLIM program (Baker and Nelder 1978), GLIM 3.77 (Payne 1986), BMDP (PLR for step-wise regression), and S-Plus, but there are many other programs that can be used for generalised linear models such as JMP, GENSTAT, some aspects of SAS, etc.

Using these types of analyses, we found that three *Centris* species (*C. bicornuta, C. nitida*, and *C. vittata*) had significant tendencies to use particular habitats whereas a fourth species (*C. analis*) showed no preferences (Frankie *et al.* 1988). With knowledge of habitat preferences, other studies were designed to answer further questions about nesting ecology. From 1987 to 1991, we studied preferred nesting habitats for seven cavity-nesting *Centris* species in the Costa Rican dry forest (Frankie *et al.* 1993). We found significant differences in frequency of nesting *Centris* bees in trap nests among sites and among habitats. Three of the common *Centris* species (*C. analis, C. nitida*, and *C. bicornuta*) preferred the closed oak forest in all five years of the study. These three species each showed significant changes in frequency through time, however, the overall frequency of nesting *Centris* bees in traps remained approximately the same from 1987 to 1991. Interestingly, the frequency of *C. bicornuta* went up through time; whereas the frequency went down in *C. nitida*. *Centris analis*, on the other hand, increased in numbers from 1987-89 before starting a downward trend. These kinds of frequency patterns also raised new questions about the ecological reasons why bee frequencies change through time (Frankie *et al.* 1993).

In California, we initiated a study in 1987 to record and monitor bee species diversity and changes in frequencies of selected species in six northern California sites (Thorp *et al.* 1992). The main impetus for this study was to record specific types of ecological data at these sites before arrival of the Africanised honeybees in the northern part of the state. For three years 1987-89, we gathered a wealth of qualitative data on cavity-nesting native and exotic solitary bees (Thorp *et al.* 1992), which was then used to design a quantitative study to examine bee frequencies and their possible changes through time. Results of this study (1990-92) were analysed using the Poisson regression (Frankie *et al.* 1998), as we had done in Costa Rica.

The California bee monitoring study has been ongoing constantly since 1990 at the six original study sites (Thorp *et al.* 1992). The first three years of this study clearly indicated significant differences among sites in bee diversity and composition; significant differences in bee frequency between sites; and significant differences in changes in bee frequency over the three year period (Frankie *et al.* 1998).

One of the most dramatic finds of the study occurred at the southern most site in the San Joaquin Valley-- Creighton Ranch Reserve, near Corcoran, California. At this site, we recorded the highest bee diversity in 1987 among all six study sites in our trial field work (Thorp *et al.* 1992). After that time, a long-term drought set in, and bee diversity and frequency declined precipitously and remained low through the winter of 1994-95 when the drought broke. Diversity and frequency of bees began to increase slowly in 1996 and then made a sharp increase in 1997, declining slightly in 1998. It is also noteworthy that cavity-nesting bees were extremely scarce on flowers at Creighton and at several other surrounding sites in the southern San Joaquin Valley during the drought period. Further, the drought had a much less severe effect on monitored bees at two other sites in the northern part of the San Joaquin Valley (Frankie *et al.* 1998). These findings raise new questions regarding weather and floral resource relationships to nesting biology of solitary bees, which must be taken into account when assessing short-term and long-term trends in bee frequencies over time (see below).

Need for additional ecological information. Trap-nesting studies provide valuable quantitative information on selected bee species diversity and changes in bee frequencies through time. They do not, however, provide insight on cause and effects of changed frequencies. It is thus important to plan ahead with specific complementary ecological studies that should provide information for interpreting bee frequency patterns. Obvious examples of this kind of study would include: i) studies on natural mortality factors; ii) monitoring usual and unusual weather patterns (e.g. drought periods, extreme rainy periods, El Niño and La Niña years); and iii) monitoring human disturbances (e.g. such as new or changing agricultural developments, pesticides, loss of preferred bee nesting habitats, fire, changes in local/regional hydrology).

Another type of ecological information that can be obtained concerns the selection of bee taxa as bioindicators of habitat change or environmental health. In our comparative bee monitoring work on *Andira inermis* in Costa Rica, we observed that changes in agricultural development over a 24 year period may have had their greatest impact on megachilid bees and stingless bees as evidenced by their noticeable decline in species diversity and frequency (Frankie *et al.* 1997). Much more work is needed to document taxa that are most affected by ecological changes and reasons for their sensitivity.

DISCUSSION

Bee monitoring in California and Costa Rica has proved to be a useful tool for answering a wide variety of questions concerning pollinator diversity, relative frequency, preferred habitats, and changes in frequency through time. The most important types of monitoring were those driven by questions that required quantitative collections of data, which could be replicated within seasons and annually. Information-filled monitoring programs, which are desirable, should contain the following kinds of characteristics:

- **Concept.** A well-defined concept stating the problems, goals and limits of monitoring study is a prerequisite.

- **Questions.** Good questions or hypotheses must drive each monitoring program. The scope of the question should be reasonable to insure that finding an answer is feasible.

- **Appropriate design** and **statistical analysis** of data should be well planned in advance of the first data collections. Pilot studies may be necessary. Consistency of collections through time is a must.

- **Emerging trends** of bee monitoring should be considered as a **first step** in a long-term monitoring program as the trends will almost surely generate new questions concerning cause and effect.

- **Complementary ecological information**. New questions that result from emerging trends should be anticipated. They will require interpretation from additional ecological information that should be gathered at the onset of the monitoring program.

- **Flexibility**. To design experiments to test new questions as they arise from emerging trends.

Very few studies exist in the literature on quantitative pollinator monitoring, especially as it relates to long-term trends. Yet, it is important for pollinator/pollination biologists to begin collecting this type of data at specific sites that can be followed through time. It is also desirable to select sites that have already received some past pollinator studies. In some cases there is probably enough data already collected to help generate questions and perhaps to provide some historical picture of bee diversity and relative frequency (Frankie *et al.* 1976, 1983, 1997; Barthell *et al.* 1997). Recent inventories by one of us (Thorp *et al.* 1994) at Santa Cruz Island, California provide a bee data base on selected plant species that is planned for future comparative surveys to assess bee diversity and frequency. Further, extensive survey studies, such as those conducted in the mid 1970's by Hurd *et al.* (1980) on bee species diversity and frequency associated with sunflower, *Helianthus*, in the Southwestern United States, could also serve as a basis for future comparative surveys to assess the status of numerous bee species.

As recommended by New (1998, pp.21) and Scudder (1996), it is desirable to combine methods in assessing diversity and frequency of selected insect taxa whenever possible. Other workers have also advocated the use of 'sampling sets' in which several different methods are employed together to help compensate for bias of a specific approach or method (Disney 1986; Stork 1994).

We have begun to work with a combination of monitoring methods in Costa Rica to evaluate changes in forest-wide frequencies of large anthophorid bees during the dry season months of January through April. The bees, which include members of the genera *Centris* (most abundant), *Epicharis*, *Mesoplia*, *Mesocheira*, and *Xylocopa*, are considered to be the most important pollinators of a large number of plant species in this forest type (Frankie *et al.* 1976, 1983b). In a 10x10 km. site around the small town of Bagaces in Guanacaste Province, we have used the following before-mentioned methods to assess anthophorid frequencies:

1) 2x2m counts on three common primary pollen hosts and three common primary nectar hosts.
2) results of annual trap-nest studies on cavity-nesting *Centris* only.
3) results from quantitative bee sampling on *Andira inermis*.

We have also integrated selected ecological information with the bee frequency information to help in the interpretation of the findings to date.

Combined results of the three methods suggest the following anthophorid frequency pattern in the area between 1996-1999:

- large anthophorid bees were at relatively medium-high frequency levels in 1996 and 1997.
- dry El Niño conditions of 1998 severely limited flowering quantity (and probably quality) of most anthophorid bee hosts, which led to fewer provisioned nest cells.
- anthophorid bee frequencies were at extremely low overall levels in 1999, and this was probably due to sparse nest provisions from very limited floral resources available in 1998.

This assessment work will be continued at this site during the next five years with the goal of recording the likely recovery of large anthophorid bees in the area.

There remains the need to develop new statistical methods that will help evaluate the evidence collected by biologists. Any statistical methods utilised by pollinator researchers will, by logistical necessity, need to work well with what will most likely be limited sample sizes. Multivariate time series methods will inherently play important roles in assessing changes in bee frequencies through time. Of interest, for example, would be a study of the trends of competing bee species counts within the same region; likewise, counts of a bee species through time compared to concurrently collected qualitative ordinal data such as flower availability. Diversity indices are occasionally used by bee ecologists, but methods to quantify bee diversity for comparative purposes have received limited testing with mixed results (see Kevan *et al.* 1997). Other methods to quantify bee diversity have been attempted by Banaszak (1996) in Europe in both cultivated and natural seminatural environments (see also Banaszak 1980, 1995).

Where to monitor pollinators will depend to a great extent on the questions posed. Some say that only agricultural croplands should receive attention; others believe that natural areas should receive the attention. We propose that both areas are important, and wherever possible, croplands and natural areas, which are adjacent, should be monitored simultaneously. Monitoring adjacent areas will also provide for a comparative approach on a wealth of information to be generated.

At some point in the monitoring studies, there will be enough data generated to suggest how pollinators will need to be protected and enhanced in the future for appropriate crop pollination. Pollinator biologists, in this regard, should always be thinking about enhancing native pollinator guilds or communities. One possible way might be to plant agriculture field edges with pollinator food plants as has been done for natural enemy populations of herbivorous insects (Long *et al.* 1998). This would be a challenging and worthwhile project to undertake.

Finally, pollinator/pollination biologists will need to become more proactive in the future and carry their findings beyond traditional scientific meetings and journals (O'Brien 1993). That is, they will need to become more interactive with land managers, engineers, planners, and other decision makers to insure scientific knowledge on pollinators is incorporated into land management plans. Further, there are other numerous audiences that need to be educated about the important services that pollinators provide (Nabhan and Buckmann 1997). Some of these audiences could be very helpful at assisting in promoting pollinator protection and enhancement in future decision making and even in possible policy and regulatory processes.

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WHAT POLLINATOR DISPERSAL STUDIES CAN DO FOR POLLINATOR-CROP SYSTEMS

Claudia Maria Jacobi

ABSTRACT

Theoretical and empirical researches have shown the need to associate landscape structure and dynamics to population dispersal mechanisms in a series of management scenarios. The knowledge of generalized dispersal patterns in agricultural settings is particularly welcome in studies of optimal foraging and plant gene flow because they have direct applications in practical issues such as crop yield, crop isolation, and pest control. The degree of genetic isolation of a crop which is animal pollinated is tightly associated with the foraging strategy of the animal. The analysis of individual pollinators' foraging behaviour is the basis of our understanding of crop isolation (in the sense of maintaining the purity of a stand), and of beehive management in the field. Likewise, data on the foraging flight of pollinators should ideally become part of risk assessment protocols when dealing with genetically modified crops, in order to reduce unwanted crop-weed hybridization and other potential problems. Simple quantitative methods for analysing pollinator movement could be widely adopted to compare the effectiveness of prospective pollinators. I review empirical and theoretical data available on pollinator foraging behaviour and pollen flow, and discuss the patterns that emerged from the most common pollination features measured.

INTRODUCTION

The foraging behavior of insect pollinators has long been regarded as a highly useful system for the study of plant-insect interactions. It has been used as a model system in optimal foraging theory (Levin and Kerster 1974; Pyke 1978; Dukas and Real 1993) and in evaluating plant gene flow (Levin and Kerster 1974; Schmitt 1980; Rasmussen and Broedsgaard 1992). In addition, data on pollinator movements can provide fundamental information to a variety of agroecosystem studies. For example, a classical growers' challenge is the arrangement (amount and location) of beehives in the field to increase seed and fruit production, that is, to optimize crop pollination (recent experimental examples in Dag and Eisikowitch 1995; Vaissière and Froissart 1996). Another important economic issue is the maintenance of crop purity for seed production, which requires that a commercial stand be effectively isolated from the pollen of nearby relatives, wild or cultivated. The reverse situation has become increasingly problematic in recent years, with the prospective commercial release of a variety of genetically modified (transgenic) organisms (Ellstrand 1988; Klinger *et al.* 1991; Dale 1992; Kareiva *et al.* 1994).

Although the foraging strategies of pollinators are complex, a common assumption is that individuals --particularly bees-- follow the nearest neighbour pollination rule (Levin and Kerster 1974; Zimmerman 1981; Rasmussen and Broedsgaard 1992). According to it, bees foraging for nectar or pollen move to the nearest neighbouring flower or plant of the same species, if it has proved rewarding. This rule is appealing because it conforms to optimal foraging theories, and seems to be consistent (Turner *et al.* 1982).

It has been shown that bees are flexible enough to accommodate to landscape changes and therefore their flight pattern reflects resource spacing (Morris 1993, Morris *et al.* 1994). However, the rule might not apply as strongly to all landscapes. This relaxation could occur because the perception of neighbours may be influenced by factors such as floral display in a single plant, distance to other floral resources in the area, and density of the preferred floral resource. Studies on how the density and distribution of resources affect pollinator flight are common (Pyke 1978; Zimmerman 1982; Geber 1985; Fenster 1991; Pyke and Cartar 1992; Morris 1993). The response of pollinators to floral display and patch size is also intrinsically related with plant reproductive strategies. For example, plants have the option of mass blooming --which increases the chance of self-pollination-- or gradual blooming over extended periods, with the risk of reduced appeal to pollinators (de Jong *et al.* 1992).

A series of methodological approaches are currently used to evaluate individual pollinator efficiency and pollen transfer. This paper reviews the applications of these methods in several aspects of pollination research in agriculture. The usefulness and limitations of some widely-used techniques are discussed with special reference to agricultural settings.

Patterns of Individual Foraging Behaviour

The individual foraging behaviour of a pollinator species affects pollination efficiency and hence crop yield. Knowledge of these patterns is essential in any decision aiming at optimization or containment measures. The patterns of foraging behaviour can be described by a list of components, most of which are tightly associated with the response of pollinator to resource display. I comment on the most common parameters measured and the patterns that emerged from these studies.

Quantitative information on pollinator response to floral landscapes has been obtained in two different ways: by manipulating both landscape and bee visits in a very artificial ways, usually in one dimension (e.g. Manasse1992; Morris 1993), and by measuring flight parameters in large-scale landscapes, with little or no manipulation of floral arrays or bee visits (e.g. Danka *et al.* 1990).

Observations of individual movement have been made in natural, artificial and agricultural settings (Plowright and Galen 1985; Ginsberg 1986; Kipp 1987; Collevatti *et al.* 1997). Most of the quantitative data available regarding foraging of insect pollinators in crops refer to the honey bee, *Apis mellifera* L. (Kipp 1987; Danka *et al.* 1990; Greco *et al.* 1995), although there are some data available on the performance of other species, particularly bumble bees (e.g. Plowright and Galen 1985; Goulson 1994; MacKenzie 1994). Overall, bumble bees have proved to be more directional than honeybees, and perform longer inter-plant flights, therefore potentially increasing pollen flow.

Regarding the role of individual foraging in optimal pollen transfer, there is ample field evidence that only a few flowers out of those available in a plant are visited by any single pollinator(references in Di Pasquale and Jacobi 1998).This visiting strategy enhances the amount of outcross pollen and reduces that of self pollen, which is crucial for seed set in the case of self-incompatible species.

Another important pattern related to optimal foraging is the well documented preference of insects for high densities of resources. Thus, in natural systems, closely packed conspecific plants are seen as one single patch of resources and benefit from outcrossing. A large-scale monoculture would then be seen as an endless patch of the same resource. Commercial crops are extremely homogeneous landscapes compared to natural populations, as a result of the dominance of a single, synchronously available resource and the systematic distribution of individual plants. These features are typical of agricultural landscapes.

On a more detailed scale, however, each crop grows or needs to be planted in a particular way. This results in rewards like pollen and nectar being offered to pollinators in a variety of patterns, of which the most common is a landscape composed of alternating strips of high (crop rows) and low (intercrop rows) resources.

When the crop landscape is composed of distinctive alternating strips of high and low resources, it has been observed that most bees tend to forage in the same row, and have a strong forward tendency (Greco *et al.* 1995; Roumet and Magnier 1993; but see Currie *et al.* 1990). This information leads to practical horticultural measures, like in the case of asparagus, a dioecious species for which the recommendation was to grow a sequence of female plants separated by one male plant in the same row to optimize seed yield (Greco *et al.* 1995). Other crops induce directionality in the insect because of their specific growth habit. In cucurbits such as the cantaloupe *Cucumis melo*, bees seldom change rows because they visit sequential flowers along a vine (Jacobi *et al.* 1995).

Besides flight path characteristics among resources, a very important parameter to evaluate pollinator efficiency is the extent of pollen carryover, i.e. the number of sequential plants or flowers that receive pollen from a focal plant. Pollen carryover is a function of physical and behavioural characteristics of the insect related to pollen handling. Carryover has usually been estimated based on the percentage of stigmas marked at different distances from a donor plant, the mark being either differentiated pollen, or pollen analogues like powder dyes (Thomson *et al.* 1986; Cresswell *et al.* 1995). Typically most pollen is transferred to the first few flowers (Cresswell *et al.* 1995; Mogie and Stamp 1995).

Finally, pollinator efficiency depends also on the fidelity to a floral resource. Although flower constancy is the rule in pollination, heterospecific pollen transfer (i.e. a single bee carrying mixed loads of pollen) is not uncommon in natural habitats and can affect the reproductive success of plant populations (Campbell 1985). High levels of resources, typical of crops, significantly reduces heterospecific pollen transfer (McLernon *et al.*1996). Still, there is some controversy over the comparative degree of floral constancy of honeybees and other bees. At least in some crops like cranberry, honeybees have proved to be inferior as pollinators compared to bumble bees (MacKenzie 1994) and leafcutter bees (Cane *et al.* 1996), on account not only of slowness and the percentage of illegitimate visits, but also of heterospecific pollen loads.

Estimating Pollen Flow Via Flight Patterns

Pollination is the most important component of gene flow because it is during this process that genes are exchanged among individuals. The combined knowledge of flight patterns of a pollinator and pollen carryover can give an estimate of genetic neighbourhood and gene flow of a plant species. The adoption of measures aiming at crop isolation will depend on studies of pollen flow.

Methods related to containment strategies are of several kinds, varying from genetic modifications (*e.g.* male-sterility) of a cultivar to physical barriers such as surrounding a crop with barren land or with a related variety that will act as a pollen-trap. The purpose in both cases is to hamper unwanted pollen flow, be it from wild populations to a cultivar that has to maintain its genetic purity, or from a transgenic crop to populations of non-transgenic commercial varieties or wild relatives.

Recent studies (*e.g.* Klinger *et al.* 1991; Rasmussen and Broedsgaard 1992; Antrobus and Lack 1993) have shown that gene flow in seed plants is not as limited as suggested by earlier techniques. However, it is still considered restricted, because of the short-range movement of most pollen and seeds (Bos *et al.* 1986; Golenberg and Nevo 1987; Gouyon *et al.* 1987; Jackson and Clarke 1991).

There are two kinds of methods for quantifying gene flow in the field: a) direct methods based on tracking marked individuals or their vectors (*e.g.* Philipp *et al.* 1992; Rasmussen and Broedsgaard 1992; Eguiarte *et al.* 1993) and b) indirect methods that infer patterns of gene flow from the spatial distribution of genetically marked offspring (*e.g.* Handel 1982; Fenster 1991; Klinger *et al.* 1991; Ranker 1992; Eguiarte *et al.* 1993).

Indirect methods have the disadvantage of not disclosing the dynamics of gene dispersal, nor the identity of its agents. It is thus difficult to adopt any sort of containment measure of pollen movement, which is the phenomenon to be focused on in the case of temporary populations such as crops. Estimates of pollen movement based on pollinator behaviour, on the other hand, give a clear picture of the dynamics of pollen flow, since the agents are known (Cresswell *et al.* 1995), and have a more robust predictive power. Because the degree of isolation of an entomophilous plant population is linked to the flight characteristics of its main pollinators, data on pollinator foraging behaviour have been incorporated into quantitative models that specifically aim to predict pollen dispersal (Morris 1993, Morris *et al.* 1994).

A widely used method, proposed by Kareiva and Shigesada (1983) consists in following individual bees from flower to flower for several steps. Visited flowers are numbered consecutively. The flight path is then reconstructed by measuring step lengths between two consecutive stops, and the turning angle between these two. These two measures can be incorporated into equations to obtain information on the distance covered after a certain amount of visits, or net squared displacement. In order to simplify the model, an important assumption is that the organism exhibits the same probability of turning left or right, in which case the expected net squared displacement is

(1)

$$E(R_n^2) = nE(l^2) + E(l)^2 \frac{c}{1-c}\left(n - \frac{1-c^n}{1-c}\right)$$

Where:
l is the mean step length
c is the mean cosine of the turning angle
n is the number of steps.

This method uses meaningful biological parameters that are relatively easy to measure in the field (*e.g.* McCullough and Cain 1989;Turchin *et al.* 1991; Cresswell 1997). It also simplifies comparative approaches of pollen flow by different insects.

If some measure of flight time is also recorded in addition to calculating the two variables (step length and turning angle) mentioned above, then the necessary requirements are completed for the eventual use in what are known as diffusion or diffussion-advection models (refs. in Cresswell *et al.* 1995), with the general equation

(2)

$$\frac{dP}{dt} = -c \frac{dP}{dx} + D \left[\frac{d^2P}{dx^2}\right]$$

Where
P is the probability of finding an individual forager at point x and time t
c is the advection velocity
D is the diffusion coefficient

The results are useful in deciding upon the necessary containment measures of genetically engineered crops, and complement gene flow studies based on indirect methods. Cotton, for example, is one of the leading transgenic target crops, so assessment of containment measures in different geographical and ecological settings is mandatory (Kareiva *et al.* 1994). As part of these studies, I compared the flight behaviour of bumble bees and honeybees, each being the main pollinator of a particular commercial cotton field. I assumed that the bees faced similar conditions of resource display, as a result of the standardization of commercial plantations. My results confirm the general view that bumble bees are more directional and perform longer flights between plants than honeybees. This behaviour increases the chances of long-distance pollen transfer, consequently aggravating the risk of transgenic gene invasiveness through hybridization with unmanaged populations.

DISCUSSION

There are two scales at which insect dispersal parameters can subsidize pollinator management techniques. One is the population scale, encompassing aspects of habitat, nesting sites, home range and territoriality, which can affect management of hives, and can give support to decisions concerning marginal land use. The second is the individual scale at which the pollinator transfers pollen among individual plants or flowers of the target crop. At this level, assessment of pollinator efficiency is made through parameters related to individual foraging such as behaviour on the flower, pollen packing, legitimate visits, flower constancy and pollen carryover. Few single studies, however, measure and associate more than two or three of these parameters, and even these have concentrated on honeybees.

Crop pollination throughout the world faces the risks of a very high dependence on a single pollinator, *A. mellifera* (Torchio 1990). One of the solutions to these risks has been to encourage research projects that develop breeding systems and appropriate bee management techniques with bees other than *A. mellifera*. Another reason for proposing greater investments in using pollinators other than *A. mellifera* is that this species has shown to be a poorer pollinator than managed bumble bees (MacKenzie 1994) or leafcutter bees (Cane *et al.* 1996) in various crops (Torchio 1990, Richards 1993). A recent review (Heard 1999) has confirmed that in the tropics, stingless bees (Apidae:Meliponini) are the effective pollinators of nine crop species and contribute to the pollination of some 60 other, but evidence is still lacking for many plant species (see also Roubik (Ed) 1995).

Although a large amount of research has been devoted to test the ability of a few non-*Apis* bees as pollinators of commercially important crops (*e.g.* Richards 1993, 1995; Rahman and Chopra 1994; Cane *et al.* 1996), data are still inconclusive to effectively support the adoption of a series of non-*Apis* pollinators in many areas of agriculture. One of the main items to investigate is how native bees react to the attractiveness of particular crops. At the scale of a commercial plantation patch attractiveness is obviously not an issue, so concern switches to evaluate the capacity of bees to reach plants in central positions or away from pollinator nesting sites, the attractiveness of the resources offered compared to nearby wildflowers, and the flight behaviour in a landscape of rows and furrows. Brookes *et al.* (1994) found that the extent of alfalfa pollination by native bees is highly dependent on the resources offered in marginal lands, and that some of them do not visit the central part of the crop.

It was also flight studies that indicated that africanized honeybees could be as effective of pollinators as European honeybees (Danka *et al.* 1990), so that the problem of their invasiveness should be looked for elsewhere than in crop yield. These examples demonstrate that it would be useful to extend this type of studies to other potential pollinators, preferably with standardized techniques or protocols, because many studies in natural landscapes have shown a large difference in gene flow depending on the main pollinator (*e.g.* Schmitt 1980).

CONCLUSION

Studies of pollinator foraging movements have proven useful in a series of agricultural problems, particularly related to crop isolation and yield. Most of these studies, however, have focused on a single species, *A. mellifera*, or have used a methodology that rendered comparisons with other studies difficult. A series of quantitative methods are available that could be applied more frequently or even be introduced in protocols so as to facilitate comparisons between prospective pollinators and different agricultural landscapes.

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THE NEW KEY TO BEES: AUTOMATED IDENTIFICATION BY IMAGE ANALYSIS OF WINGS

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ABSTRACT

World-wide studies on bee diversity, conservation and on pollination ecology are hampered by the difficult taxonomy of bees, the lack of suitable literature and bee taxonomists.

The automated identification system consists of an electronic notebook connected with a CCD camera mounted on a stereomicroscope. The identification of bees is based exclusively on characters of the fore-wing venation: The fore-wing is video-recorded and the image of the wing is transferred to the notebook. With a mouse-click the user marks defined vein junctions. The system then connects the junctions by automatic line-following and thus digitises the whole venation. The system has to be trained with a minimum of 30 well defined specimens of each sex per species. With data of each bee it learns and gets better. Species identification is achieved by automatic comparison of incoming data with already memorised data. Currently the system employs linear and non-linear discriminant analysis methods. We tested the system with very difficult cases like closely related species of *Andrena*, *Bombus* and *Colletes* which are a real problem for traditional taxonomy. In all cases the system identified the species with a confidence between 98 and 99,8%.

This system can be applied by museum taxonomists as well as by field workers with no special training in bee taxonomy. Dry specimens as well as live bees can be identified. Identification of a bee takes no more than 5 minutes. Wing images or readymade data can also be sent on disc or via internet to institutions which offer this automatic identification service.

INTRODUCTION

We can only monitor and conserve those animals that we know. For a long time all of us have been aware that studies on bee diversity, on conservation of bees and on pollination ecology are severely hampered by to

- the difficult taxonomy of bees,
- the lack of bee taxonomists
- and as a consequence the lack of classification literature such as modern identification keys and actual revisions of many taxa (O´Toole 1996).

These were the main reasons we developed a computer-based system for the automated identification of bees. Such a system should use the informations hidden in the wing venation. In the early stages of the development of the system (Schröder *et al.* 1994) many experts in bee taxonomy had severe doubts about this approach, as in classical bee taxonomy wings are rarely used for identification to the species level. Their general assumption was that there is too little discriminative information in the wing venation. Already in the1950's, when numerical taxonomy was developed as a helpful tool in taxonomy, other experts envisioned at least semi-automatic identification machines (Michener-by personal communication). However, at those times image processing and other computer tools were not available to realise such visionary plans.

Our automated identification system has the following advantages:

- it is small, mobile and handy so that it can be used in the field
- it works with live bees as well as with mounted collection specimens without removal of any body parts
- it works with a minimum of interaction by the user
- to operate the system, no knowledge of taxonomy is required
- only wing venation is used to identify bees to the species level.

The system should enable any person or working group which studies bees

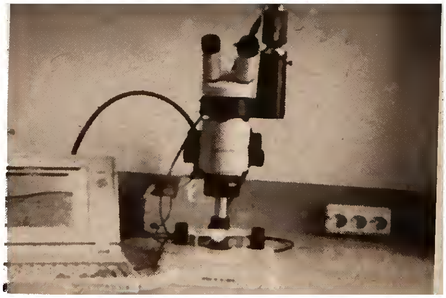
- to either install and operate its own identification system or
- to send photographs of wings via mail or via internet to an institution which provides access to its identification system.

MATERIAL AND METHODS

Hardware

The identification system consists of an electronic notebook connected with a CCD camera which is mounted on a stereomicroscope (Fig 1). The notebook is equipped with a standard video port in the PCMCIA-slot. The image of the wing is transferred from the camera to the notebook.

FIGURE 1: The portable identification system.



Software

Image processing: The identification of the bee is based on characters of the venation of the fore-wing like vein length, width, curvature, angles and descriptions of the cell area. To extract these parameters from the wing image we equipped the system with a modified automated line following program (Steinhage *et al.*1997).

Identification: For the identification the system employs the discriminant analysis. For statistical analysis we currently employ linear discriminant analysis (Hastie *et al.* 1994) but also non linear methods (Schölkopf *et al.* 1998). All identification processes are conducted by our newly developed and adapted programs.

RESULTS

A) Identification process

The result of our study is an identification process which consists of simple manipulations carried out by the user and the following 2 processes - image analysis and identification - which are conducted automatically by the system. However, it should be made clear that before any bee can be identified, the system has to be trained.

1. Training

For this it is necessary to have at least 30 specimens of each species. These bees must have been well identified by experienced bee taxonomists. In the training phase one fore-wing of each specimen has to be processed in the below described steps. The system memorises all data of each bee that participated in the training. With each further bee which is grouped into the training set the confidence of the identification will increase.

2. Image analysis

The first action of the user is to clip the fore-wing of the bee under a microscope slide and to video-record it. This procedure is done in a few seconds. The image of the wing appears on the screen and will be stored in the database. If a alive bee has been used, it can now be set free again.

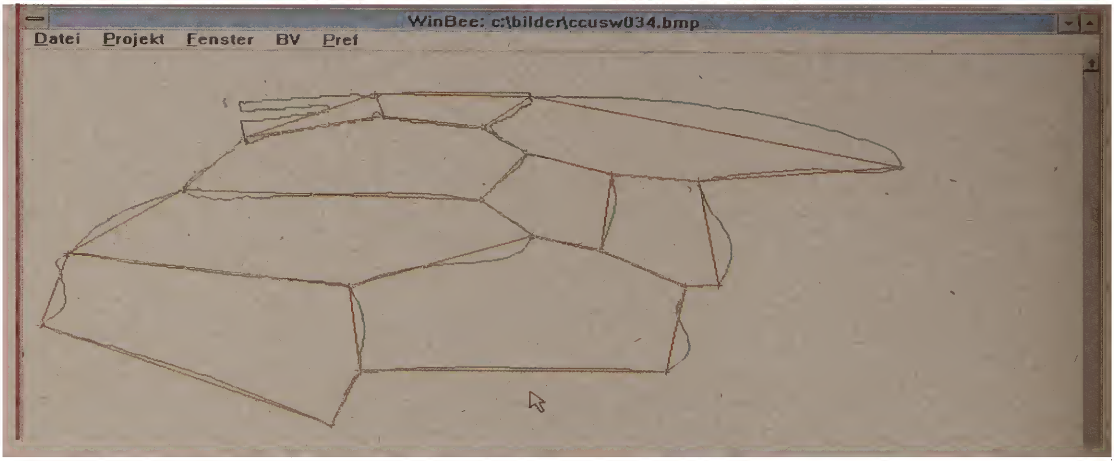
Now follows the image analysis that consists of two steps.

a) Only in the first step the user interacts with the system. Supported by the program he marks defined vein junctions with a mouse-click. The system then connects the junctions by automatic line-following.

For the final version of the system we are actually working on the implementation of a completely automatic image analysis with which the system itself detects and marks the vein junctions.

FIGURE 2: The vein junctions were zoomed and marked with a mouse click (insert lower right). The line following program has then digitised the wing venation.

FIGURE 3: From the wing image (curved lines) the venation graph is extracted. This is the graph in which all vein junctions are connected by straight lines



As a prerequisite for any identification process, characters have to be named and measured. However, while the system follows single venation lines and measures all elements like the length of the veins, the angles between them and the area of all cells it has no information about the surroundings, for example, whether it is measuring the first or second cubital cell.

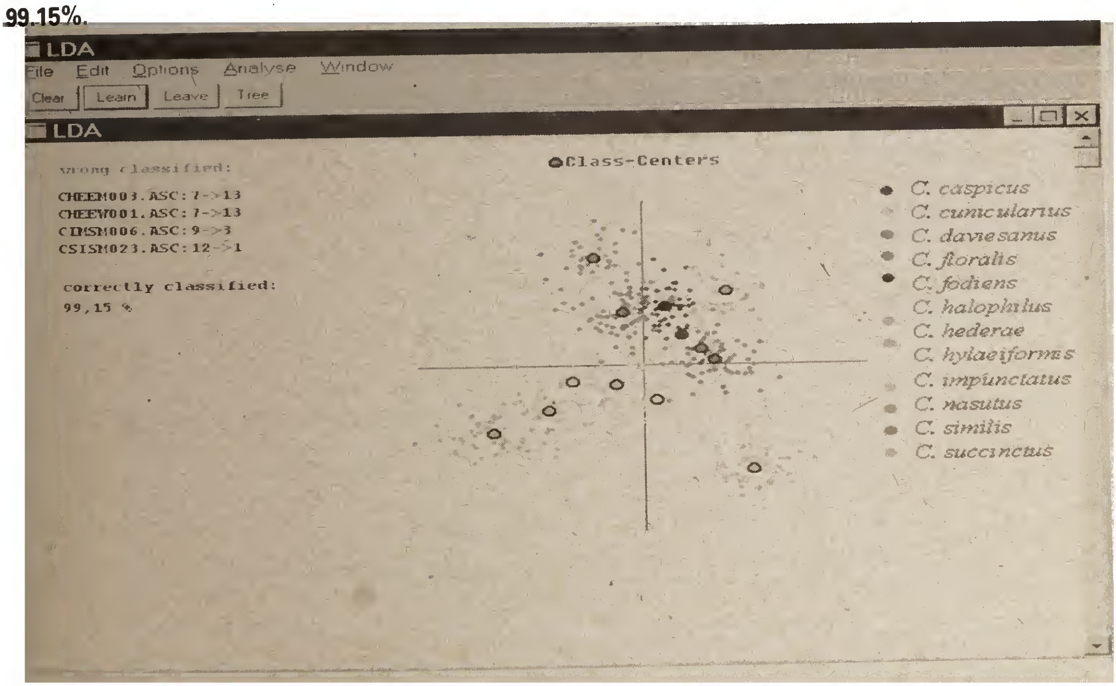
b) Therefore, in the second step of image processing the system has to name veins, angles and cells. This task is resolved by automatic comparison of the graph with model-venation-graphs from the database. Only when all features are named then all data can be stored in a data file together with the correct name of the measured item.

To represent all European bee genera the system needs only 9 model vein graphs. If we would add a South American bee that does not fit these graphs, the system would ask whether we want to incorporate this new wing graph as a model graph.

3. Identification

The image analysis results in a data file with about 200 measured features of the venation. All attributes and relations of the veins, junctions and cells of an extracted vein graph can be used as quantified characters for a statistical identification process. The system currently employs multivariate discriminant analyses that are implemented in a newly developed classifier for the automatic processing of the identification. In the first phase of the discriminant analysis the classifier uses the data of the training specimens to calculate the discriminant functions. In the second phase these functions are used with the data of the unknown bee to calculate its position in the multi-dimensional classification space.

FIGURE 4: A screen snap that shows the status of the trained system ready for the identification of an unknown bee. Coloured dots (here grey scaled) represent the 469 specimens of 13 species. Names of the species are given on the right. Left: Code names of 4 training specimens that could not be grouped to the right clusters. Lower left: classification rate = 99.15%.



```
wrong classified:

CHEEM003.ASC:7->13
CHEEW001.ASC:7->13
CIMSM006.ASC:9->3
CSISM023.ASC:12->1

correctly classified:
99,15 %
```

B) Application tests and confidence control

We tested the automatic identification steps with difficult cases of closely related species of European bees (see below). Here we present the test with 13 *Colletes* species, which is a real problem for traditional taxonomy.

1. Training of the classifier

For this test and for the confidence control the system has been trained with 469 specimens of the 13 *Colletes* species. In Fig.4 these specimens are represented by dots which form 13 clusters around their class centres. One should be aware that in the reality of the system these clusters are distributed in 12 dimensions. This means the clouds are much more distant from each other with little intermingling. After the training the system gave the list of those 4 bees which could not be attached to their species cluster. Reasons for this may be that these training bees were not correctly labelled or that they have aberrant venation. In this test 99,15% of the training bees were attached to the correct cluster (classification rate).

2. Identification of an unknown bee and confidence test

For the identification of an unknown bee the data of its image analysis are loaded and automatically processed in the trained classification program. The result of the identification is shown as a screen snap in Fig.5.

Any time after the training the user can check the system with the so called "leave one out test" (Fig.5). This test measures the identification confidence wich is achieved with the actual training set of bees. In this test the system calculates the position of each but one *Colletes* bee species in the database. It then incorporates the data of the one bee that was left out and then leaves out the data of another bee. It repeats this for each of the 469 specimens and then gives the confidence of the identification, in this case 98.3%. In general the identification will became even more confidential with an increasing number of training specimens.

A further ability of the program is to calculate the real distances between the clusters in the multi-dimensional classification space. These distances are represented in a dendrogram that gives a preliminary view of species similarity (insert in fig.5). Such dendrograms may be useful as a first indication of phylogenetic relations between species.

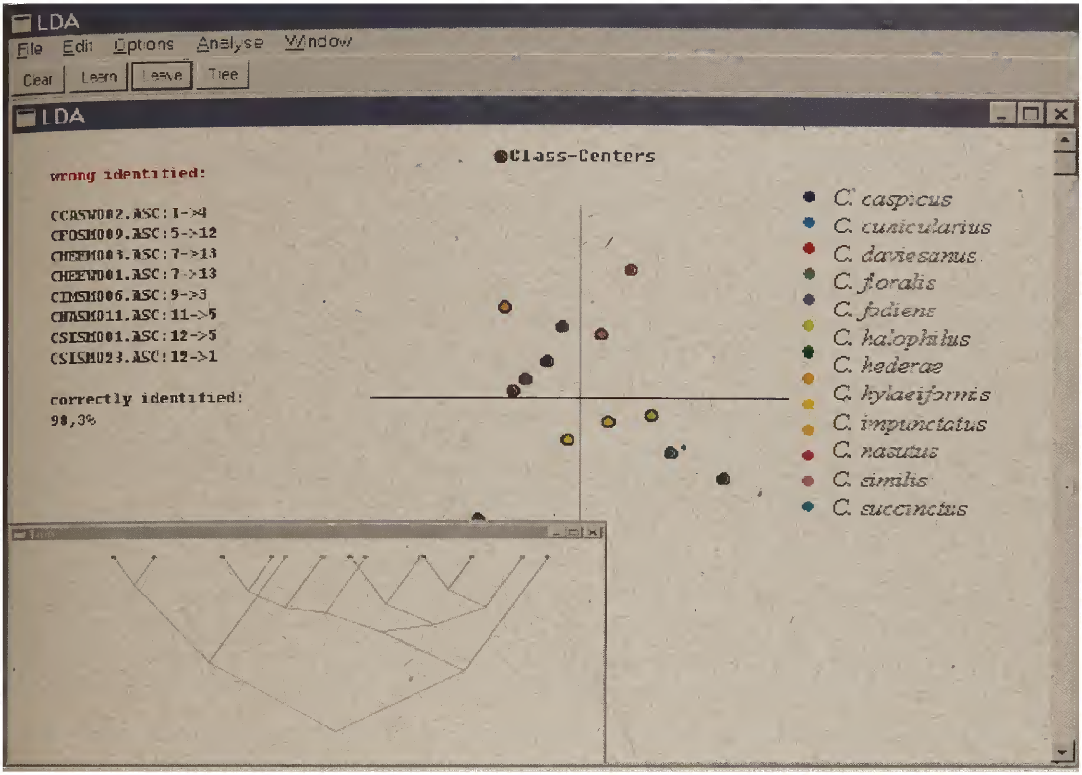
3. Further applications

The application of the system was also successfully tested with closely related species of the genera *Andrena, Osmia* and *Bombus* (Schröder *et al.* 1995, 1998).

Also, in all cases bees of different sexes could be distinguished by the system. In the case of social bees it succeeded in separating casts and different *Bombus* populations and even colonies. We also have adapted the system to cope with reduced wing venation as in stingless bees. Analyses of the "similarity" of populations could give new and important information for species conservation.

The system was also successfully applied to identify other Hymenoptera like wasp species of the genera *Ceramius* (Masarinae) (Mauss 1998).

FIGURE 5: Screen snap showing the result of the identification: The single dot (marked by an arrow) represents the unknown specimen. It was identified to belong to the cluster of *Colletes succinctus*. Upper left: list of those bees that could not be identified during the "omit one" test. Insert: Similarity dendrogram calculated from the distances between the clusters.



```
wrong identified:

CCASW002.ASC:1->4
CFOSM009.ASC:5->12
CHEEM003.ASC:7->13
CHEEW001.ASC:7->13
CIMSM006.ASC:9->3
CHASM011.ASC:11->5
CSISM001.ASC:12->5
CSISM023.ASC:12->1

correctly identified:
98,3%
```

DISCUSSION

This identification system is by no means a substitute for well-trained taxonomists. Rather, it requires them to establish training a set of well-identified specimens. Once trained and installed, the system unburdens taxonomists from routine identification jobs giving them more time for the scientific work on species descriptions and revisions etc. As the system employs statistical identification methods the results can be checked by a confidence test. This is a great advantage in comparison with the use of conventional keys.

The data in the training set can easily be copied and made available for other researchers who can work with it and eventually add further data to it. Thus the data, which can be viewed as a digitised reference collection, can rapidly be increased and multiplied. They can swiftly be given from one working group to another: Wing images or readymade data can be sent on disc or via internet to institutions which offer this automatic identification service.

Important for the effective operation of the system is a large pool of training data. To build up this database, we suggest that those institutions which want to employ the system should form a network. Museums, universities, private institutions and any other students of bees should co-operate in the exchange of bee data in order to create the basis for an automated identification of bees on the local, regional or countrywide level.

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MELISSOCOENOLOGY: HISTORICAL PERSPECTIVE, METHOD OF SAMPLING, AND RECOMMENDATIONS TO THE "PROGRAM OF CONSERVATION AND SUSTAINABLE USE OF POLLINATORS, WITH EMPHASIS ON BEES" (ONU)

Sebastião Laroca and Afonso Inácio Orth

ABSTRACT

Melissocoenotic studies are key for the conservation of plant biodiversity, because pollinators play an important role in the reproductive success and gene flow of many important plant groups to agriculture and forestry and these plants in turn are important food sources for pollinators.

Melissoecoenology emerged in southern Brazil after the development of a method to gather standardized samples of pollinators (Hymenoptera: Apoidea). The sampling of pollinators consists basically of collecting wild bees on flowers without random sweeping, in which the restricted sampling area and duration of the survey are previously fixed.

The analysis of five, long term surveys, carried out in the center of the city of Curitiba, PR and in the surroundings of the Airport Afonso Pena (São José dos Pinhais, PR) are presented. Some changes, mostly negative, in the patterns of bee species composition and their abundance allowed us to make some recommendations in order to preserve, restore and avoid the extinction of the wild bee populations in urban and agricultural areas.

INTRODUCTION

The demand for melissocoetic knowledge (the interactions of bees with their environment) is becoming a key issue in biological diversity studies. In parallel of the necessity of such data for implementing practical policies involving conservation issues, the number of worldwide contributions has also been increase quickly since the sixties, when the development of the melissocoenotic approach began. These kinds of studies require a multidisciplinary approach. In fact, it combines a multitude of disciplines ranging from meteorology, edaphology, phytochemistry, ethology, energetics, phenology, palynology and taxonomy, besides integrative fields such as geomorphology, paleoecology and biogeography. All studies characteristically require evolutionary approach. In other words, they are genuine ecological approaches.

The melissocoenology mainly emerged in southern Brazil, and some of its first steps were made in the early sixties by Sakagami and Laroca, they developed a method in order to gather standardized samples of pollinators (Hymenoptera: Apoidea), that permit quantitative comparisons, and therefore allow spatial/temporal analysis of bee assemblages. Sakagami came to the Universidade Federal do Paraná, Curitiba, Brazil in 1961 to study sociology of wild bees, halictines, following earlier work by Michener and Lange. Sakagami was especially interested in: weather effects on bee activities, annual cycle of particular species, their flower preferences, as well as some biogeographical correlations, as tools for his taxonomic and sociological studies. Laroca, as his field assistant, was interested in studying truly ecological interactions; so his studies were directed to meteorology, natural history (undergraduate), geomorphology (specialist), and entomology (M.Sc. and Ph.D., with concentration in community ecology and insect behavior).

The planning of the first census project (São José dos Pinhais survey) began in Paraguay, in 1961, when Sakagami and Laroca visited Schrottky and Bertoni's Hymenoptera collections and the rich and diversified ecosystems of the Chaco. Laroca (from March, 1962 to February, 1963) did most of the fieldwork, while Sakagami went to Rio Claro (São Paulo) to work with Kerr and collaborators. The first study site, in the vicinities of the Aeroporto Afonso Pena (São José dos Pinhais, PR, Brazil), was chosen for its potentiality for high insect diversity as suggested by Marston (USDA) and Laroca in 1959. The first publication was that of Sakagami, Laroca and Moure (1967), a joint contribution between Hokkaido (Japan) and its antipode Paraná (Brazil). This paper presents one of the first attempts to establish a quantitative sampling of bees at their food site, with a standardized procedure in relation to space and time. Before Sakagami *et al.* (1967), there were only two similar papers, one on research from near the Chicago surroundings (Pearson, 1933), and another from the Ukrainian steppes (Osychnyuk, 1959).

The Pearson's paper is of particular interest because it has a heuristic relationship with the work of the "Chicago School" (such as the classical works of Cowles, Clements, and Shelford) immediately following Wraming's publication of Lehrbuch der Oekologischen Pflanzengeographie. While in Lagoa Santa (Minas Gerais) Brazil, Warming discovered and described the phenomenon of ecological succession.

In South America, besides the work of Schrottky (*e.g.*, Schrottky 1908 and 1909), we also draw attention to contributions of important mellitologists such as: Ducke, also a botanist (1901, 1902), Jensen-Haarup (1907, 1908) and Jörgensen (1909, 1912) and Nogueira-Neto (1997) and North-Americans such as Schwarz (1948), Michener (1954), Hurd and Moure (1963), Mitchell (1980), and Europeans such as: Smith (1863).

Although not directly related to the subject at hand, Michener *et al.*'s study (1958), based on an assemblage of bee nests in earth around Curitiba, considers associative ecology germane applied to the study of pollinators and their conservation.

More recent papers on melissocoenoses are by, Sakagami and Fukuda (1973) from the campus of the Hokkaido University.

Then from 1976 to 1978, one of us (SL) made censuses in three temperate melissocoenoses in the surroundings of Lawrence (Kansas) as part of his Ph.D. studies. Unfortunately most of the data are not yet published.

Since the beginning of the eighties, in Brazil, from the steppes (pampas) of Rio Grande do Sul to the Amazonian rain forest region, several excellent thesis and articles have been presented and/or published.

Those contributions together with those our group from the Universidade Federal do Paraná deal with melissocoenotics under several conditions, ranging from typical urban to agricultural and little disturbed nearly wild habitats. In this chapter, we describe the methodologies and compare long term studies done in a single community of bees (Hymenoptera: Apoidea). Thus, we wish to contribute to diversity monitoring at the community level in the "International Program on the Conservation and Sustainable Use of Pollinators in Agriculture, with Emphasis on Bees".

MATERIAL AND METHODS

The following methodology for sampling pollinators has been compiled from Laroca (1983) based on the studies described above. Basically, it consists of collecting wild bees on flowers or in flight near the flowers without selecting which bees are to be taken. The samples are separated on an hourly basis. Each bee is collected individually or in a group, but not by random sweeping. The specimens are transferred to various killing tubes according to the flowers visited (the number of killing tubes corresponds to the number of species of plants in bloom in each collecting day). A sampling day is divided up into four collecting hours. In each hour 1/4 of the study area is sampled. Prolonged collecting in a particular spot should be avoided. For instance, in dense flower patches, which attracted many bees, as many specimens as possible are captured at a precise moment, then the collector moves on, not waiting for the arrival of more bees.

Weather conditions (temperature, wind velocity, relative humidity, cloud cover, and insulation) are recorded at the start of each collecting hour. In the laboratory, each specimen is labeled according to the date, hour, and flower visited. In our samplings, *Apis* was not taken but its relative abundance on the flowers in the study sites was recorded.

The results obtained by the above method are not free from sampling biases. Some sources of error are: influence of the removal of individuals from the total assemblage, adoption of individual capture instead of random sweeping, relative ease of capture based on specific differences, differences in distinctive flower visiting habits, and varying efficiency of the parts of collectors.

Influence of removal of individuals upon the total assemblage

This is a serious defect of the method but inevitable because it is almost impossible to identify many of the bees in the field. Linsley and MacSwain (1959) use capture-identify-release method in estimating the number of andrenid bees visiting *Ranunculus* flowers. Heinrich (1976) counted the number of easily identifiable foraging bumblebees in walking transects, without capture. This method is more accurate in gauging temporal changes in the composition of the bee populations on flowers in a given area than capture and removal of the bees from the flowers would be. The influence of removal is more drastic for rare species, especially if collecting is selective. In most cases this effect is probably small because collecting is: normally only four hours per week. Every effort has to be made to avoid selectively collecting rare species.

Adoption of the individual capture method instead of random sweeping

Random sweeping is sometimes efficient. For instance, for small and inconspicuous bees (such as *Perdita, Hylaeus, Lasioglossum, Ceratinula* , and *Leurotrigona*) might be missed by using one-by-one capture method. On the other hand, the efficiency of random sweeping for capturing sensitive, strong flying insects, such as large bees which are visiting (not inhabiting) flowers, is relatively low.

Relative ease of captures resulting from specific differences

Generally, the larger, slower, less sensitive bees with conspicuous coloration or other peculiarities are more easily discovered and caught than those with opposite features. Species with painful stings, such as bumblebees, require more time to transfer from the net to killing tubes. On the other hand, bees such as *Niltonia, Plebeia, Tetragonisca, Melipona, Trigona* and certain *Andrena* that do not sting are easier to manipulate. Noisy fliers, such as *Megachile, Xylocopa,* are also more easily discovered. Excessively hot or cold conditions differentially affect the bee species, inhibiting activities of stenotherms. Also, nocturnal and crepuscular species one usually ignored by daytime sampling.

Flower characteristics and their influences on bee sampling

The estimation of relative abundance of oligolectic bees tends to deviate from the actual density because the flowers visited by these bees are either dispersed or patchily distributed, so that the rate of discovery varies from case to case. Bees that visit spiny plants are often difficult to collect, and the capture of bees visiting flowers on tall trees is usually impossible. This is particularly important in habitats in which tall trees, lianas and epiphytes are abundant but is not important in open areas, such as prairies, steppes, tundra, savannas and shrubby vegetation. The contrast between flower color and visitor color seems to be important too. Generally the bees tend to be dark and, therefore, when visiting flat, open, pale colored flowers, they are easy to see and catch. Finally, there is a natural attraction of individual collectors towards peculiar flower colors and shapes and that can bias sampling of bees.

Varying efficiencies by personal differences of collectors

The ability to discover and catch bees varies among persons. Some knowledge of bees, their flower visiting habits and locomotion patterns, is needed.The fatigue of the collector has also to be considered, but division of each sampling day into separate periods can reduce the effect.

Data Bank Structure And Manipulation Of Community Information

One of us (SL) developed (1976, Laroca *in lit.*) a structure of a data bank and a FORTRAN program to manipulate it for information about ecological communities. Several versions of this program (Fortran IV, Basic, and dBase) are available. The data banks are described and discussed in Cure and Laroca (1984), Schwartz and Laroca (1999) and Jamhour (1998).

Diversity monitoring parameters for pollinators, and recommendations, based in two long term melissocoenotic studies

Two long-term melissocoenotic studies in Curitiba (one around Airport Afonso Pena (Município de São José dos Pinhais) and the other city center of Curitiba (Passeio Público) were made detect general ecological patterns. For the Airport site we have two one-year samplings, from March 1962 to March 1963, and from March 1981 to March 1982. In the last few years, this site was practically destroyed. The one-year samplings at Passeio Público were as follows: from January to December 1975 (approx. once a week); from June 1986 to June 1987 (once a week) and from June 1992 to May 1993 (once every two weeks). Passeio Público is a public zoological garden situated just in the central part of the city of Curitiba. The collecting site suffers air pollution by solid particles and chemicals, intensive gardening, large and increasing number of human visitors, strict control of honeybee colonies by heavy use of insecticides, loud noisy and vibration from vehicular traffic, etc. Thus there are frequent radical and erratic changes. The only factor that was more or less stable was the presence of native and exotic species of trees (*Ligustrum*, oak tree etc.).

The data are discussed in the strict field of melissocoenotics but also in specialized books (*e.g.*, Roubik 1992); textbooks (Laroca 1995) and educational biology papers (Nagasawa, 1969). Reports on the melissocoenoses of Passeio Publico are by Laroca, Cure-Hakim and Bortoli (1982), Taura and Laroca (1991), Almeida and Laroca (1988); and thesis: Taura (1990 and 1998).

The effort of capture in the two periods and places was different. In 1962/63, 130 hours of effective collecting were performed but in 1981/82, 150 hours. The number of species recorded is the same in both periods (167 spp.), but the number of individuals is very different: 4,218 individuals in 1962/63, and 1,906 individuals in 1981/82 (average number of individuals 32,4 and 12,7 per hour respectively). The diminished populations seem to be related to intensification of agricultural (horticulture) activities and reduction in the abundance and possibly diversity of native plants.

A group that nearly faded out the between first and second survey was the parasitoid bees, including the extinction from the Airport site of seven genera. In *Coelioxys* for instance, there were five species represented in the 1962/63 sample, but only one remained in 1981/82. On the other hand, the number of potential host species (Megachilidae), although with lower populations increased, perhaps as a result of the decrease of parasitoid species but possibly also because of the increase of diversity of appropriate leaves for constructing their nests. In Andrenidae there was a light increase in number of species, as well as in Anthophoridae. In Meliponinae, in 1962/63, there were three species (*Trigona spinipes*, *Plebeia emerina* and *Melipona q. quadrifasciata*), but in 1981/82 only one (*Trigona spinipes*) remained. The population of the remaining species decreased drastically (from 675 individuals to 9 individuals). This pattern seems to be linked to the extinction of appropriate nesting substrates.

In both samples there were three species of bumblebees, two more generalists in terms of habitats: *Bombus morio* and *Bombus atratus* and one, possibly, more specialized and distributed in the natural open fields of South Brazil and Argentina (*Bombus bellicosus*). The relative abundance of *Bombus bellicosus* decreased greatly from 1962/63 to 1981/82 but the relative abundance of *Bombus morio* and *Bombus atratus* increased.

In Anthophoridae, the number of species, from 1962/63 to 1981/82, increased a little, but the parasitoid genera: *Trophocleptria* and *Isepeopus* present in 1962/63 did not occur in

1981/82 sample. In Halictidae, the number of species decreased (from 88 in 1962/63 to 79 species in 1981/82). A unique genus of parasitoid bee (*Temnosoma*) disappeared from 1962/63 to 1981/82 sample and in Collectidae the same tendency was seen (from 10 species in 1962/63 to 7 species in 1981/82).

The assemblage of the plants visited by the bees has also been modified. In both samples, the bees were collected on the flowers of 118 species of plants. From this total, 32 species are common in both periods, but 35 species are exclusive to 1962/63, and 51 species are exclusive to 1981/82. Exotic plant species comprised 4 in 1962/63 and 10 species in 1981/82. Thus, the number of invading plant species greatly increased.

Changes in the pollinators (Apoidea) community inside the metropolitan city of Curitiba (Paraná, Brazil)

In Passeio Publico, the decline in species was great: respectively from 74 species (1975), 70 species (1986/87) to 49 species (1992/93). The changes seem to be related to the growing urbanization, local extinction of some plants, such as *Polygonum puctatum* (habitat destruction), *Abutilon bedfordianum*, *Cosmus* sp. (cultivated), that were the main food resources for many bee taxa, construction of barriers (wide streets) and insecticides for control of Africanized bees.

It seems that the success of certain species of Meliponinae species in an urban biotope inside a large city such as Curitiba, reflects the ecotonal preferences of the Meliponinae species involved.

The observed population sizes for the samples (as a whole) varied: 34,38 (1975), 40,20 (1986/87), and 19,54 individuals/hour of capture effort. And the average number of individuals per species also varied: 33,96 (1975), 45,95 (1986/87) and 34,69 (1992/93).

Taura (1998) grouped the species according to classes of abundance (see Preston, 1948), but data from the three surveys did not adjust well to the lognormal curve. This finding suggests instability in the community and such abnormalities seem to result from habitat disturbances such as from human activities (Laroca *et al.* 1989; Kevan *et al.* 1997).

Local extinction of 5 genera was observed: 25 genera were present in 1975, 24 genera in 1986/87 and 21 genera in 1992/93. As well local extinction of 2 families has occurred: Megachilidae: 3 genera in 1975, 0in 1986/87 and 0 in 1992/93; and Andrenidae: 3 genera in 1975, 2 in 1986/87 and 0 in 1992/93. Great reduction in the number of species was also observed in Colletidae: 4 in 1975, 2 in 1986/87 and 1 in 1992/93. Incidentally, the remaining species of Colletidae is an oligolectic Paracolletinae (*Bicolletes*) visiting *Vassobia breviflora.*The number of species of Halictidae has also decreased drastically: 45 in 1975, 47 in 1986/87 and 32 in 1992/93.

Local extinction of genera and families in urban biotopes is a very serious problem, but the severity of these problems could be diminished by the use of local ornamentals instead of exotic plants.

On the basis of the foregoing, and in summary, we present ten recommendations:

Thus, our **first recommendation** is the immediate cessation of the expansion of the agricultural frontiers, without regard to pollinating bees. Corresponding efforts must be made in regard to agricultural productivity and food distribution so as to address the needs of the hungry.

Thus, our **second recommendation** is to preserve and improve environmental heterogeneity in agricultural landscapes, aimed at conditions for pollinators and their associates.

Our **third recommendation** is for a special program of research on pollination life history aimed at increased knowledge of nesting requirements. To reach this goal, joint contributions of people such as scientists and farmers, scientists and designers, and scientists and the press (including modern media such as television and Internet).

Our **fourth recommendation** is the development of a special program on behavior and ecological studies of parasitoids that enable a germane *praxis* of conservation and control of these organisms.

Our **fifth recommendation** is that for agricultural ecosystems, ecological studies on the influence of combination of exotic and native plants on the conservation of the diversity of potential pollinators are needed.

Our **sixth recommendation** is for discussion, on an international level, of new land use policies, specially for the construction of new architectonic structures, such as airports, industrial plants, roads, dams, mines, large buildings etc., and to encourage reutilization of areas already allocated for such purposes in order to minimize adversity to agricultural ecosystems including potential pollinators.

Our **seventh recommendation**, given that much data exists but remains unevaluated and unavailable because of financial constraints, is to implement an effective policy of data analysis, meta-analysis and scientific publication diffusion of pollinator issues, especially for developing countries and regions.

Our **eighth recommendation** is the development of an immediate international program of eco-ethological studies on the interactions between exotic honeybees (*Apis*) and native pollinators in the various regions of the world in order to enable a germane praxis of conservation and control of these organisms, and a rational conjugation of both categories (exotic and wild) pollinators.

Our **ninth recommendation** is that special care must be given to the pollinator assemblages of the contact (or ecotone) zones between the great vegetational formations of the Earth, especially in the xeric-mesic as well as in mesic zones where we can find the highest diversity of potential pollinators.

The **tenth recommendation** that is the promotion of the local and regional native plants, and recognition of their aesthetic values and value in pollinator conservation.

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Session IV

Neotropical Crop Pollination

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23. Motta-Maués, M. "Reproductive Phenology and Pollination of the Brazil Nut Tree (*Bertholettia excelsa* Humb.& Bompl. Lecythidaceae) in Eastern Amazonia"

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IDENTIFYING POLLINATORS AMONG AN ARRAY OF FLOWER VISITORS, AND THE CASE OF INADEQUATE CASHEW POLLINATION IN NE BRAZIL.

Breno M. Freitas, Robert J. Paxton and João P. de Holanda-Neto

ABSTRACT

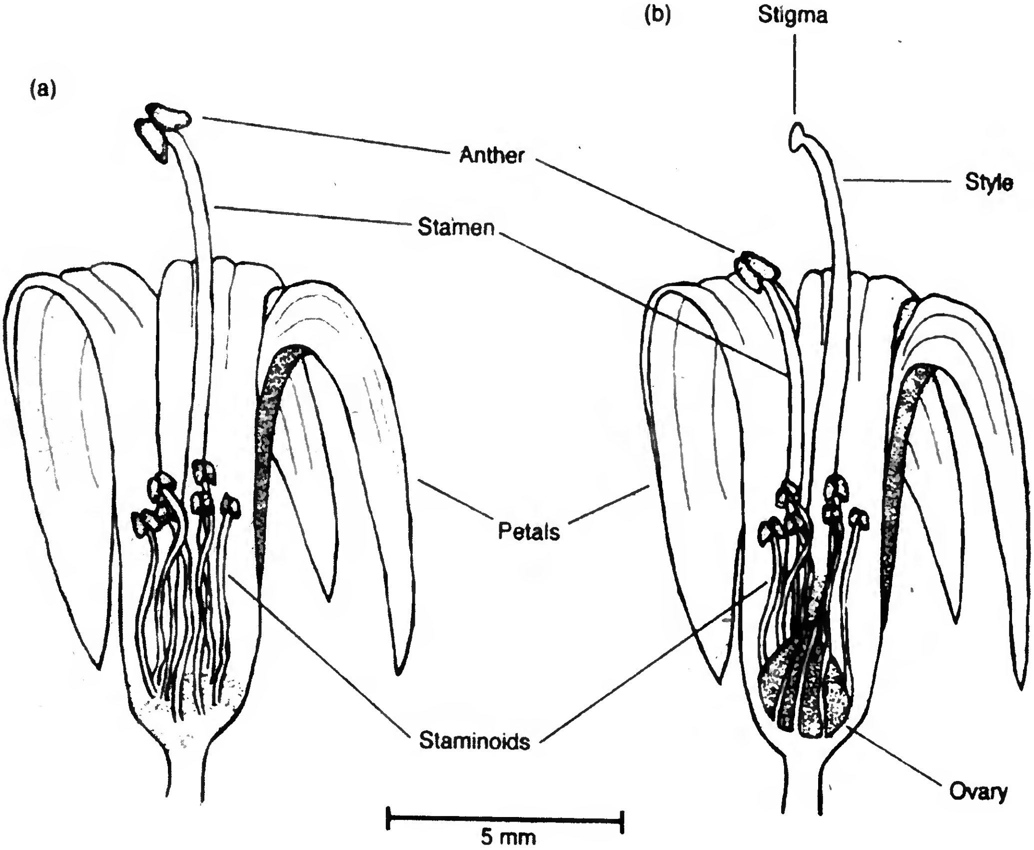
Cashew (*Anacardium occidentale*) is a andromonoecious tree native to NE Brazil. It is of considerable economic importance to the region for its nut, oil and cashew apple production, though crop yields are disappointingly low from commercial orchards. Cashew's flower form and presentation suggest that it is pollinated by insects, particularly bees, though other agents, namely wind and ant, have been cited as its pollinators. Our experiments incorporating the bagging of flowers confirmed that wind was not important as a pollinator. Numerous insects visited cashew flowers, though only bees did so regularly. By observing the visits of individual bees to virgin flowers in cashew's natural habitat, we defined the 'single-visit pollination efficiency' of two frequent flower visitors: honey bees (*Apis mellifera*) and a native oil bee (*Centris tarsata*), in terms of their (i) pollen removal from anthers, (ii) pollen deposition on stigmas, and (iii) initial fruit set. Though both performed well, *C. tarsata* was generally a superior pollinator compared to *A. mellifera*. In commercial orchards, *A. mellifera* was the only regular cashew flower visitor whilst *C. tarsata* was absent. Hand pollination experiments in this agricultural setting demonstrated a need for cross-pollination of commercially grown cashew strains, and inadequate pollination as an important cause of low nut set. To improve cashew crop yields, serious consideration needs to be given to both the conservation and management of its recognised, efficacious pollinators (*C. tarsata* and possibly *A. mellifera*) and also the design of orchards with appropriate mixes of compatible cashew strains.

INTRODUCTION

Cashew and its importance

The cashew tree (*Anacardium occidentale* L.) is andromonoecious, presenting male and hermaphrodite flowers (Fig. 1) in the same panicle. Both types of flowers produce pollen and nectar and both have five white petals at anthesis that gradually become red over a period of five days before withering. Each flower has 6-10 pollen-bearing structures, one (the stamen) being much longer than the others (staminoids). In the hermaphrodite flower, the style assumes the same position as the stamen of male flowers, and its own stamen is shorter than its style (Fig. 1). The ovary bears one single ovule and is rudimentary in male flowers (Northwood 1966; Free 1993; Freitas 1995). Panicles last around 100 days in a flowering season that varies from 5 to 7 months, with each tree producing hundreds of panicles across the flowering season. The proportion of hermaphrodite flowers per panicle ranges from <0.5% to circa 25% (Madhava Rao and Hassan 1957; Damodaran *et al.* 1979; Barros 1988).

FIGURE 1. Cross-sectional diagram of a male (a) and an hermaphrodite (b) cashew flower, highlighting the relative positions of the stamen and staminoids of each and of the stigma of the hermaphrodite flower.



Cashew is native to coastal areas of Brazil (Fig. 2), especially the environmentally harsh sandy dunes in NE Brazil, where 40,000 to 50,000 ha of cashew trees are still found in the wild (Lopes Neto 1981; Freitas 1994). Before the arrival of the Portuguese to Brazil in 1500 and the subsequent spread of cashew around the world, cashew nuts were already cropped from the wild by native Indians; wild trees are still harvested by poor communities in NE Brazil nowadays. Besides extensive exploitation of wild trees, there are around 650,000 ha of cultivated cashew orchards in NE Brazil alone (Araújo and Silva 1995, *cf* Table 1).

FIGURE 2. Map of Brazil showing the natural distribution of Anacardium occidentale (light shaded), the major commercial cashew orchards (dark shaded), and the field sites where observations and experiments on cashew pollination took place (natural dune habitat at Frecheiras = F; commercial cashew orchards at Pacajus experimental station = P).

TABLE 1. Cashew and its estimated economic value to Brazil per year.

Total area of commercial cashew orchards	650,000 Hectares
Total annual yield of nuts	126,000Tonnes
Value of exports (nuts only)	US $ 135 million
(nut shell oil)	US $ 91 million
Value of crop (nuts, oil and fruit) within Brazil	US $ 54 million

Source: Sindicaju 1991, Freitas 1995, Araújo e Silva 1995

The cashew nut provides an edible kernel and industrial oil, both of value to local communities and many national economies, including that of Brazil (Morton 1961; Heard *et al.* 1990; Reddi 1991, see Table 1). However, yields from cashew orchards have often been poor, circa 200 kg nuts/ha in Brazil when 1,300 kg nuts/ha could be expected (Araújo and Silva 1995), with blame being placed on under-pollination and the fall of immature fruits (Thankamma Pillai and Pillai 1975; Reddi 1987; Free 1993; Freitas and Paxton 1996). Earlier studies in orchards have suggested that wind and many insect species, such as ants, wasps and honey bees, are the pollinating agents of cashew (Bigger 1960; Damodaran *et al.* 1966; Free and Williams 1976; Reddi 1991; Freitas and Paxton 1996). However, their importance has not been critically determined. Indeed, only recently has attention been paid to the natural pollinators of cashew in its native range (Freitas and Paxton 1998).

Defining the role of specific flower visitors as pollinators

There are numerous reports documenting how to assess the pollination requirements of a plant with respect to its fruit, nut or seed set (Corbet *et al.* 1991; Free 1993; Roubik 1995). These incorporate manipulative experiments in which flowers pre-anthesis are bagged within insect-proof netting and to which pollen from varying sources (self, cross) may be added to stigmatic surfaces. For most of the world's Angiosperms, animals have been implicated as important pollen vectors, with insects, particularly bees (Hymenoptera, Apoidea), predominating (Proctor *et al.* 1996).

Plants that are pollinated by a taxonomically restricted set of animals often have similar floral traits, referred to as a pollination syndrome (Faegri and van der Pijl 1979; Proctor *et al.* 1996), and suggesting close coevolution between flower and vector, or at least convergence of floral traits across taxonomically disparate groups of Angiosperms. Mellitophily, the bee pollination syndrome, is typified by flowers with a sweet odour, having pollen and nectar as rewards, often protected in a shallow to moderately deep corolla (Faegri and van der Pijl 1979; Proctor *et al.* 1996). Cashew flowers have bright corollas which change colour with age, they produce nectar and an aroma, they have a reduced number of pollen grains and their staminoids presumably represent 'feeding anthers'. These traits would suggest cashew to be attractive to, and pollinated by, bees. However, the pollen and nectar in its flowers is readily accessible and so its flowers are conceivably attractive to a wide range of insects other than bees (Bigger 1960, Northwood 1966; Damodaran *et al.* 1966; Free and Williams 1976; Khoo *et al.* 1982; Reddi 1991; Dantas de Araujo 1994). Other crops of NE Brazil that require pollination to set seed vary in their floral traits, some apparently attracting a diversity of insects like cashew whilst others appear to conform to a pollination syndrome and attract and are presumably pollinated by a taxonomically restricted set of floral visitors (Table 2). Kevan has suggested that moths may be important pollinators of cashew in the Costa Atlantica of Nicaragua (personal communication).

TABLE 2. Some crops grown in NE Brazil that require pollination for adequate fruit, nut or seed yield, ordered according to their floral traits and assumed pollination requirements.

Crop plant species	Common name	Presumed or known pollinators
Floral traits suggest pollination not dependent upon one specialist visitor		
Anacardium occidentale	cashew[a]	bees (this study)
Mangifera indica	Mango	bees, flies, beetles, butterflies (Free 1993)
Persea americana	Avocado	bees, possibly flies (Free 1993)
Floral traits suggest pollination dependent upon a specialist visitor		
Malpighia emarginata	West Indian cherry	oil bees, Centris (Freitas *et al.* 1999)
Byrsonima verbascifolia	murici [a]	oil bees, Centris (personal observation)
Annona muricata	Soursop	beetles, Cyclocephala (Aguiar 1998)

[a]: indigenous to NE Brazil

More recently, the concept of the pollination syndrome has been questioned (Waser *et al.* 1996). This is partly because of the circularity of reasoning that it introduces, as exemplified in our description of cashew as likely being bee pollinated. It is also partly because observations of floral visitors have indicated that many flowers supposedly adapted for pollination by a select group of animals are in reality visited by a much wider array of potential pollen vectors (Waser *et al.* 1996). However, it is crucial to distinguish between a mere flower visitor versus a pollinator, not only in order to shed light on this debate; when inadequate pollination is responsible for reduced crop yields, as may be the case for cashew in NE Brazil, it is also necessary to identify the importance of different flower visitors to the crop's pollination. This allows management aimed at augmenting pollinator numbers to be directed at the appropriate species.

Numerous methods to evaluate a flower visitor's role in the pollination of a plant species have been employed for a variety of crops and wild plants (Kendall and Smith 1975; Tepedino 1981; Dafni *et al.* 1987; Inouye *et al.* 1994), many providing only indirect estimates of a visitor's importance. A corollary is that the term 'pollinator efficiency' has been used in a multitude of senses. In an attempt to bring order and consistency among studies, Inouye *et al.* (1994) have suggested a standardised lexicon, to which we attempt to adhere in our studies on cashew pollination described below.

A direct method for evaluating the relative importance of different groups of flower visitors to a plant's pollination has been proposed by Spears (1983). The experimental paradigm involves allowing virgin flowers to be visited by one visitor and monitoring subsequent fruit, seed or nut set. Spears' (1983) single-visit pollination efficiency' index allows a pollinator's relative contribution to plant reproductive success from among a suite of flower visitors to be measured. Though this measure relates to a plant's reproductive success through only its female function, this may suffice for a number of agricultural crops where fruit, seed or nut yield (ie female function) is the focus of attention. We use this method to evaluate the importance of different pollinators in cashew pollination via a flower's female function.

Direct estimates of the importance of a pollinator to a plant's reproductive success via its flowers' male function have not been devised. We therefore adapt Spears' (1983) single-visit paradigm, recording pollen grains removed from a flower in a single visit, to obtain an indirect measure of the importance of different pollinators to cashew pollination via its flowers' male function.

Here we report on our researches upon cashew over its past six flowering seasons, 1993-1998 inclusive (and see Freitas 1994, 1997a,b; Freitas and Paxton 1996, 1998). These have been aimed, firstly, at defining cashew's pollination requirements, secondly, at evaluating the importance of different flower visitors in the pollination of cashew in native habitats where the plant is indigenous and, thirdly, at determining whether and why lack of pollination is a cause of inadequate crop yields in agricultural settings.

METHODS

In Brazil, cashew trees are grown commercially from clonal strains supplied by EMBRAPA, the national governmental agricultural research and support department. Limited selective breeding of clonal strains has been practised (Araújo and Silva 1995; EMBRAPA/CNPAT 1997) and, in flower form and presentation at least, wild and commercial cashew blossom is essentially identical.

Our fieldwork has been undertaken at two locations within the natural distribution of *A. occidentale*. At one location, Frecheiras, cashew grows wild in its natural dune habitat; at location Pacajus experimental station, clonal strains of cashew are grown (Fig. 2). A few clonal varieties are present in orchards at Pacajus, reflecting their use by EMBRAPA as experimental field sites. But each orchard contains only one clonal variety, as found in commercial orchards typical of NE Brazil.

To describe cashew flower form, presentation and phenology, we examined 400 each of male and hermaphrodite flowers at Pacajus across their entire period of bloom. Hand pollination experiments involved bagging flowers pre-anthesis in fine mesh netting (1 mm^2 mesh) and adding pollen from the same or another tree's flowers to the bagged stigmas when at peak receptivity (see Freitas and Paxton 1996 for further details).

Florescences were examined at Frecheiras and Pacajus to record the number of visits to them by different insect species, and their behaviour on individual flowers. To count the number of cashew pollen grains adhering to an insect's body, the insect was washed thoroughly in a solution of ethanol with detergent and dislodged cashew grains were counted under a haemocytometer (Freitas 1997a; Freitas and Paxton 1996). The 'single-visit pollination efficiency' (sensu Spears 1983) of *A. mellifera* and *C. tarsata* was evaluated at Frecheiras in terms of three components of relevance to cashew's pollination: pollen removal from anthers, pollen deposition on stigmas, and fruit set (Freitas and Paxton 1998). To do so, we compared the pollen removed, or deposited, or the fruit set by a single visit of a bee to a virgin flower (N = 50 flowers for each pollination component and bee species), as compared to that of permanently bagged flowers (N = 50 flowers for each pollination component) and that of flowers permanently open to floral visitors (N = 50 flowers for each pollination component; see Spears 1983; Freitas and Paxton 1998).

RESULTS

Cashew's need for pollination

Panicles consisted of approximately 10% hermaphrodite flowers to 90% male flowers (N = 500 panicles). Flowers of both types were white at anthesis with two pink stripes on each petal. They progressively acquired a pink coloration towards the end of the day, turning red by the third day and withering by the end of the fifth day after anthesis (see Free 1993; Freitas 1994).

Anthesis of male flowers started at 06:00 h and 82.2 3.1% of flowers were open by 10:00 h (N = 500 flowers). In hermaphrodite flowers, anthesis and stigma presentation started around 10:00 h and 95.0 ± 2.3% of hermaphrodite flowers were open by 12:00 h, with only a few stigmas being first presented later in the day (N = 500 flowers). Anther dehiscence of stamens occurred mainly after 09:00 h for male flowers and 10:00 h for hermaphrodite flowers, but male flowers contributed proportionally most of the stamen-derived pollen available to insect visitors. Cashew stigmas were receptive up to 30 h after anthesis (N = 300 stigmas), but stigma receptivity varied with age (G^2 = 126.8, df = 9, $P < 0.001$). Stigmas up to 4 h old were more receptive than older ones (N = 30 stigmas for 10 age cohorts from 0 h to 46 h; see Freitas and Paxton 1998).

Flowers excluded to insect visitation did not set any fruit and those open to floral visitors at Pacajus set 50.5% of their flowers (Table 3). Hand pollination of cashew stigmas using self- and cross-pollen grains gave an initial fruit set varying between 65.0 and 73.8% (Table 3) and did not differ significantly from each other (X^2_1 = 1.441, $P > 0.05$). There were no differences in pollination for pollen derived from male and hermaphrodite stamens (Freitas and Paxton 1996).

TABLE 3. Fruit set of cashew flowers either open to insect visitors (in a commercial orchard, Pacajus) or closed to insects and hand pollinated by pollen from male and hermaphrodite flowers.

Treatment of flower and origin of pollen, if bagged	N°. of Flowers	N°. of fruits set	% flowers that set fruit
Open to insect visitors	200	101	50.5
Bagged to insect visitors, no pollen	200	0	0
Bagged, stamen (cross)	80	59	73.8
Bagged, stamen (self)	80	52	65.0
Bagged, staminoid (cross)	80	2	2.5
Bagged, staminoid (self)	80	0	0

Other experiments caging a whole tree and capturing wind-blown pollen grains in cashew orchards (Freitas 1995a; Freitas and Paxton 1996) have indicated that wind and very small insects play little or no role in cashew pollination, contrary to previous assertions (Madhava Rao and Hassan 1957; Bigger 1960; Damodaran *et al.* 1966). Thus, initial fruit set in cashew seems to be from both self- and cross-pollination, effected by larger flower visitors. Pollination is likely restricted to the first day of anthesis, too. A delay in anther dehiscence of hermaphrodite flowers diminishes the chances of self-pollination. Yet despite this partial dichogamy, the great number of male flowers per tree may increase the level of geitonogamy (De Jong *et al.* 1993; Harder and Barret 1995).

The potential pollinators

A number of insect species have been recorded visiting cashew inflorescences in agricultural habitats, particularly ants, bees, butterflies and wasps (Freitas and Paxton 1996). In contrast, only an ant, *Camponotus* sp., and two bees, the honey bee *Apis mellifera* and the native oil bee *Centris tarsata* Smith, were recorded visiting cashew in natural sand dune habitats (Freitas and Paxton 1998).

We consider visitors of cashew inflorescences other than bees of little importance in pollinating its flowers. Either non-bee visitors made little or no contact with the flower's reproductive organs (*e.g.* ants, see Table 4). Alternatively, they did not discriminate between young flowers with fresh pollen or receptive stigmas and old ones (*e.g.* the butterfly *Aphrissa* sp), or they visited flowers only when little viable pollen was available (*e.g.* the butterfly *Oanaus erippus* Cramer), or they did not show flower constancy to cashew (*e.g.* the butterfly *E. hegesra*) (Freitas and Paxton 1996).

In contrast, bees appeared to be important to cashew pollination. The most frequent visitors of cashew flowers in natural habitats were *A. mellifera* and *C. tarsata* (Freitas and Paxton 1998). Both bee species showed foraging behaviour conducive to effective pollination; flower constancy, timing of visits in relation to hermaphrodite flower's anthesis, touching of anther and stigma in the same area of the body (Fig. 3), systematic movement between young flowers, and great numbers of cashew pollen grains on their bodies (Table 4). When both bee species visited cashew flowers, most cashew pollen grains were acquired in the ventral mesothorax of their bodies, an area in which the flower's reproductive organs usually touched the forager (Fig. 3). However, while *C. tarsata* bore between 52 and 118 cashew pollen grains per mm^2 in this body area, *A. mellifera* only carried only 5 cashew pollen grains per mm^2 of the same body area (Freitas 1997a), suggesting it might be a less efficacious pollinator of cashew flowers. Cashew pollen carried in the ventral mesothorax was however of equal germinability in the two bee species (Freitas 1997b).

TABLE 4. The average number of cashew pollen grains carried on the bodies of the principal visitors of cashew inflorescences and their abilities to touch the flower's reproductive organs. + = yes, - = no, oc = occasionally.

Type of insect visitor Common name	N°. insects sampled	N°. cashew pollen grains per insect	Touch Anther	Touch Stigma
APIS MELLIFERA	20	1241 ± 56	+	+
honey bee[a]				
Camponotus sp.	20	17 ± 6	-	-
an ant[b]				

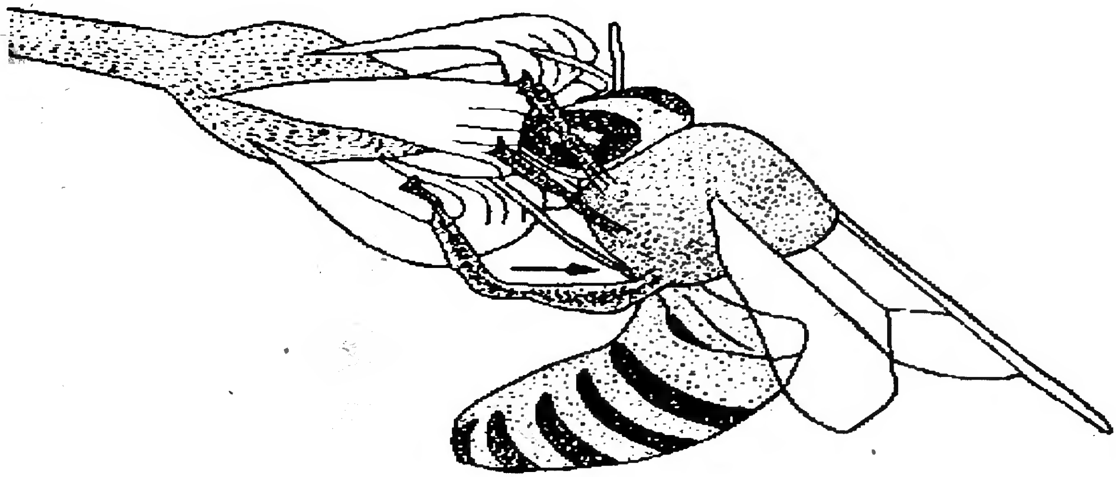
Centris tarsata (pollen collector)	20	2271 ± 141	+	*
an oil bee[a]				
Centris tarsata (nectar collector)	20	1805 ± 182	+	+
an oil bee[a]				
Polistes sp.	20	25 ± 8	oc	oc
a social wasp[b]				
Trigona spinipes	20	118 ± 20	oc	-
a stingless bee[b]				

* Female *C. tarsata* collecting pollen visit only male cashew flowers; nectar collectors always touch the stigma of hermaphrodite flowers.

a: insects collected in a natural habitat, Frecheiras, September 1994.

b: insects collected in a commercial orchard, Pacajus, July-September 1993.

FIGURE 3. Schematic diagram of a honey bee (*Apis mellifera*) in its characteristic position when foraging for nectar on a cashew flower. Note that the stigma touches the bee's ventral thorax.



The importance of *A. mellifera* and *C. tarsata* as pollinators

We employed observations and experiments incorporating single visits by *A. mellifera* and *C. tarsata* to virgin cashew flowers growing at Frecheiras, a natural dune habitat, to evaluate the relative importance of these flower visitors in cashew pollination.

Firstly, the efficiency in removing pollen grains from stamens (ie viable pollen) differed significantly between the two bee species (Kruskal-Wallis ANOVA, $P<0.001$; Table 5). In particular, flowers receiving single visits by female pollen collectors of *C. tarsata* removed most of the available pollen from a stigma in a single visit. Nectar collectors of *A. mellifera* and *C. tarsata* each removed approximately 67-68% of the available pollen (Table 5).

TABLE 5. Single-visit pollination efficiency measures for two bee species on cashew flowers at Frecheiras.

Single visit by	Efficiency of pollen removal from anther (±SEM)	Efficiency of pollen deposition on stigma (±SEM)	Efficiency of fruit set (±SEM)
Apis mellifera			
nectar collector	$0.68^b \pm 0.05$	$0.24^b \pm 0.03$	$0.43^a \pm 0.10$
Centris tarsata			
nectar collector	$0.67^b \pm 0.05$	$0.48^a \pm 0.07$	$0.59^a \pm 0.08$
Centris tarsata			
pollen collector	$0.99^a \pm 0.04$		

Means followed by the same letter within a column do not differ at $P < 0.05$

Honey bee foragers never actively collect pollen from cashew flowers, hence their absence from Table 5. The extent to which *C. tarsata* females switch between pollen collection (from male flowers only) and nectar collection (from male and hermaphrodite flowers) is not known, though nectar collectors usually carry some pollen in their scopal hairs, suggesting frequent switching. Further, we have merely measured the removal of pollen from anthers and not its subsequent fate; we have only recorded an indirect measure of a plant's reproductive success via its pollen export (see Queller 1997). Notwithstanding these limitations, our data suggest that *C. tarsata* is a more important pollinator than *A. mellifera* in terms of cashew's male reproductive function (Freitas and Paxton 1998).

Secondly, *A. mellifera* foragers deposited substantially fewer pollen grains on stigmas than did C. tarsata foragers during single visits to a hermaphrodite flowers (Mann-Whitney test, $P<0.001$; Table 5). These data suggest that honey bees were of lesser importance than *C. tarsata* to pollination in terms of cashew's female reproductive function and its fruit and nut set. Despite initial fruit set through single visits by *A. mellifera* also being lower than those by *C. tarsata*, differences between the two species were not statistically significant (Table 5). Together, these data suggest that both bees may effect fruit set in cashew, with *C. tarsata* possibly a little superior to *A. mellifera* in terms of a cashew flower's female reproductive function (Freitas and Paxton 1998).

There is however a caveat to the interpretation of our data on fruit set. We have only recorded each species' single-visit pollination efficiency in terms of initial fruit set. For cashew, reproductive self-incompatibility may be manifest later in fruit development (see below). In this case, there is still a need to evaluate the relative importance of the two bees in terms of both the compatible pollen they carry and also the mature fruit and nuts to which their visits give rise.

Pollination in an agricultural setting

We have more recently re-examined the pollination requirements and fruit set of cashew within a commercial orchard setting at Pacajus, where a single clonal strain is typically grown over a large area. To effect hand cross-pollination, different clonal strains of cashew were used as pollen donor and recipient. Though initial fruit set through hand cross- or self-pollination was high in 1998, there was great loss of self-pollinated fruit later in fruit development (Table 6), most fruit drop occurring 13-15 days after pollination (Holanda-Neto *et. al.* in preparation).

Cashew fruit requires 56-60 days to mature following pollination. Microscopic examination of embryo development in young fruit suggests that pollination may stimulate preliminary fruit growth but that rarely does an embryo develop and a fruit complete development when pollination is by self-pollen (Holanda-Neto *et. al.* in preparation). Cashew, at least the clonal strains grown commercially in NE Brazil, appears to exhibit partial self-incompatibility.

TABLE 6. Fruit set of cashew grown in a commercial orchard, Pacajus, either open to insect visitors or closed to insects and hand pollinated. N = 100 flowers per treatment.

	1997	1998	
Treatment of flower[a] and origin of pollen, if bagged	**N°. fruits harvested**	**N°. fruits remaining at given time after pollination**	
		7 days	30 days
Open to insect visitors	2	75	2
Bagged to insect visitors, no pollen	0	0	0
Bagged, cross pollen[b]	17	89	31
Bagged, self pollen	5	89	4

a: clone CCP-76; b: clone CC-12

A large amount of fruit drop following pollination was observed in commercially grown cashew, even when flowers were hand cross-pollinated (Table 6). However, for open pollinated flowers, levels of successful fruit and nut production were even lower, at only 2% in both 1997 and 1998 (Table 6). This was despite the addition of extra colonies of honey bees to the study orchard in 1998. These data reflect the complaints about low yields by commercial cashew producers in NE Brazil.

A compounding problem for cashew pollination in commercial orchards is that its flowers receive few visitors, the commonest being *A. mellifera* (Table 7). Honey bee foragers can affect initial fruit set in natural environments (Table 5). However, despite the fact that honey bee colonies are regularly brought into cashew orchards, *A. mellifera* frequently forages on the flowers of weeds growing beneath the cashew trees rather than from cashew blossom itself (Freitas 1994, 1995b). We have never recorded *C. tarsata* in cashew orchards despite several hundred hours of observation of blossom (*eg* Freitas and Paxton 1996). Given the apparent need of commercially grown cashew for cross-pollination, the restricted foraging range of individual *A. mellifera* foragers, often confined to one or a few adjacent fruit trees (Free 1993), may severely limit its ability to effect cross-pollination. In this regard, *C. tarsata* may effect greater cross-pollination as it flies rapidly between trees when foraging and deposits more pollen grains on a stigma per single flower visit than does *A. mellifera* (Table 5).

TABLE 7. The relative and absolute frequency of the principal floral visitors to cashew inflorescences (2400 inflorescences over a 3 month period) in a commercial orchard, Pacajus.

Insect species	Relative frequency on panicles (%)[a]	Mean N°. of panicles with species present
Apis mellifera (honey bee)	28	6.25
Camponotus sp. (an ant)	24	5.25
Polistes sp. (a social wasp)	14	3.12
Trigona spinipes (a stingless bee)	12	2.50

[a]: For additional species comprising the remaining 22%, see Freitas & Paxton 1996.

DISCUSSION

Which are the pollinators among the flower visitors?

Lower visitor and pollinator are not synonymous terms. For any plant species whose reproduction is dependent upon pollination and where more than one potential vector is recorded visiting its flowers, it will be necessary to evaluate through manipulative experiments and observations the importance of each to the plant's reproductive output. Such an approach may also shed light on the debate over the validity of the pollination syndrome concept (Waser *et al.* 1996). For crops that are dependent upon pollination for fruit, nut and seed production, it is also important to identify the crop's pollinator or pollinators to ensure appropriate management of them. Despite earlier reports suggesting that cashew was pollinated by a wide range of insects (Northwood 1966; Free and Williams 1976; Khoo *et al.* 1982; Reddi 1991; Dantas de Araujo 1994), and even wind (Madhava Rao and Hassan 1957; Bigger 1960; Damodaran *et al.* 1966), it is clear from our results that only a few bees are the important vectors of cashew pollen.

Spear's (1983) index of 'single-visit pollinator efficiency' provides a direct measure of the importance of individual flower visitors to a plant's female reproductive function. For many crops dependent on pollination for adequate yields, and where crop yields are the focus of attention, determination of this index may be the most convenient and accurate means by which the relative importance of different flower visitors is evaluated.

Using this index in cashew fruit and nut production, we were easily able to compare the single-visit pollination efficiencies of two bees. We found that single visits by the indigenous *C. tarsata* led to slightly though not significantly higher initial fruit set than single visits by *A. mellifera* foragers. Our data also allowed us to state that both bees may provide an adequate pollination service to cashew.

Of course, the actual role of an insect species in effecting pollination in the field will be dependent not only upon its single-visit pollination efficiency but also on its relative and absolute frequency of visits to flowers. For example, several visits by *A. mellifera* foragers to a flower may compensate for fewer visits by *C. tarsata*. We also note that interacting flower visitors may compete for floral rewards such that one reduces the frequency of visits of the other to those flowers (Schaffer *et al.* 1979), or diminishes the duration of its flower visits with consequential effects on its pick-up from anther or deposition on stigma of pollen. Nevertheless, the single-visit pollination efficiency paradigm may still be useful in providing an estimate of the theoretical importance of a flower visitor in pollination and crop production.

Inadequate pollination and poor cashew yields - the lack of pollinators

That cashew in NE Brazil is dependent upon bee pollination is clear from our work over the past six years. Cashew commercially grown in orchards also suffers from low crop yields, in large part due to inadequate pollination.There are two sides to this shortfall.

On the one side, there are few or no visits to orchard-grown cashew flowers by the appropriate bee species that are competent pollinators. One seemingly suitable pollinator, A. mellifera, does not readily visit cashew flowers even when brought into orchards in large numbers because it is attracted to competing weeds in bloom (Freitas 1995b). Methods are available to increase the pollination potential of honey bee foragers by directing them to visit specific crops in need of pollination (Jay 1986), theoretically overcoming this difficulty. However, commercially grown strains of cashew also seem to need cross-pollination. In this case, the flower constancy and narrow foraging range of individual honey bees (Free 1993) may limit further their role in cashew pollination and crop production. However, methods to enhance specifically the cross-pollination potential of honey bee foragers are available (Hatjina *et al.* 1999).

Another seemingly suitable cashew pollinator and one with higher single-visit pollination efficiency measures than those of the honey bee is *C. tarsata,* though it is not even found in commercial cashew orchards. In the natural dune habitats of cashew, cropping of wild trees does not use any sort of pesticides or agricultural practices that may harm its pollinators. However, in agricultural areas using the new dwarf strains of cashew, insecticide spraying and land ploughing have been widely practised. It has for long been recognised that insecticide spraying can be harmful for pollinating insects in general *(eg* Kevan 1975), and ploughing is particularly damaging because it may destroy nests of fossorial (ground-nesting) bee species such as those of *C. tarsata. Centris* bees nest in sandy ground beneath the bushes of *Byrsonimia verbascifolia.* Unfortunately there is a lack of direct information on the impact upon *C. tarsata* of insecticide spraying and ploughing, though the absence of the bee from commercial cashew orchards may in part be related to both forms of agricultural practice.

Inadequate pollination and poor cashew yields - the lack of compatible pollen

A second side to the shortfall in adequate pollination of commercially grown cashew is undoubtedly related to horticultural practices in which a partially self-sterile clonal stain is grown over large areas without thought being given to the need for compatible sources of pollen.This problem is exacerbated as more and more cultivated areas are being planted or replanted with dwarf clones (Freitas 1994; Araújo and Silva 1995). One obvious solution is to intercalate trees producing compatible pollen within main cropping strains. Hand-pollination experiments carried out in Australia and Brazil have identified types or strains of cashew, crossing among which produced higher yields (Wunnachit *et al.* 1992; EMBRAPA/CNPAT 1994, 1997).However, it will still be necessary to consider management of bees within commercial cashew orchards because they will be needed as the vectors of the compatible pollen.

An alternative approach is to introduce colonies of honey bees with 'hive inserts' to cashew orchards requiring pollination, those hive inserts containing pre-collected compatible pollen which foragers departing their colony pick up and subsequently transfer onto the stigmas of the flowers they visit (Jay 1986). The efficacy of hive inserts as a means of promoting cross-pollination has been called into question (Hatjina 1998); the method requires a source of pre-collected pollen which may be difficult to acquire, and it is likely impractical for a crop like cashew that blooms over a 5-7 month period.

CONCLUSIONS

Cashew requires pollination for fruit and nut set; commercially grown strains are partially self-incompatible. Though a native bee, *Centris tarsata*, and the introduced honey bee *Apis mellifera*, appear to provide adequate pollination in cashew's natural habitats, orchard crops suffer low crop yields through inadequate pollination. To improve crop yields, attention needs to be paid to (i) pollinator management, to ensure that sufficient numbers of pollinators are present during flowering, and (ii) horticultural practices, to ensure cashew strains with compatible pollens are grown in the vicinity of each other. Widespread use of pesticides and intensive horticultural management may be detrimental to profitable cashew yields, in part because these practices are associated with the decline or extermination of pollinators, both native and introduced.

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REPRODUCTIVE PHENOLOGY AND POLLINATION OF THE BRAZIL NUT TREE (*Bertholletia excelsa* HUMB. & BONPL. LECYTHIDACEAE) IN EASTERN AMAZONIA

Márcia Motta Maués

ABSTRACT

The brazil nut tree (*Bertholletia excelsa* Humb. & Bonpl. Lecythidaceae) is an economically important fruit tree, endemic to the Amazon Region. Investigations of the reproductive phenology and insect pollinators of B. excelsa were carried out in the orchards of Embrapa Amazônia Oriental, in Belém (1°27'S 48°29'W) and in the experimental Field Station of Capitão-Poço (1°27'S 48°29'W), in the eastern region of Pará State, Brazil. The main flowering period occurred from August to November, during the driest months of the year and the main fruiting period lasted from October to December. The maturation period extended throughout the following year with the ripening and dissemination occurring in the rainy season, from February to April. The pollen:ovule ratio was 26,755.29. Indicating obligate xenogamy. The main pollinators are medium- to large-sized bees, belonging to the following species: *Xylocopa frontalis, X. aurulenta, Epicharis rustica, E. affinis, Centris similis, Eulaema nigrita, E. cingulata, Bombus brevivillus, B. transversalis*. From this study it was concluded that *B. excelsa* is a mellitophilous species dependent on the pollinators activity to ensure its fruit production.

INTRODUCTION

The brazil nut (*Bertholletia excelsa* Humb. & Bonpl., Lecythidaceae) is a large tree, up to 50 m high, native to the Amazon rainforest. It is considered one of the noblest and most valuable plants of the Amazon region, due to the economic value of its nuts, one of the main products in the exportation list of the state of Pará (Almeida, 1963; Müller *et al.*, 1980), as well as timber production from opened plantations (Kanashiro 1992).

The Lecythidaceae family is predominantly Neotropical (Mori 1987; Endress 1994). The majority of the species of this family tend to flower in the dry season. In places without a regular dry season, the phenological events may be influenced by other factors, such as longer duration of the photoperiod within the day (Mori & Prance 1987).

The main flowering period of *B. excelsa* occurs from October to December, showing erect and short-ramified terminal panicles, with zygomorphic flowers with pale-green calyx and yellowish fleshy petals, offering nectar and pollen as rewards for visitors (Moritz 1984). According to (Pinheiro & Albuquerque 1968), the flower/fruit ratio is low, approximately 0.4%. The fruits are large and indehiscent, with seeds dispersed by agoutis (*Dasyprocta* sp.) (Huber in Kanashiro 1997). Many authors emphasize the importance of the pollination agents in the brazil nut fruit set, stating that this low ratio may change in agreement with the activity and efficiency of natural pollinators.

The brazil nut is an allogamous plant with mellitophilous pollination syndrome. The flower structure bears a chamber composed of congruent staminodes, creating a robust structure (ligule) that conceals the stamens and the stigma. This chamber restricts the insects visitors' entrance and selects a specific guild of pollinators with physical vigor and compatible size, required to lift the ligule and to assess the reproductive organs. The main visitors and pollinators of the of brazil nut are the bees, belonging to the following genus: *Bombus, Centris, Xylocopa, Epicharis and Eulaema* (Müller *et al.* 1980; Moritz 1984; Maués & Oliveira 1996; Maués *et al.* 1996).

From this study, the phenological patterns and the legitimate pollinators of *B. excelsa* in the northern Brazilian state of Pará were identified in order to obtain subsidies for further studies on management of native pollinators in orchards.

MATERIAL AND METHODS

The field studies were carried out between 1994 and 1997, in experimental orchards in the municipalities of Belém, (1°28'S;48°29'W) and Capitao-Poço (1°46'S 47°28'W), in the eastern Amazon region, north of Brazil. Grafted plants with ages varying between 15 and 20 years old were utilized.

From March 1994 to March 1996, phenological observations were realized every two weeks, taking into account the occurrence, duration and frequency of the following events: flowering (e.g., floral buds and flowers); fruit set (e.g., green fruit, mature fruit and seed drop) and leaf changes (e.g., new and mature leaf; partial and total defoliation), in agreement with the methodology of Fournier and Charpantier (1975). The phenologic records were correlated with meteorological data (*e.g.*, precipitation, temperature, relative humidity and photoperiod) obtained in the Meteorological Station of Embrapa Amazônia Oriental. For these studies, five trees of precocious brazil nut were selected in a 15-years-old orchard, in the experimental area of Embrapa Amazônia Oriental.

During the flowering period, direct observations about the behavior of the insect visitors were accompanied by specimen collection and photographic documentation with a Nikon F90 camera and 35-135mm lens, aiming to support the identification of the main pollinators. The insects were identified in the Entomological Museum of Embrapa Amazônia Oriental, and/or sent to specialists from the Faculdade de Filosofia Ciências e Letras de Ribeirão Preto (FFCLRP-USP). Voucher specimens were incorporated into the Entomological Museum of Embrapa Amazônia Oriental.

The investigations on the floral biology concentrated on the determination of the pollen: ovule ratio, osmophores location, determination of the main receptive stigma area, pollen viability, number of stamens and number of flowers opened daily by inflorescence. According to Cruden (1977), the pollen:ovule ratio is an indicator of the mating system. 20 flowers were used to obtain the ovule number per flower, after dissection of the ovary under stereomicroscope. To estimate the number of pollen grains per flower, three anthers of five flowers were separately picked and macerated with a solution of distilled water and detergent. A sample of this solution was spread in a Neubauer chamber (hemacytometer) and the number of pollen grains was properly scored under microscope. The results were divided by three, multiplied by the dilution factor and by the number of anthers. The osmophores were determined by submerging the flowers for two hours in a solution of neutral red 0,1% and then washing in running water, according to Vogel mentioned by Faria (1989). Afterwards, the areas colored in dark red were verified, which revealed the presence of the scent glands. The stigma receptivity was tested in flowers bagged one day before the anthesis. The stigmas were cut off and submerged in four reagent types: solution of Peroxtesmo KO (Dafni & Maués 1998), PerexTest Merck, Hydrogen Peroxide solution (H_2O_2) 6% and Baker's solution. The pollen viability was also tested in bagged flowers, using Peroxtesmo KO and Baker's solution.

Peroxtesmo KO indicates the presence of an enzyme, peroxidase The viable pollen or the receptive stigma turns into a blue or purple color, thereby confirming the enzymatic activity. The PerexTest shows the presence and intensity of hydrogen peroxide (H_2O_2), measured through a colored scale varying from pale-yellow to red, with scores for each nuance. Hydrogen peroxide itself indicates the receptivity through the appearance of air bubbles, being a simple and inexpensive method, but if there is any damage on the stigma surface or even pollen germination, it may give a false positive result. Baker's procedure also indicates the presence of enzymatic activity, through the alcohol-dehydrogenase enzyme. It is a reliable method for demonstrating pollen viability and stigma receptivity. All of these procedures were done in accordance with Dafni (1997), using a Olympus BH-2 microscope and Olympus SZH stereomicroscope.

Photomicrographies of the surface of visited and not visited stigmas (on flowers protected before anthesis with pollen-proof bags) were done with JEOL JSM 5.400 LV Scanning Electric Microscope (SEM), in order to verify the importance of the pollinator's activity on the pollen deposition on the stigma surface.

Some of these procedures were carried out with the aid of a disassembled metallic tower, of 12m height, in order to reach the tree canopy.

RESULTS AND DISCUSSION

In the first year of study, 40% of the studied plants exhibited the flowering phase from March to June, coinciding with the rainy period. However, the most expressive flowering period occurred in the dry season, extending from September to December, when up to 100% of the individuals were flowering (Fig. 1). Precipitation and sun light data are presented in Fig. 2. The same pattern was found in the second year, with two peaks in September and November (80% of the total plants). There is a narrow relationship between the precipitation and the phenological events of tropical species. Mori & Prance (1987) in studying the reproductive phenology of 14 species of Lecythidaceae in French Guyana, verified that the flowering period usually happens in the driest months of the year or in the transition among the dry and rainy months. The flowering type can be classified as "cornucopia" according to Gentry (1974), characterized by a large amount of one-day-long flowers opening each day within a period of three to eight weeks, in the majority of the trees in the population.

Fig. 1 – Phenological events (flowering and fruit set) of Bertholletia excelsa in Belém, from March 1994 to March 1996, expressed by the percentage of trees with flowers and fruits among the studied plants.

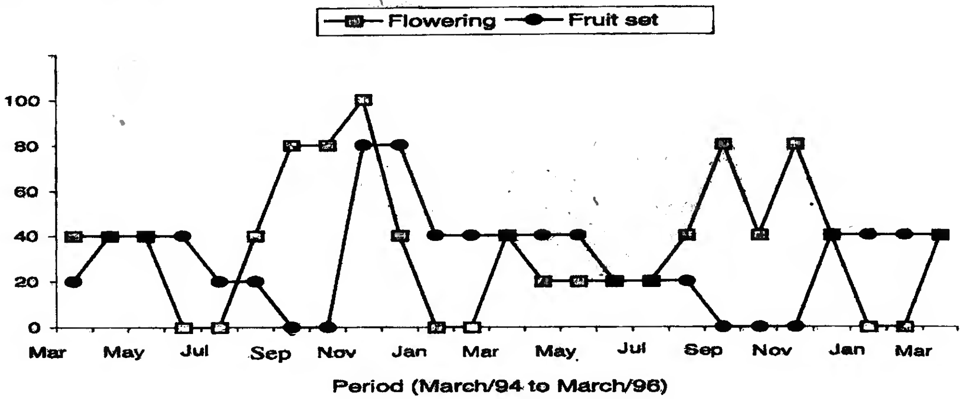
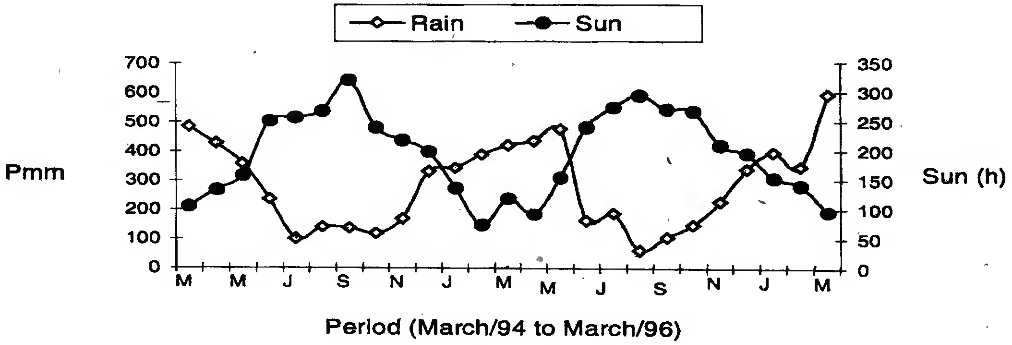


Fig. 2 - Meteorological data (precipitation=mm and photoperiod=hours) from Belém, Para State, Brazil, from March 1994 to March 1996.



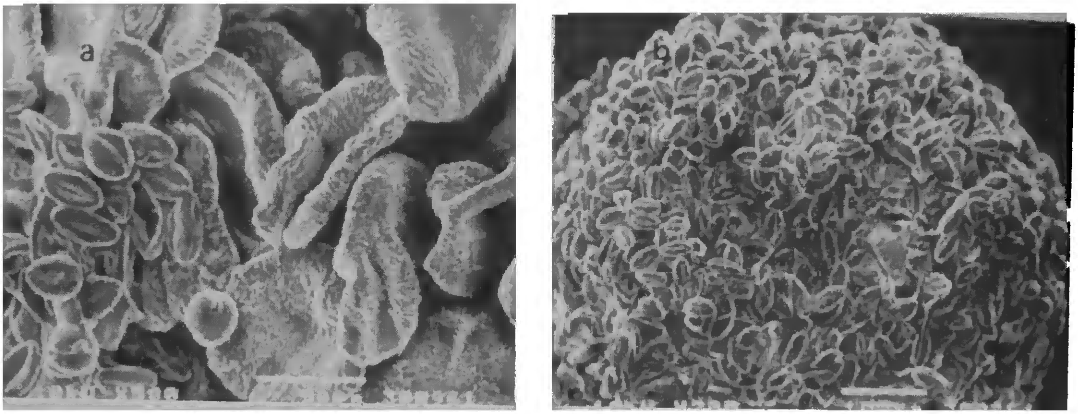
One fruit set cycle extended from November 1994 to May 1996. The fruits of *B. excelsa* present a long development period, with an average of 14 months, therefore it is common to find fruits in different development stages in one plant during the whole year. Seed drop occurred mainly in the beginning of the wet season (January to March). Green fruits drop was particularly verified in the dry season (September to November). The appearance of new leaves preceded the floral buds emergence. Some individuals presented total defoliation in the dry season, especially from October to December. Figure 2 shows the variation on the meteorological data from 1994 to 1996.

B. excelsa presents terminal inflorescences with 15 to 45 cm long and an average of 0.76 (n=182) flowers opened per day (Fig. 3). The anthesis happens slightly before dawn, about 5:30 h, confirming the observations of Müller *et al.* (1980). Its special morphology permits only the entrance of robust and vigorous insects into the staminode chamber, to collect pollen or nectar. Mori *et al.* (1978), Müller *et al.* (1980), Moritz (1984) and Maués & Oliveira (1996), already mentioned that the morphological structure of brazil nut flowers select the pollinator's entry.

Figure 3 –*Bertholletia excelsa* inflorescence.

The stigmatic surface of *B. excelsa* carries innumerous papillae. These structures facilitate the adherence of the pollen grains (Fig. 4a). In newly opened flowers, the papillae are turgid and white, changing to pale-brown in the senescence period, and loosing the turgidity. The analysis of the photomicrographies demonstrated that the stigmatic surface of the non-visited flowers presented small amounts of pollen, compared to the visited flowers, where the pollen grains almost totally covered the stigma (Fig. 4b). Considering the strong auto-incompatibility system allied this observation, this evidence emphasizes the importance of pollinators' activity for the reproductive success. Photomicrographies of the pollen morphology and anther dehiscence were also made (Fig. 5a and 5b).

Figure 4. Stigmatic surface of *B. excelsa* – Scanning electron Microscope: a) evidencing the papillae (500x); b) pollen deposition (200x).



The test with neutral red indicated a concentration of osmophores in the internal portion of the petals. The main receptive area of the stigma is placed in the basal portion of the central papillae, confirmed by all the tests performed. There was no response in the tests of pollen viability. However, using Baker's procedure to analyze stigma receptivity, any pollen grain attached to the stigmatic surface turned into a deep blue color, evidencing the viability. For some reason, the pollen collected directly from the anthers behaved differently from the pollen attached to the stigma, indicating that a reaction (or hydration) may occur, when the contact between the pollen and the stigma is made. Richards (1997) states that in wet stigmas the turgidity of the stigmatic papillae marks the period of the stigma receptivity, helping in the fertilization process by the secretion of a sugary solution that hydrates the pollen. The ovule counting revealed flowers with four and five locules, always presenting five ovules on each locule. The average number of stamens was of 90.3±6.7; the mean number of pollen grains was 601,993.98 and the pollen:ovule ratio was of 26,755.29, indicating obligate xenogamy, according to Crudden (1977).

Figure 5. Scanning Electron Microscope photopicrographies: a) Anther dehiscence of B. excelsa, exposing the pollen grains (350x); b) pollen germination in the stigma (750x).

The main visitors were bees of the following families: Apidae (*Bombus brevivillus, Bombus transversalis, Eulaema cingulata, Eulaema nigrita, Euglossa sp., Eufiesea sp., Apis mellifera, Trigona hialinata, Trigona pallens, Trigona fuscipennis, Tetragona clavipes*) and Anthophoridae (*Xylocopa frontalis, Centris similis, Epicharis rustica, Epicharis (Hoplepicharis) affinis, Epicharis* sp.). Other insects such as Chrysomelidae beetles, Sphecidae and Vespidae wasps were also recorded as flowers visitors. The most frequent bees were *Epicharis, Xylocopa, Eulaema and Bombus*. Prance (1976) mentioned that the main pollinators of *B.excelsa* are euglossine bees and Mori & Boeke (1987) agreed with his statement. The legitimate pollinators penetrated in the flowers, forcing the ligule upward, and stayed approximately 10 to 30 seconds collecting nectar. When they left the flower, the thoracic surface was covered with pollen. In visiting other flowers, they promoted the pollination, transferring the pollen to the receptive stigma. These bees are vigorous and robust, some of them being able to fly long distances (up to 20 km) (Janzen 1971), which is extremely important for maintaining the gene flow among allogamous plants in tropical forests.

The insect visitors' activity begins immediately after the anthesis, about 6:00h, and the visiting period can extend to 11:00h. (Table1).

TABLE 1 – Insect visitors and pollinators of brazil nut (B. excelsa) in the eastern Amazon region, Pará State, Brazil.

Family	Species	Importance*	Category**	Activity period
Anthophoridae	*Xylocopa frontalis*	+++	P	6:00 - 11:00
Anthophoridae	*Xylocopa aurulenta*	+	P	6:00 - 9:00
Anthophoridae	*Epicharis rustica*	+++	P	6:00 - 9:00
Anthophoridae	*Epicharis (Hoplepicharis) affinis*	+++	P	6:00 10:00
Anthophoridae	*Epicharis sp.*	+++	P	6:00 - 10:00
Anthophoridae	*Centris similis*	++	P	7:00 - 8:30
Apidae	*Bombus brevivillus*	++	P	6:30 - 9:30
Apidae	*Bombus transversalis*	++	P	6:30 - 9:30
Apidae	*Eulaema meriana*	+	P	7:00 - 9:30
Apidae	*Eulaema nigrita*	+++	P	7:00 - 930
Apidae	*Euglossa sp.*	+	P	6:30 - 9:30
Apidae	*Eufriesea sp.*	+	P	7:00 - 9:00
Apidae	*Trigona pallens*	-	V	8:00 - 10:00
Apidae	*Trigona hyalinata*	-	V	8:00 - 10:00
Apidae	*Trigona fuscipennis*	-	V	7:00 - 10:30
Apidae	*Tetragona clavipes*	-	V	8:00 - 10:00
Vespidae	*Synoeca surinama*	-	V	9:00 - 11:00
Vespidae	*Polistes infuscatus*	-	V	9:00 - 11:00
Vespidae	*Polybia sp.*	-	V	9:00 - 11:00

* +++: strong; ++: moderate; +: weak ** P: pollinators; V: visitors

The Trigona and Tetragona bees were classified as pollen thieves and opportunists, according to the classification of Wille (1963). Its presence was frequently observed, and in many times T. fuscipennis drove away the natural pollinators (*Bombus and Xylocopa,* mainly) when they tried to penetrate in the flower. Similar incident was observed and tested in passion fruit flowers (*Passiflora edulis*) in the state of São Paulo (Sazima & Sazima 1989). These authors verified that Trigona bees impeded the carpenter bees' visits, through direct attacks by biting the base of the antennas, legs and wings of the carpenter bees, driving them away. The presence of dead *Trigona* specimens on the flowers was just enough to move away the carpenter bees of the plantation. These bees perforate the flower to collect nectar and pollen without contributing to the pollination process, in a classic robbery behavior.

B. excelsa flowers are typically mellitophilous, "sensu" Faegri & Pjil (1979). The main pollinators are medium to large-sized bees.

It is important to emphasize that brazil nut yields are conditioned by the pollinator's activity, therefore any inbalance that affects the pollinator's population within plantations or natural areas will reflect directly in the fruit production. The low yields in sapucaia (Lecythis pisonis) were attributed to the lack of native pollinators by Mori *et al.* (1980). Prance & Mori (1987) also highlighted the need for studies on the Lecythidaceae's pollinators, attributing the failure of brazil nut plantations to the pollinators decrease. As an alternative, to avoid the decline of the natural population of pollinators in extensive plantation fields, inter-cropping systems with plants that attract the same pollinators' guild, e.g. passion fruit (*Passiflora edulis*) and the anatto (*Bixa orellana*), would help to supply food during the interval in the flowering periods. It is also recommended that natural vegetationbe permited to grow in strips among the plantation lines, in order to provide nest sites for the bees.

CONCLUSIONS

The main flowering period of the brazil nut occurred during the months of weak precipitation (August to November).

The pollen:ovule ratio corroborates the auto-incompatibility stated for this species in previous studies.

The main pollinators were carpenter bees and bumble bees, families Apidae and Anthophoridae, e.g. *Xylocopa frontalis, Epicharis rustica, E. affinis, Epicharis sp., Eulaema nigrita, Bombus transversalis and B. brevivillus.*

The pollination syndrome was characterized as melittophily.

In order to avoid the decrease of the pollinator's natural population in commercial plantations, and therefore a low fruit production, the development of management programs for the main pollinators will be of major importance for wide-scale cultivation of the brazil nut.

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FERAL AFRICAN BEES AUGMENT NEOTROPICAL COFFEE YIELD

David W. Roubik

ABSTRACT

No previous work describes natural history of coffee pollination in semi-natural habitats, but without intrusion of hived bee colonies. In Panama highlands having feral honeybees since 1985, the fruit and seed set of *Coffea arabica* was monitored during 1997 in bagged and open flowers on 558 shrubs in 11 transects within a range of 13 km, at elevations of 1300-1600 m. Caturra varieties were studied either next to old forest or in more open, mosaic habitats, while Catimor, an interspecific hybrid grown in "sun" plantations, was studied at a single site. Four honeybee hives were kept in the Catimor plantation.

Bees, the common visitors, were most abundant on flowers near old forest. Significant native visitors included *Centris festiva, Bombus pullatus, B. volucelloides, Trigona fulviventris, T. nigerrima, and T. (Tetragonisca) angustula,* but *Apis mellifera scutellata* made >95% of all flower visits in all areas. Visitation was not accurately measured by number of bees per flowering shrub, compared to bees per flower. Neither was the value of open pollination adequately gauged within a single branch with bagged and open flowers, compared to bagged and open branches on the same shrub. Flowers of *C. arabica* were found to be distylous, with 11 individual shrubs having short-styled flowers. Their fruit set and seed set, both in bagged and open flowers, was no different from the more common long-styled plants.

Caturra and Catimor showed over 25% fruit retention increases from pollinating visits by bees. For the former, seeds were over 25% heavier and developed faster from open pollination. Yield benefit from open pollination, chiefly by feral African bees, was 56%. Older plants, however, did not respond by increasing fruit set, nor did Catimor produce heavier fruit when pollinated by bees.

Key words: pollination, coffee

INTRODUCTION

The foremost tropical cash crop, *Coffea arabica* has surprisingly not been studied as to natural pollinators and their impact without introduced bee hives present, either in its native Africa or other tropical mainland areas (Free 1993; Smith *et al.* 1992; Wrigley 1988; Alvarado and Rojas 1994; Clifford and Wilson 1985; Amaral 1960; Badilla and Ramírez 1991; Nogueira-Neto *et al.* Filho 1959; Sein 1959). Maturation of coffee berries requires seven months. Fruit retention is apparently enhanced by degree of outcrossing (Free 1993) although *C. arabica* is self-fertile. In Panama I experimentally excluded visitors from flowers and compared berry production to normal, open flowers. Visitors were observed by old-growth forests and in agricultural areas. Not unexpected was discovery that feral African honeybees visited these African shrubs. However, naturalized African honeybees constituted most visitors and made nearly all the pollinating visits. Their impact, far greater than anticipated, suggests that many of the hundreds of crops visited and potentially pollinated by *Apis* are now experiencing changes in productivity in tropical America (Roubik 1989, 1995; Freitas and Paxton 1998). At coffee, flower visitors before invasion of the neotropics by *Apis melifera*, which only occurred in the last 45 years, were probably a diverse group and were still found at flowers near forest.

MATERIAL AND METHODS

I studied one of the most common modern cultivars of *Coffea arabica* (Rubiaceae) used in the tropics "Caturra" and also "Catimor" — an interspecific backcross of *C. canephora* to *C. arabica*, which thrives, depending on adequate fungicide application, in sunlight (Alvarado and Rojas 1994; Smith *et al.* 1992; Clifford and Wilson 1985; Perfecto *et al.* 1996; Greenberg *et al.* 1997). I established study transects in February 1997 in the western Panama province of Chiriquí, at 1300 to 1600 m elevation (9'80" N). This area is within 30 km of Costa Rica and touches Amistad National Park. Average annual rainfall is 1300-1800 mm with temperatures during the study ranging from 14 to 24° C. Sites were in extensive coffee growing regions at the foothills of the Talamanca mountain range.

Coffee begins flowering during dry season in response to showers, usually one week after a substantial rain, often after true bud dormancy (Clifford and Wilson 1985). Flowering begins synchronously within individual plantings and finishes after three days. Flowering then ceases for a few to several weeks, until again triggered by rain. For example, in the primary study area, consisting of 100 ha over 5 km in both relatively open and shaded plots ranging from 1300 to 1500 m elevation, coffee flowered a mode average of four times in each year during 1993 to 1997 (R. Hartmann, personal communication). One to five flowerings occurred during these five years, between January and early May. During my study, the first flowering on 20 January was small. The second and third occurred on 2-7 March and 23-26 March, and the last on 1-4 April. The second and fourth were the year's largest. We observed animals visiting flowers during the last three flowerings. The parallel study of Catimor was initiated on10 March. Flowering plants of a commercial coffee company, Durán, Lot 94, were observed for visitors during one of the year's two largest flowerings, on 11-13 March.

Study plantings and honeybee colonies

In the Caturra plantings, trees from the original forest were present, 20 to 35 m in height. These were managed for shade characteristics deemed correct for Caturra. The ten study transects, designated A-J, were of 9 to 25 coffee shrubs, using every tenth shrub where adjacent plants and rows were separated by 1 to 1.5 m. Transects were not made on edges of plantings. Over 95% of the plants were relatively young Caturra. Interspersed on some transects were older individuals of "Arábigo" or "Criollo Híbrido" which occurred in plots G, D, C, J and H. Several in D and J were over 30 years in age. All except 'I' were less than 500 meters from forest, and plots D and J were within 50 m of extensive primary forest. Study transects having several shade trees above the coffee were in all but plots E, F, A, B and (due to clearing in March) plot C. Plot D had one feral colony of honeybees nesting at ground level in one extreme. The 10 transects were oriented so that they remained at an even distance from forest, or extended perpendicular to it.

A 100% Catimor planting consisting of 2-y old shrubs constituted the Catimor site. Grown on terraced hillsides covering 10 ha, plants were separated by 1-2 m and had no shade during times of maximum daily insolation (1000-1400 h). The nearest forest was five km distant. Six small areas were selected on a transect 300 long, perpendicular to a line of four honeybee hives placed at 150 m from the end study plot. No insecticides or herbicides were used in plantings but fungicides were applied after April. In addition, Catimor was artificially fertilized. Caturra plantings were given some organic compost before flowering.

For Caturra, 12 honeybee hives were present at a lower elevation approximately 2 km from the study plots. No other managed bee hives existed within over 4 km. All honeybees in mainland Panama have been the African or 'Africanized' *Apis mellifera scutellata* since 1985 (Roubik and Boreham 1990). In Chiriqui African colonies are numerous in the wild, yet no European colonies have been present since 1985, and only 400 African bee hives were maintained by local coffee producers in the entire region in 1997 (Mr. M. F. Pardo, Duran Coffee, personal communication). To assess the degree of honeybee specialization on pollen from coffee flowers, two managed hives in the Duran planting, and two near forest where coffee plantings were few were kept with pollen traps during the April flowering (courtesy of M. Pardo). The pollen pellets were examined using a light microscope and standard palynological techniques (Amaral 1972; Roubik and Moreno 1991).

Pollination experiments and fruiting success

Open and bagged pollination experiments were made using branches with dense mature buds that were selected one or more days before flowering on 120 Caturra plants and 20 Catimor plants in 9 total plots, with an additional 24 Caturra plants included prior to April flowering. Open mesh tents were also placed over 10 shrubs in two Caturra plantings. A total of 30,861 (34% bagged) flowers on 447 branches were studied in Caturra plots and 8,289 (41% bagged) on 104 branches were followed in the Catimor plot. Bag mesh material was nylon with 1.25 mm openings. In Caturra plots A and B, both regular and very fine (0.25 mm) mesh bags were used on each plant, to assess the consequences of limiting wind pollination within fine mesh bags. Microhabitat conditions within a planting were scored as either relatively sunny or shaded. The shaded coffee shrubs had trees within 10 m.

One month after major flowering ended bags and tents were removed and total small green ovules at bases of wilted flowers were counted from bagged and open flowers. Flower numbers were written on masking tape at the base and tip of each treatment inflorescence series, and also on plastic flagging tape. Larger fruit, resulting from flowering before March, were removed. In addition, a total of 45 branches had both open and bagged flowers (bagged inflorescences were outermost on branches).

A total of 551 branches on 164 plants were monitored for developing fruit. In both Catimor and Caturra plantings, further sporadic flowering occurred after bags and tents were removed. A large flowering took place in the Catimor planting during late April. No attempt was made to remove these flowers or their fruit. For subsequent analysis of augmented fruit yield due to open pollination, the assumption was therefore made of equal flowering on portions of a given plant used for bagged and open pollination treatments, after the initial recording of flower number. Fruit retention and maturation were scored during May, June, August and October. All green, ripening fruit or red, mature fruit were counted on marked treatment branches. Fruit were also weighed during the last two censuses. To sample fruit weights, at least 40 of the largest fruit from bagged or open flowers were selected from 8-10 plants in each plot. An equal number of each category was taken from a given plant. Random subsamples of 10 to 20 fruit were then weighed in the field with a Pesola balance, to the nearest 0.2 g. In addition, fruit and seed weights were scored for 100 fruit from 12 plants, to test for relationship between fruit and seed weight.

Flower visitors and floral rewards

Bee visits and behavior (tempo of visitation, collection of nectar or pollen, interspecific aggression, floral corolla perforation) were recorded during two to four days in flowering episodes and included the same focal plants used for fruiting studies. Total open flowers, including day-two flowers that have wilted anthers but continue to secrete nectar (Nogueira-Neto *et al.* 1959) were estimated on each plant monitored for visitors. The number of bees and other animals was scored during a brief inspection of labeled transect plants, usually in less than a minute, as all study transects were walked two or three times a day. To supplement the focal plant approach, unlabelled plants nearby were monitored if, on a given day, flowers on a labeled plant were fewer than 80. Honeybee visitation tempo was recorded by timing five consecutive visits to flowers. A different bee was chosen each time, until at least 100 had been observed on more than one day and during each hour in which visits occurred (0730-1630). Nectar sugar concentration was measured in brix units with a hand-held refractometer corrected for temperature by extracting nectar from bees (see Nogueira-Neto *et al.* 1959) collected from mid morning until early afternoon (0900-1400).

Genetic variation in plantings

To explore the possibility that genetic variation differed greatly within Catimor and Caturra plantings and between the two principal cultivars, 25 individual plants were sampled along a continuous transect from two areas of both Caturra and Catimor plots. Horizontal starch gel eletrophoresis was used on fresh leaf samples prepared with tris-maleate grinding buffer and run on 300 ml gels of 13% starch, using tris-citrate tray and gel buffers of pH 8.2 (Kephart 1990). Enzyme systems assayed were 6-phosphogluconate dehydrogenase (6-PGD), acotinase (ACO) and diaphorase (DIA). Each had shown variation in preliminary assays using leaf samples of Caturra. Gels were run for 7 hours at 75 volts, 50 milliamps.

RESULTS

Fruit retention and yield

Ratios of open-pollinated to bagged flower fruit retention are given in Table 1 and Fig 1, for fruit counted on 24 August or 18 October (largest sample sizes were used). Plots averaged from 5% less to 56% more fruits produced from open pollination. Ninety-seven shrubs were included in the final census, including 464 branches. The grand mean of fruiting augmentation in individual plots was 17.08%. However, only plots E, F, A, B and 'Duran' had yields that were significantly increased by open pollination (t-test, one-tail comparison to a population mean of 1). Mean increase in this subset was 26%. Because comparison of bagged and open flowers on the same branch showed much higher fruit retention for open flowers (mean = 62% greater, n = 23), fruit set increases were computed only from pollination treatments including entire branches.

The ANOVA comparison of fruit set showed significant plot differences (df = 7, 90; F = 3.15, p = 0.005), but only between two Caturra plantings. Differences between plot F (full sun) and plots D and J (older plantings, considerably shaded) were significant at 95% confidence by Scheffe a-posteriori tests (Table 1). Significant variation in fruiting related to plant age was found within Caturra (Scheffe test, Table 2), although no difference existed between younger Catimor and Caturra plantings. Fruit set was moderately higher for plants in sunnier conditions (Table 2). A factorial ANOVA showed no significant interaction effect of plot and shade conditions on yield (F = 0, df = 4, 4, 85, p = 0.73). Fruit set also was uninfluenced by bag mesh size. No differences were observed in fruit retention from flowers bagged with fine or larger mesh (paired t-test, 2-tail, p = 0.30, N = 28).

The fruit set did not differ among plants with typical long styles, or shorter styles. Of 164 Caturra, 20 had flowers with short styles. Short-styled plants were found in plots H, D, G, J, and I. Stigmas rested on petal surfaces in newly opened flowers, as well as in day-2 flowers. The tent placed over eight shrubs in plot G contained both a large short-styled plant and a normal plant of similar size. Their proportional yield per flower did not differ (Wilcoxon signed ranks, z = 0.94, p = 0.35, n = 31). Among other plots no difference was found in fruit retention ratio on open and bagged branches of short-styled shrubs, compared to adjacent, normal, long styled focal plants (z = 0.245, p = 0.81, n = 26).

Mature seed weights were over 25% greater in open-pollinated Caturra and Arabigo of all experimental plots (paired t-test, 1-tail, p = 0.0001, n = 416), but not for Catimor. Regressing seed weight on fruit weight produced a line with slope greater than one ($r^2 = 0.82$, $p < 0.001$, n = 112), showing that an increase in fruit weight was met by a similar and greater increase in seed mass.

Flower visitors and behaviour

All 11 transects revealed visits to coffee flowers by *Apis mellifera L., Trigona nigerrima Cresson, T. (Tetragonisca) angustula (Lat.), T. fulviventris* Guérin-Meneville, *T. corvina* Cockerell *and Bombus volucelloides* Gribodo. Bees collected nectar, were seen with full coffee pollen loads and the visits of the first and last, in contrast to the other species, were rapid. At the Caturra plots, African honeybees visited five flowers in an average of 26.4 sec, SD 6.9, n = 127, while at Catimor, visits were significantly shorter (20.7 sec, SD 6.8, n = 189; p = 0.0001, Wilcoxon signed ranks). Some *Bombus pullatus* Franklin, *B. ephippiatus* Say and *B. volucelloides* Gribodo, both queens and workers, visited five flowers in less than 11 seconds, but my observations were limited. Similarly rapid was *Centris festiva* F. Smith, seen in plots H and D. Other, less common visitors were *T. (Tetragona) dorsalis* Friese, *T. amalthea* Olivier, *Eulaema polychroma* (Mocsáry), *Melipona panamica* Cockerell, *Nannotrigona perilampoides* (Cresson), *Epicharis rustica* (Olivier), *Centris, Lasioglossum, Augochlora, Partamona bilineata*

(Say), *Scaptotrigona subobscuripennis* (Schwarz), *Paratrigona ornaticeps* (Schwarz) and *Brachygastra*. All bees but *Centris* and *Epicharis* are social and *Brachygastra* is a social 'honey wasp'. Five nests of *Melipona, T. corvina, Partamona and T. angustula* were found in original forest trees felled in plot C during the study. The crowned woodnymph (Trochilidae) was observed in plot D. Syrphid flies of several genera, as well as hesperiid, ithomiine, danaid, and heliconiine butterflies also occasionally visited coffee flowers. Visits of most taxa could not have been a significant factor, and their numbers were far too low to be tested as to relevance in coffee pollination.. In contrast, total observed Apis numbered 1415 and native bees 511, but two-fifths the latter were *T. corvina and T. fulviventris* which perforated flowers for nectar. *Trigona corvina* foraged in aggressive groups.

If nesting near coffee plantations, the honeybee harvested almost exclusively coffee pollen during the major flowering period in April. Pollen specialization by honeybees from hives in the Catimor planting was indicated by over 95% coffee pollen, with seven other pollen types observed. In contrast, colonies separated by a distance of several km from the coffee growing areas intensively harvested native tree pollen, with coffee pollen comprising under 5% of incoming pollen during the same interval.

Visitation rates

The number of bees per coffee plant or bees per flower varied appreciably among plots and sunny or shaded shrubs (ANOVA, Tables 1, 2). On a per-plant basis, Catimor plants had significantly more bees, but this comparison proved inadequate to assess differences in floral visitation (Table 1). Scheffe a-posteriori comparisons showed a statistical difference in bees per flower only in plot D, which had the most honeybees, native bees, was shaded, and was close to old forest. In general, there were more *Apis* per flower and more native bees per flower in shaded conditions and near forest, although the average number of flowers per shrub was higher in sunny plots more distant from forest (ANOVAs, $p = 0.0001$, Table 2). When the near-forest component was removed by excluding plots J and D, *Apis* per flower had no significant variance due to sun or shade ($df = 1{,}491$, $F = 2.73$, $p = 0.1$). A weak but significant positive correlation was seen between *Apis* per flower and flower number on coffee shrubs (adjusted r-squared = 0.10, $p = 0.0001$, $n = 696$). Adjustment in visits per flower for the Catimor plants, where Apis was 27.5% more rapid in flower visitation, did not change the ANOVA results — only plot D had significantly more visits than all other plots except J (Table 1).

Other general results

Fruit from open and bagged flowers ripened at different rates, evident in red coloration and also in greater weights among open pollinated fruit ($df = 9$, $p = 0.0001$, t-test, 1 tail, comparison of ratios of open to bagged weights to a population mean of 1.0, $n = 416$). Fruit drop was pronounced during the first three months after flowering, with initial fruit set at 91% (Durán) and 85% (Caturra plots); only a 2-3% decrease was detected between August 22 and 18 October.

The isoemzyme results merely confirmed that single plantings of coffee were not clones. Neither DIA nor 6-PGD were monomorphic isoenzymes in Catimor (5 of 35 individuals polymorphic) and plots D, G and J of Caturra (2 to 8 of 25 individuals polymorphic). Resolution was poor for ACO.

Nectar sugar concentration averaged 36% (SD 8%) for Caturra (n = 305 bees) and 27% (SD 4%) in Catimor (n = 41).

DISCUSSION

This Panama study is a sample representing tropical, continental America in 1000-1500 m elevations at which Arabica coffee is generally cultivated, but where honeybees were previously absent or ecologically irrelevant. While Catimor is not suitable for export on the international market, its shrubs yield more berries per hectare (Alvarado and Rojas 1994). The present study suggests that Caitmor productivity is less on a per flower basis, compared to young Caturra, but its increased fruit set in response to open pollination is similar (Table 1).

Neotropical studies of coffee pollination show varied results and some ambiguity (McGregor 1976; Free 1993), and none was conceived to address natural history questions where pollinators had not been displaced by hives of bee colonies or wholesale habitat manipulation. Augmented fruit retention and larger size seem to result from outcrossing (Nogueira-Neto *et al.* 1959; Raw and Free 1977; Badilla and Ramirez 1991). However, such research was conducted in the absence of what is likely the primary flower visitor of Coffea in the Neotropics — the feral African honeybee, *Apis mellifera scutellata* Lat. Furthermore, experimental studies have utilized cages remaining in place for several weeks to months. After a few weeks for coffee, which requires several months to produce mature fruit (Wrigley 1988), potential negative influence of shading from cages is expected (Corbet and Delfosse 1984). Caged plants studied by Raw and Free (1977) showed lower fruit retention, even if pollinating bees were introduced into them during flowering, compared to open-pollinated shrubs. In addition, either branches or entire plants have been covered to exclude pollinators, with results that differ five-fold in the implied value of pollinators (Amaral 1960). Claims persist for nearly a doubling of "yield" among widely varying "natural outcrossing" levels (Badilla and Ramírez 1991; Reddy *et al.* 1988; Free 1993). If yield refers to fruit retention, then these claims are not justified. If yield refers to the mass of a coffee bean produced per flower, then the present study gives some confirmation. But if such statements refer to older individual plants, they are patently false.

Apis mellifera scutellata, the east African honeybee (Hepburn and Radloff 1998), was the preeminent flower visitor of *Coffea arabica* despite the presence of dozens of other animals. Coffee is visited by many pollinating native social bees and wasps in the neotropical mainland, particularly *Trigona, Melipona*, and other Meliponini (Nogueira-Neto and Filho 1959; Martinez-Hernandez *et al.* 1993) and as documented for the first time in this study, *Bombus* and *Centris*. Compared to these native neotropical insects, the African honeybee quickly saturates rich resource patches such as flowering coffee plantations, by having large colonies, large flight range and an extremely effective recruitment system (Roubik 1989). Honeybee visits to any flower in any plot totaled over 40 in a day and did not differ significantly among most plots. Regardless of proximity of the known hives, honeybees evenly dominated the coffee landscape.Their pollen in hives near coffee plantings was found to consist of over 95% coffee pollen, while coffee pollen was less than 5% of total pollen from hives well separated from coffee plantations.This indicates opportunism as well as the likelihood that bees visiting the flowers came from close by.The honeybees were 82% of bees at flowers, and considering a much faster tempo in visitation, accounted for >95% of actual visits. Studies with none of the native bee genera present, but with European honeybees on Caturra, have shown the 16-17% fruiting augmentation that I observed (Badilla and Ramírez 1991; Free 1993; Sein 1959; Nogueira-Neto *et al.* 1959) strongly suggesting the honeybee alone can account for at least this degree of seed set increase.

Variation in seed set on the same branch demonstrated that at the ramet level, allocation of nutrients shifted considerably toward open pollinated fruit. Fruit set showed a 62% increase among open-pollinated flowers, compared to 17% mean augmentation for single-treatment branches. Wind excluded by fine mesh bags appeared insignificant as a pollinating agent. Autogamy by gravity was possibly a large component of pollination. As these authors make clear, open pollination can change both the outcome and origin of pollen transferred to stigmas. Artificial pollination experiments would be necessary to determine whether outcrossing versus improved pollination with self-pollen were the primary benefits derived from open pollination. Such benefits, seen not only in fruit retention over the long maturation period, but also in faster growth and greater seed and fruit mass, are thought to derive primarily from pollen brought from other shrubs by flower visitors (see Free 1993; McGregor 1976). Although six of nine study plots displayed only moderate or insignificant increase in fruiting success due to open pollination, the developmental rate and weight of ripe berries increased a mean of 23% among all open-pollinated Caturra plantings. Combined with mean numerical increase of 27% in fruit retention (where statistics were significant) open pollination could result in over 56% increase (1.23 x 1.27) of fruit mass and yield. As indicated by the results, within berries the seed mass increased more steeply than fruit mass.

The potential gain from pollinators was greater in Caturra plots. Even though the most productive plots in Caturra plantings were those receiving more sun, this was not due to more bee visitation or applications of fertilizer, and was thus potentially due to greater insolation during fruit maturation. Although Catimor plants did not evince increased berry weight from open pollination (means 1.6 and 1.75 g, n = 44), fruit set increased by 17% from open pollination. Because Catimor is derived from an interspecific hybrid, the negligible size response to open pollination may be linked to this variable. According to a-posteriori comparisons in ANOVA (Table 1), Catimor did not differ appreciably from Caturra in the seed retention increase resulting from open pollination.

The preliminary results from allozymes suggests both cultivars were genetically variable within distances of 25 m and therefore recombination potentially occurred via bees. Genetic monomorphism is unlikely to explain lack of response to outcrossing within some plots, particularly because less responsive plots had both short-styled plants and mixed cultivars present. No published work has mentioned distyly in *C. arabica*, but the decreased distance between stigma and anthers, compared to normal long-styled flowers, neither caused a reduction in development of selfed seed in covered plants, appreciable differences in mature berry weights in covered plants (means 1.67 and 1.72 g, n = 20), nor differences in seed set among open plants. Berry weights among open-pollinated plants were not compared. Observed increase in seed size among open pollinated Caturra did agree with individual berry weight increases implied by Badilla and Ramírez (1991), Nogueira-Neto and Amaral (1959, data re-analyzed using a 1-tail t-test on average weights of berries per plant), and Raw and Free (1977).

Past neotropical studies suggest honeybees are principal pollinators of coffee. Such findings were arbitrary because *Apis mellifera* had no independent or well established feral populations. This bee entered Panama in 1982 and became established for the first time in the wild (Boreham and Roubik 1987; Roubik and Boreham 1990). In Chiriquí Province, where the local fire department recorded honeybee 'cases' since 1957 feral *Apis* in the highlands also was unprecedented. Before 1967 there was one colony recorded in David, Chiriquí, while between 1977 and 1986 there were 706, virtually all in 1985 and 1986. Yearly data for 1993-1995 show 179 to 268 colonies recorded in the provincial capital (archives of the David, Chiriqui, fire department).

Significantly more bees, both native and African, were present on coffee flowers near forest. In younger plantings this should result in higher fruit production. Yet the highest visitation rate was not correlated with any benefit from open pollination in plots near forest. The oldest Caturra plants were present there, and productivity declines with plant age in coffee (Alvarado and Rojas 1994; Wrigley 1988; Clifford and Wilson 1985). My observations also suggest that sun or shade conditions were unlikely to influence flower choice by bees because exclusion of the sites by forest resulted in no analysis showing different visitation between sun and shade conditions. Bees were thus distributed fairly evenly over plots, despite a total spread of 13 km and the presence of known hives or feral colonies next to some plantings. Honeybee colonies seem to exist throughout the area. Pollen analysis strongly suggests they take the closest forage. Furthermore, visits seemed linked to the presence of nest sites and bee colonies in plot C, where tree removal may have caused reduced visitation by native bees (Table 1). Another potential cause of diminished fruiting with more bee visits is nectar robbing by Trigona, but further studies are necessary (Roubik 1989; see also Nogueira-Neto *et al.* 1959). Slower visitation rate of honeybees at Caturra flowers may have been related to a nectar quality higher than that of Catimor. Nectar quality of Caturra was the same found in one of its progenitors, Bourbon, in Brazil (Nogueira-Neto *et al.* 1959), thus the conditions studied in Panama could well be applicable to many areas in the neotropics.

In conclusion, while feral African honeybees in the Amazon produced a decline in fruit production in a native leguminous shrub (Roubik 1996), evidence presented here shows this exotic bee sustained and extended a positive pollination impact on a plant from its native environment.

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TABLE 1. Final fruit retention increase on branches of *Coffea arabica* due to open pollination, the observed visitation by native and African bees, and flowering characteristics of 11 study plots in Chiriquí, Panama (plot means). Yields of plots A and B were pooled, from a single planting. For sample sizes, N = branches, n = shrubs. Statistical differences are indicated.

Plot	Mean	Mean			Apis and Native Bees
	Fruit Set	Flowers	(open/bagged), N,n	on shrubs	Apis shrub^{-1}bees flower
A	1.20**	77,10	1449	1.98	14, 5
B	1.20**	50	2118	1.97	11,10
C	1.16	20,11	416	0.63	17,1
D	1.03	139,24	327	1.63	66, 53ψ
E	1.14*	87,9	1759	1.43	12,14
F	1.56**	72,10	1700	2.07	15,7
G	1.17	26,9	748	0.89	15,7
H	----	33	870	1.36	15,7
I	----	27	977	1.04	15,18
J	0.95	65,9	750	2.27	41,21
Dur	1.17*	101,16	1222	3.73ψ	42,4

**$p < 0.005$, t-test, 1-tail

*$p < 0.06$, t-test, 1-tail

ψ$p < 0.05$, Scheffe a-posteriori F test, Model 1 ANOVA, (Table 2)

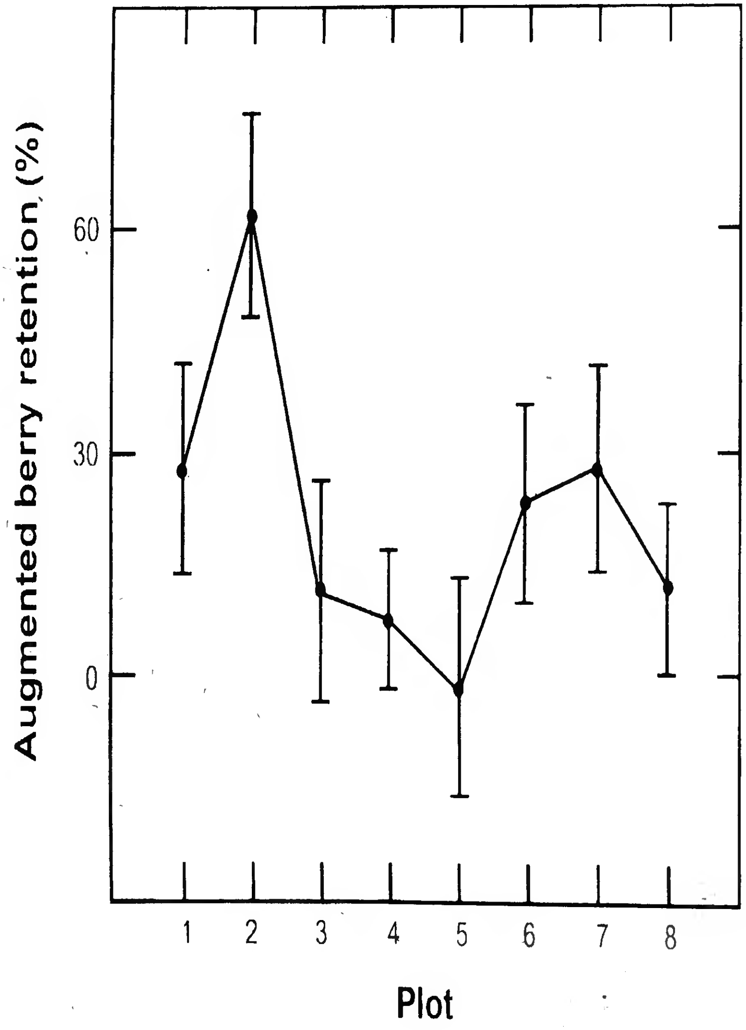
\+ bees per 10,000 flowers, left column *Apis*, right column native bees

TABLE 2. ANOVA (Model 1) of differences among fruit yield in coffee plantings related to bee visitation, sun or shade conditions, numbers of flowers open on study trees, and cultivar. A posteriori comparisons among groups are Scheffe tests at the 95% significance level. All yields are proportional numbers of mature berries from open compared to bagged flowers on individual plants, considering means when multiple branches were used.

Factors Compared	df	F	P	Scheffe F
Plot • yield	7,90	3.2	0.005	plot F: D, J
Cultivar • yield	2,95	4.9	0.01	Caturra age
Plot • Apis/plant	10,686	15.5	0.0001	Duran: all
Plot • Apis/flower	10,686	66.5	0.0001	plot D: all but J
Plot • native bees/flower	10,686	8.0	0.0001	plot D:A,B,E,F,Dur
Sun or shade • yield	1,96	3.84	0.053	
Sun or shade • Apis/flower	1,695	66.5	0.0001	
Sun or shade • Apis/flower*	1,29	1.79	0.19	
Sun or shade • native bees/fl	1,692	38.86	0.0001	
Flowers/plant • sun or shade	1,550	110.15	0.0001	
Flowers/plant • plot	10, 540	23.1	0.0001	

*recorded in plot D only, single day

FIGURE 1. Mean augmentation in fruit retention, at maturity, of *Coffea arabica* in response to pollination by feral honeybees, *Apis mellifera scutellata,* and native pollinators in Panama. Bagged and open branches on 97 shrubs were compared (n = 9 to 24 per transect). Plots 4 and 5 included older, Arabigo cultivars (8 to 60 years) with relatively young Caturra; plot 8 was Catimor (2 years old), and the remainder were Caturra (6 to 8 years). Plots 1,2,6 (two adjacent transects combined) and 8 demonstrated statistically increased fruit retention in the open pollination treatments (paired t-test, one-tail, $p < 0.06$).



POLLINATION OF *Prosopis Tamarugo* IN THE ATACAMA DESERT WITH REMARKS ON THE ROLES OF ASSOCIATED PLANTS

Haroldo Toro

ABSTRACT

A few species of *Prosopis*, growing in the desert of northern Chile have facilitated the settlement of a small human population keeping herds of goats, sheeps and llamas that graze on *Prosopis* seeds. The pollination of *Prosopis* occurs during the main spring- summer blooming season by *Centris mixta* (Anthophoridae), but during the autumn-winter period, the only available pollinators are some species of butterflies and moths. *Centris mixta* is polylectic over almost all of its geographic range, but it behaves as oligolectic in the area of *Prosopis*, the emergence and flight activities of the bee are synchronous with the sequential blooming period of the different species of Prosopis. The biology of *C.mixta*, with permanent nest sites, seems to promote intimate insect-plant relations. Survival of both, the plants and specially the pollinators are in jeopardy because of human activities in the area.

INTRODUCTION

A few species of *Prosopis*, established for a long time in the northern desert of Chile, can survive and show particular "adaptations" to the extreme water scarcity in the area. In the early 1900s, intensive mining activity in the desert resulted in an almost complete eradication of the arboreal Prosopis, but the implementation of conservation policies and the reforestation of large areas have now given rise to a new community with a few plant species associated with a small number of pollinators. This community has been found to be extremely fragile, with only a few plant and animal species (Bobadilla *et al.* 1987) distributed in isolated patches. After forestation, a small human population settled in the area and kept herds of domesticated sheep, goats and llamas that graze on Prosopis seeds.

Most of the trees, in the forest, are *Prosopis tamarugo* Phil. ("tamarugos" in this paper) and a few of intermixed plants of *Algarrobia* sp., with *Prosopis alba* Gris, *P. atacamensis* Phil. and *P. flexuosa* DC# (Villaseñor *et al.* 1994). More taxonomic work is required to clarify the chilean *Algarrobia* (Palacios, personal communication).

The native vegetation in the area includes two other species of *Prosopis*: *P. strombulifera* (Lam.) Benth and *P. burkhartii* Muñoz. The first of these two species is a small bush, rather scarce, which grows in small patches frequently foraged by the native people who use their fruits as amulets. On the other hand, *P. burkhartii*, also bushy, is very rare, poorly known and probably very close to extinction. Besides *Prosopis*, one native bush *Caesalpinia* sp. is abundant in few, but large, patches widely isolated by barren desertic areas.

From the area's economic perspective, *P. tamarugo* is interesting and presents advantages over the *Algarrobia*. *P. tamarugo blooms* and produces fruit and seeds almost year round, which is very important for cattle when there is no other food available. The blooming period shows two main, very distinctive peaks in some years; one in spring, which is common for other species of *Prosopis*, although not exactly synchronous; and another, in the late fall. The *Algarrobia bloom* only during springtime, with flowers apparently more attractive to pollinators than those of "tamarugos" and with sweeter fruits. The fruits are also more attractive to cattle and to the human population that eats it directly or uses it to prepare alcoholic beverages.

Experiments made with fabric bags (used to block the access of insects) cover young inflorescences with no emerging pistils, have revealed a low percentage of self-pollination (Villaseñor *et al.* 1996). Likewise, fine net bags, which allow pollen to be carried in by the wind, but not by insects, show absence of anemophilous pollination.

According to above, the amount of seeds available for the human population is mostly determined by the quality and quantity of pollinators and by the mass of herbivorous insects feeding on the flowers and seeds. Most of the pollination of *Prosopis*, during the spring blooming season, is mainly by the native bee *Centris mixta tamarugalis*, but during the colder seasons, there are no bees in the area and, therefore, pollination depends on various species of butterflies and moths.

Although the number of insect species associated with *Prosopis* (Ward *et al.*1997; Genise *et al.* 1990; Simpson *et al.* 1977) and recorded for the area is relatively high (Bobadilla *et al.*1987), only the following species have shown free pollen on the body hairs:

Hymenoptera
Colletidae
    Colletes murinus Friese
    *Chilimelissa luisa*Toro y Moldenke
Halictidae
    Caenohalictus sp.
Anthophoridae
    Centris mixta Friese
    *Centris moldenkei*Toro y Chiappa
Apidae
    Apis mellifera Linné
Vespidae
    Pachodynerus peruensis Saussure.
Lepidoptera
Lycaenidae
    Leptotes trigemmatus Butler
Diptera
Bombyliidae
    Villa sp.

There are also few examples of Syrphidae,Tachinidae, Calliphoridae, Cecidomyidae and Sarcophagidae as flower visitors.

All the potential pollinators that were found are polylectic on a broad geographical scale; however, given the scarcity of species present in the desert, they are necessarily oligolectic there.

Colletes murimus and *Caenohalictus* sp. are rather scarce in the area but show a broader distribution throughout the north of Chile, reaching heights of 2,500 m. They are associated with native vegetation and alfalfa. *Chilimelissa luisa* is a small bee found abundantly on *Cesalpinia aphylla,* with which it seems to be well associated. It also finds hollow stems on this plant in which to build its nests. This bee visits algarrobos and tamarugos and flies mainly around branches close to the ground. Because *C. luisa* has been detected only around some specific trees, it is concluded that its occurrence is spotty.

Apis mellifera shows variable population density. Previously it was a rare species, but it dramatically increased in number in a few years as a result of transhumanance beekeeping. In unprotected conditions, survival of *A. mellifera* is uncertain, not only because of environmental conditions but also because of the destruction of its hives for honey extraction. The search for colonies of honeybees in the *Prosopis* forest over a period of 4 years resulted in only three being found. Two were in hollow trunks and one in an abandoned well. Toro *et al.* (1992) estimated the size of the colony by measuring the inflow of specimens into the hive (Toro *et al.*1992). For the three unprotected colonies under study, the inflow varied between 16-43 individuals in10 min. At the end of the study, the colony became extinct. At the same time, the flow of bees in protected, managed colonies was 143 specimens/10 min.

Most individuals of *A. mellifera* go to *Prosopis* for nectar. On average, only 25% of bees recorded had corbicular pollen loads, and very few among those showed full loads (11%). Transportation of pollen is greater in spring than in the rest of the year. The amount of highest nectar foraging seems to be related to water shortage. Nectar is widely used, besides for other metabolic functions, in thermo-regulation of individuals and colonies.

Nevertheless, data published by León (1985) reveal interesting results from the perspective of beekeeping. The average weight gain per colony was 36.95 kgs over the season. In addition to the bees obtaining honey, which is characteristic and virtually pure as far its plant origin is concerned, the weight gain means a significant volume of nectar has been harvested by the bees especially considering the 120 hives noted by León (1985). The nectar removal may influence resource availability for the native pollinators of the area.

The association of *Leptotes trigemmatus* (Lycaenidae) and possibly of *Prosopis* with some other moth species (marked "tamarugo-attacking insects", Bobadilla *et al.*1987, Vargas *et al.*1989) are interesting in the area, particularly in the fall-winter period, when Apoidea are not present. In the absence of Apoidea, these Lepidoptera are the only possible pollinators for *P. tamarugo*, in addition to being the most important pollinators for *Prosopis strombulifera* and *P. burkhartii*. Nevertheless, larvae of *L. trigemmatus* feed on *Prosopis* blossoms. For that reason, the density of this species has a direct effect on reducing the fruit yield and is considered a plague by the local people. With regard to self-regulation, the Prosopis-Lepidoptera association is interesting because the species that feed as larvae on flowers and green seeds are the same as those which act as pollinators. The long-term situation suggests a self-regulatory mechanism whereby the density of herbivorous species is quite dependent on the number of available flowers.

L. trigemmatus visits the inflorescence in a somewhat disorderly manner; it arrives at the inflorescence and stays at highly variable durations. It also moves over the flowers with no fixed trajectory, virtually independent of its nectar foraging time, which is sometimes tens of minutes, but approximately 5 min when the female is laying eggs. These two species appear to rely more on *L. trigemmatus* than the other *Prosopis* sp. do and show a blossoming peak when there are no other pollinators in the surroundings. Like other butterflies, *L. trigemmatus* easily goes from one tree to another, even distant trees, a behaviour particularly shown by the males in search mates.

Most pollination of *Prosopis* during the spring bloom is performed mainly by the native bee *Centris mixta tamarugalis* (Klein and Campos 1978; Toro *et al.* 1993), an extremely abundant species in the area.

The *Prosopis- C. mixta* association is well synchronized. *Centris mixta* seems to recognize and respond to the same environmental stimuli as *Prosopis* does and shows a behavior more similar to a specialist than to a generalist pollinator. The adult bees appear in the area in late August or early September, at the time algarrobos bloom (*P. alba, P. flexuosa, P. atacamensis*).

Centris mixta spends the hibernation period as a post-defecating larva. In the absence of environmental stimuli, when it is kept away from its natural habitat, it continues hibernating so that when kept in the laboratory, it can live some years without transforming itself into pupa (Chiappa and Toro 1991). The emerging adults show a slight protandry.

In using the sequential Algarrobia-tamarugo blooming period, adults of *C. mixta* fly from September to December. In our observations we have registered a considerable reduction of males as the season progresses and by late December, they become rare. The single blooming period of algarrobos is from September to October, and the blooming peak of tamarugos occurs in the October-November. This blooming sequence allows *C. mixta* to have food for a long period, in a milieu that, in general, is characterized by very restrictive reproductive periods for most of the biota. From the plants' point of view, the sequence is mutualistic with evident benefits for *P. tamarugo*, which blooms when there is a high density of pollinators.

The onset of the "tamarugo" bloom overlaps with that of the "algarrobos". In the Atacama, *C. mixta* shows a strong preference for flowers of Algarrobia with exceptional individuals visiting "tamarugos". The end of the blossoming of algarrobos makes for a new situation for *C. mixta*, which must then learn to collect on tamarugo in order to meet its food requirements. This behavior points to *C. mixta* as a selective force for the beginning of the blooming period of the algarrobos, although we have found scattered flowers before the emergence of *Centris*. In the same way, *C. mixta* is also selective in the sequential blooming of algarrobos and tamarugos because of the visiting preference to algarrobos.

The bushy species of *Prosopis* (*strombulifera* and *burkhartii*) are not considered as an attractive resource for pollinators because of the small number of plants present in the area.

However, the synchronic blooming of *Cesalpinia aphylla*, the only native species abundant in the area besides *Prosopis*, is clearly an important nectar and pollen resource in the area. In the absence of Algarrobia, *C. mixta* prefers *P. tamarugo* rather than the flowers of *C. aphylla*. The latter is pollinated by the tiny species *C. luisa* (Xeromelissinae) and another species of *Centris, (C. moldenkei)*, also showing oligolectic behavior, and rarely found on *Prosopis*. *L. trigemmatus* (Lycaenidae) and some *Diptera* also visit *Cesalpinia*.

Centris mixta used permanent nest sites close to *Prosopis* trees. The sedentary nature of the chief pollinator quite unlike the vagility of other species of *Centris* (Rozen and Buchmann 1990), is probably determined by restrictive environmental conditions. The bees require soil with great amounts of salt. The absolute absence of resources beyond the forest, may also result in a stability in the pollinator-plant interaction over time (*e.g.* synchronicity, phenology, etc.). This situation must also affect the population density of both the pollinator and the plant. Besides, the permanent use of the nest site gives rise to a population of parasites and predators, dependent and synchronized on their host. This community clearly shows Mutillidae and Bombyliidae as parasites, other than predator birds and lizards, all dependent on *C. mixta*.

Pollination behaviour of *C. mixta*. As a result of a particular reproductive behaviour, differences in the frequency of visits of males and females to flowers were observed in the course of the day. In the morning, the great mass of males patrols the nesting territory and waits for emerging virgin females. The mated females mostly collect nectar and pollen to supply the nest cells. Their visits to flowers decrease between 13 to 15 hrs. as ambient temperatures rise. Many individuals rest in the shade, with their glossae protruding and evaporating nectar. In the afternoon, the number of males at flowers increases, while large numbers of females were found on the ground and working in their tunnels.

Both males and females pay short and quick visits to the flowers (X=11.26sec +/- 8.74 (S.D.), n=36). On most individuals (80%) arrive at the distal or central part of the inflorescence, then following a spiral path from the distal to proximal end. At the end of its visit, the bee flies to another inflorescence, in the same tree or in another distant tree. The bee's trajectory on each inflorescence favours efficient pollen flow among protogynous inflorescences (the stamens are first exposed in the proximal end, when the pistils are already exposed along the whole inflorescence).

The following practices are considered potential problems for the proper conservation of the pollinators and in the whole system of the Atacama desert:

1. *Prosopis* is used as fuel because the isolation and difficult access to the area make gasoline and other petroleum derivatives expensive and difficult to get. This generates a strong pressure for the people to use *Prosopis* (there is no other wood resource) for fuel and the pressure is strong to produce charcoal. There are few other economic opportunities to supply the demand of the local mining companies.

2. The blooming spring-summer peak also generates pressures from honeybee keepers. The beekeepers are non-local people and bring in a number of hives and house them in the *Prosopis* forest. As pointed out before, *A. mellifera* collects a large amount of nectar and the pollen is probably significant too but difficult to assess. The low diversity in vegetation suggests a limited pollen-nectar resource would produce competition with native pollinators and that this competition should be stronger towards the end of the blooming period. When there is no *A. mellifera* in the area, the availability of nectar-pollen for *C. mixta* is

guaranteed because only females are present and males have previously been eliminated by predation or other causes.

3. The nesting sites located in open flat grounds are used occasionally, or sometimes frequently, as roads for cars or other kinds of vehicle. The traffic produces high mortality of *C. mixta* during the reproductive period, spoiling the nesting tunnels and smashing the males while they are waiting for females to emerge.

4. The defoliation and seed damage caused by lepidopteran larvae have induced people to try pesticides derived from *Bacillus thuringiensis*. This practice has shown positive results as many more seeds are obtained than without pesticide use. Nevertheless, in a relatively short term, intensive applications could result in great damage because the eradication of Lepidoptera also means the eradication of the pollinators for the fall-winter blooming period. The recovery of pollinators by their immigration from adjacent areas is considered very difficult because of the strong isolation created by the desert between areas with vegetation.

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BEE FAUNA OF SOME TROPICAL AND EXOTIC FRUITS: POTENCIAL POLLINATORS AND THEIR CONSERVATION

Marina Siqueira de Castro

ABSTRACT

Pollinators play an important role in the reproductive success and gene flow in many agricultural and native plants and the plants produce important food sources for the pollinators.The bee community of a mixed orchard was studied at an experimental Station in the state of Bahia, Brazil. At this station, 32 species of native tropical and exotic fruits were studied.

The data showed the importance of stingless bees (Apidae; Meliponinae) as potential pollinators for some native tropical fruit trees. Apidae was the most abundant bee family, while Anthophoridae showed higher diversity (species richness). A total of 95 species of Apoidea were observed and collected. Some patterns of bee species composition and relative abundance was studied.These ecological studies are important for the conservation of plants and bee biodiversity.

INTRODUCTION

Maintaining the biological diversity of potential pollinators in agricultural ecosystems is not easy. However, it is necessary for the sustainability of agricultural crops that depend on these pollinators. In this context, bees play a prominent role in pollen transfer.

Agricultural politics still emphasize the short term gains and high productivity often leading to the erosion of soil, contamination of water, fragmentation of natural ecosystems, loss of cultural and biological diversity and other environmental problems.The severity of these impacts depends on the technological level the production system adopted.The expansion of the agricultural borders is always linked to the use of a reduced number of agricultural crops with few varieties. Thus, monocultures occupy great expanses of land which degrades the genetic diversity of all wildlife.

New perspectives for the expansion of agriculture in a global economy are opening in the direction for sustainable production. Although biodiversity does not stem from the concept of sustainability, it is essential for agricultural production. It is the key for production of balanced agricultural systems, offering both socioeconomic and environmental benefits. Crop productivity is a benefit that is entirely dependent upon pollination to produce fruit and seeds. Many bee species contribute to the pollination of the agricultural crops, the most common of which (Africanised honey bee) is neither the only or the most important pollinator.

At the regional level, several ecosystems of Bahia State, northeast of Brazil, present a great diversity of bees. The Apoidea diversity of the natural ecosystems of Bahia has been systematically studied for the last ten years as follows:

- Caatinga
  Casa Nova (Martins 1990; Castro 1994)
  Milagres (Castro in preparation)
  Itatim (Monteiro *et al.* 1998)
- Campos rupestres with cerrado elements
  Lençóis (Martins 1995; Viana 1992)
- Fragments of Atlantic forest
  Conceição do Almeida, (Castro and Oliveira 1998),
  Caravelas and Mucuri (Lima *et al.* 1998)
- Fragments of dunes (litorâneas) with "restinga" vegetation
  Abaeté/Salvador, (Viana in preparation)
  Parque Pituaçu, (Ramalho *et al.* 1998; Ramalho and Silva 1998)
- Dunes of San Francisco river
  Ibiraba, (Viana in preparation);
  forests of Ibiraba - San Francisco River (Neves and Viana 1998)

Studies on agricultural crops in Bahia are scarce. Thus, with the objective of enhancing knowledge about the diversity of potential pollinators in agricultural ecosystems in Bahia, we conducted field observations of bees visiting 32 fruit trees of various species, in a mixed orchard.

METHODS

The study site

Location: the study was conducted at the Experimental Station of Tropical Fruits (Empresa Baiana de Desenvolvimento Agrícola - EBDA), 159 km northwest from Salvador and 60 km from the Atlantic ocean coast. The Station is located at Conceição do Almeida Province, Bahia State, Northeast of Brazil, 12°45'S; 39°11'W, altitude 190m (Fig 1). The local climate is hot (28°C mean annual temperature) and humid (65 - 90% mean annual relative humidity). At the study site, 60 native tropical and exotic fruit species grow in an area of 82-ha. In addition, this Station was comprised of a small

Atlantic forest fragment (18 ha) subject to intense human activity.

Bee sampling

Sampling of bees visiting the flowers of 20 fruit tree species was carried out systematically, from September 1996 to March 1998. The sampling of pollinators was based on the standardised methods from Sakagami, Laroca and Moure (1967). In addition, 12 fruit species were sporadically observed.

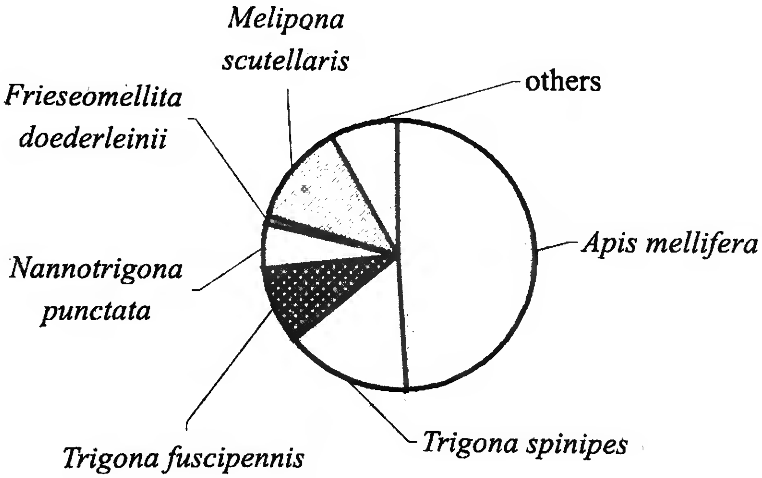
Over 4,809 bees were collected visiting fruit flowers Dr. Jesus de Santiago Moure identified the bees. Voucher specimens of our survey were deposited at the CEM&C (Moure and Costa Entomological Collection) of EBDA.

RESULTS

A total of 95 bee species (Apoidea) were recorded in the mixed orchard containing 32 fruit species. Apidae was the most abundant family, representing about 79.5 % of the observations.

Despite the relatively small number of species (14), highly eusocial bees represented more than 3/4 of all fruit flower-visiting bees. The Africanized honey bee (Apis mellifera scutelatta L.) was the most abundant species, representing 41.1% of all individuals or 51.7% of all highly eusocial bees. Of the stingless bees (fig. 2), 5 species can be considered frequent visitors to the flowers, representing 1% or more of the sample, and 8 species can be considered rare. Anthophoridae family showed higher diversity (38 species).

FIGURE 2 - Abundance of flower visiting highly eusocial bees. Others: *Partamona helleri* (Friese, 1900), *Trigonisca* sp1, *Trigonisca* sp2, *Nannotrigona testaceicornis* (Lepeletier, 1836), *Melipona asilvai* (Moure, 1971), *Melipona subnitida*.(Ducke, 1910).



Fruit trees and their potential pollinators

The bee visitors of the 32 species of fruit tree studied systematically (20) and sporadically (12) are represented in table 1 and fig. 3. The visiting bees of the fruit trees are considered in greater detail as follows:

BARBADOS CHERRY - ACEROLA (*Malpighia punicifolia* L.)

Presently some of the largest plantations of acerola are in Brazil. These small trees with red, pink and white flowers have fruits that are being used more and more as a rich source of vitamin C. Some botanical families, like Malphighiaceae, have oil glands in their flowers which is collected by certain species of the Anthophoridae family, mainly *Centris*. *Centris* is one of the most important groups of pollinators of Tropical America. Several species of *Centris* were observed visiting the "*Malpighia punicifolia* L." flowers: *Centris dirrhoda* (Raw 1979); *Centris fuscata, C. aenea* and *C. sponsa* (Melo *et al.* 1997) and *Centris flavifrons*, (Magalhães and Oliveira 1998). This trend continued at the study site in Bahia where the acerola was mainly visited by species of the genus *Centris* and *Centris aenea* was the most abundant (42.6%) (Castro, 1998). In the caatinga, a semi arid ecosystem, it was found that *Centris* (Hemisiella) *tarsata* (71.4%) was the most important visitor of acerola flowers (observations done in the period of October/1996 to March/1999 in Milagres (12°53′ S and 39°51′ W), Bahia.

AVOCADO - ABACATE (*Persea americana* Mill.)

In many places, the avocado has the honey bee (*Apis mellifera* L.) as its main pollinator (Ish-Am and Eisikowitch, 1993). In Brazil, Silva *et al.* (1998) found a predominance of the Africanized honey bees (89.3%) visiting flowers of avocado, mainly for pollen collection. Other less abundant species found were *Trigona spinipes* (4.7%) and *Tetragonisca angustula* (1%). These results also demonstrated a predominance of the Africanized honey bee visiting avocado flowers (85.8%). Other less abundant species were *Melipona scutellaris* (5.6%), *Frieseomelitta doederleinii* (4.2%) (Castro and Silva, 1998) and the rare ones were Nannotrigona punctata, Partamona helleri, *Trigona spinipes* and Melipona subnitida.

COCONUT - COCO DA BAHIA (*Cocos nucifera* L.)

Coconut is an important palm on the northeast coast of Brazil. It is a known nectar source for the honey bees (Crane *et al.* 1984). In Bahia, in Mata de São João, "Praia do Forte" beach (12° 31′ 47″S, 38°18′ 00″W), the coconut was visited mainly by the Africanised honey bee (76%) and by Auglochlora (Augochlora) sp. n. Moure (about 23%). Other species of Halictidae *Dialictus (Dialictus)* sp. n. Moure, was a rare visitor. Africanised honey bees mainly visited the high palms (more than 10 meters), while *Augochlora (Augochlora)* visited shorter palms(Castro and Viana 1997). In this study, the flowers of the coconut were predominately visited by the stingless bee *Trigona spinipes.*

GUAVA - GOIABA (*Psidium guajava* L.)

Some species of the Myrtaceae family are economically important in Brazil. Species with fruits are known and cultivated in the coastal area: guava; rose apple, malay rose apple, watery rose apple and jambolam (*Eugenia* spp.). Despite of the economic importance of Myrtaceae, very little is known about its pollination and importance to bees. In the mixed orchard, the bee visitors of some cultivars of guava (araçá, thais large guava and rubby supreme) were observed. Apidae was the most abundant family (82.8%). *Apis mellifera* (21.6%), *Nannotrigona punctata* (19.8%), Trigona spinipes (19%) and *Melipona scutellaris* (12.9%) were the predominant species (Castro and Araújo, 1998).

MABOLO - MABOLO (Diospyros blancoi A. DC.) and JAPONESE PERSIMMON - CAQUI (Diospyros kaki.L)

The family Ebenaceae comprises 4 genera distributed in the tropical and subtropical areas. The genus *Diospyros* includes the well-known fruit tree species kaki (*Diospyros kaki* L.) and the less known mabolo (Diospyros blancoi). These fruit trees are being successfully cultivated in the Bahia State. Our sporadic observations on persimmon flowers revealed visitation by the Africanised honey bee (85.7%) and *Centris (Paremisia) fuscata* (14.3%). McGregor (1976) found honey bees collecting nectar and pollen from persimmon flowers and he listed mabolo as dependent on insects for pollination (McGregor, 1975). We found females of *Euglossa securigera* (52.8%) as the most abundant bee visiting male mabolo flowers. Other less abundant visitors were the Africanised honey bee (19.8%) and *Xylocopa (Neoxylocopa) gricescens* (Anthophoridae) (5.7%).

MACADAMIA - MACADAMIA (*Macadamia integrifolia*)

Macadamia nuts are becoming more and more commercially important in the Bahia State. The varieties grown come from Hawaii. It adapts very well to climates with abundant precipitation distributed thoughout the year (1200 to 1600mm). Studies in Queensland, Autralia in the 1980s showed that *Trigona* were more effective pollinators than honey bees (Roubik, 1995). We collected 13 species of Apoidea visiting macadamia flowers, with 90% being Apidae. The most abundant visiting species were *Trigona spinipes* (44.1%), *Apis mellifera scutellata* (28.6%), *Nannotrigona punctata* (9.4%) and *Trigona fuscipennis* (7.7%) (Castro *et al.* 1998).

PHALSA - FALSA (*Grewia asiatica DC*)

A large number of insects visit the yellow flowers of *Grewia asiatica.* In India, Manzoor-ul-haq *et al.* (1979) found 27 species of Hymenoptera, Lepdoptera and Diptera visiting phalsa flowers. *Apis florea* and several species of *Halictus* (Halictidae) and *Andrena* (Andrenidae) were the most common visitors. Parmar (1976), also in India, observed that honey bees were the most abundant visitors, and pollinated the flowers while collecting nectar. In this study, it was found that 30 bee species visited phalsa flowers. The most abundant among them were the Africanized honey bees (32.5%), *Melipona scutellaris* (28.1%), *Exomalopsis (Phanomalopsis)* sp.1 (18.1%) and *Xylocopa (Neoxylocopa) suspecta* (6.6%) and can be considered the potential pollinators of phalsa flowers.

PITOMBA - PITOMBA (*Talisia esculenta Radlk*)

The family Sapindaceae, with 140 genera distributed in the tropical and subtropical areas, includes several species of *Talisia* that are important edible fruits in the Amazon region and northeastern Brazil. We found 11 different bee species visited the "pitomba" flowers. The most abundant were the Africanized honey bee (54.6%), the stingless bee Melipona scutellaris (32.2%) and *Augochloropsis (Augochloropsis) calicroa* (Halictidae) (6.2%).

STARFRUIT - CARAMBOLA (*Averrhoa carambola* L.)

The Asian tropical starfruit is generally dispersed along the Brazilian coast. Their flowers are visited by honey bees (*Apis cerana),* flies and other insects in India (Nand, 1971). Phoon *et al.* (1985) observed *Apis cerana* and *Trigona thoracicia* as the most common bee visitors of starfruit in Malaysia. In this study, it was found that there were 39 bee species visiting the pink flowers of starfruit distributed amoung 5 bee families of which Anthophoridae was the most diverse (17 species). The most abundant bees were the Africanized honey bees (50%), *Exomalopsis* (*Phanomalopsis*) sp1 (11%), *Augochloropsis* (*Augochloropsis) calicroa* (8.1%) and *Exomalopsis (Exomalopsis) auropilosa* (5.5%).

TAMARIND -TAMARINDO (*Tamarindus indica L.*)

Pollination experiments conducted on tamarind trees indicate that cross-pollination is required. The bee *Apis dorsata* is the main bee pollinator of this fruit tree in its native India (Free 1993).. The bee visitors of the tamarind flowers were observed in two areas in Bahia, in a mixed orchard (sub-humid climate) and at caatinga (a semi arid ecosystem), in Milagres. In total, 22 species were found visiting the tamarind flowers in the mixed orchard and 14 species at caatinga. Three species were collected in both areas: *Apis mellifera, Centris (Centris) aenea* and *Centris (Paremisia) fuscata. Apis mellifera* was not important to tamarind flowers in the mixed orchard (1 specimen). At caatinga it was relatively abundant (18.5%). The most abundant bee visitors of the *Tamarindus* flowers in the mixed orchard were *Centris (Heterocentris) analis* (20.8%), *Centris (Centris) aenea* (18.2%), *Xylocopa (Neoxylocopa) suspecta* (14.3%) and *Centris (Paremisia) fuscata* (11.7%). At caatinga the most abundant bee visitors were *Partamona cupira* (34.1%); *Apis mellifera scutelatta* (18.5%); *Trigona spinipes* (13.7%); *Centris (Hemisiella) tarsata* (12.3%) and *Ceratina (Crewella) madeirae* (10.3%). The results above indicate that these species are the possible pollinators of the tamarind (Castro and Oliveira,1998).

WAMPEE- UAMPI (*Clausena lansium Skeels*); SWEET ORANGE - LARANJA (*Citrus sinensis Osbeck*) and WHITE SAPOTE - SAPOTA BRANCA (*Casimiroa edulis Llave & Alex*)

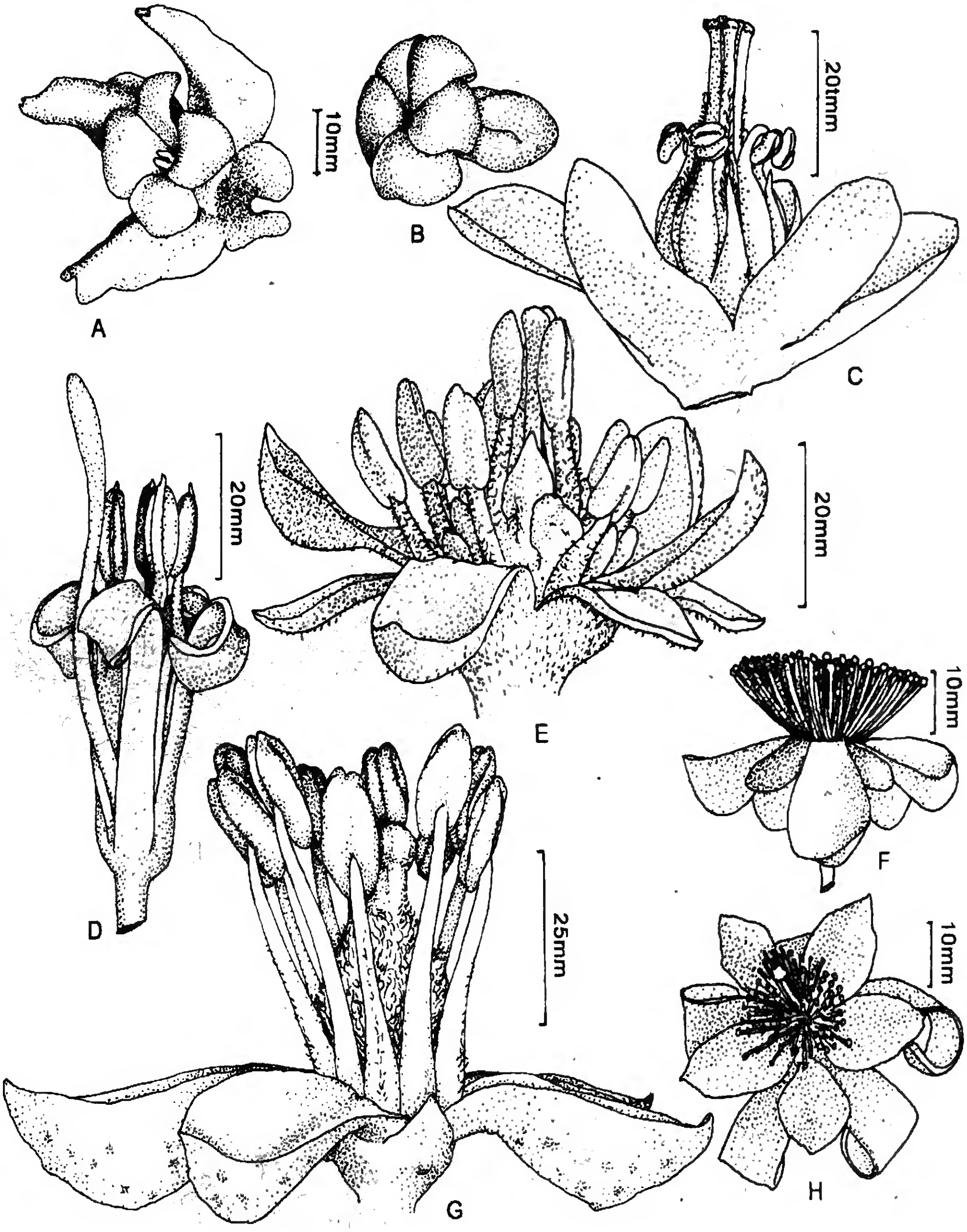
Bees often visit some species of the family Rutaceae . *Citrus* species are well known for its fruits. Other Rutaceae fruit trees are less known but also pollinated by bees. In this study, bees were found visiting *Citrus sinensis, Casimora edulis* and *Clausena lansium* (wampi). Apidae was the most abundant family visiting. Wampiee was mainly visited by the Africanised bee (92%) and white sapote by *Trigona spinipes* (95.7%). Sweet orange was visited by 13 different species of bees but *Trigona spinipes* (60.2%) and *Apis mellifera* (26.7%) were the most abundant in its flowers.

The questions for conservation and sustainable use of pollinators, with emphasis on bees and recommendations.

Efforts to preserve and restore the wild bee populations in urban, natural and agricultural ecosystems have been made through scientific research, and by several governmental and non governmental agencies, but it must be improved. Some questions are relevant: What is the role of natural ecosystem fragments of different sizes in the maintenance of the diversity of tropical crops? Would mixed orchard be one of the solutions to increase the local diversity of bees (alpha diversity)? What is the role of stingless bees in the pollination of tropical and introduced crops? How does the introduced *Apis mellifera* L. affect the native bee populations? What are the consequences to pollination?

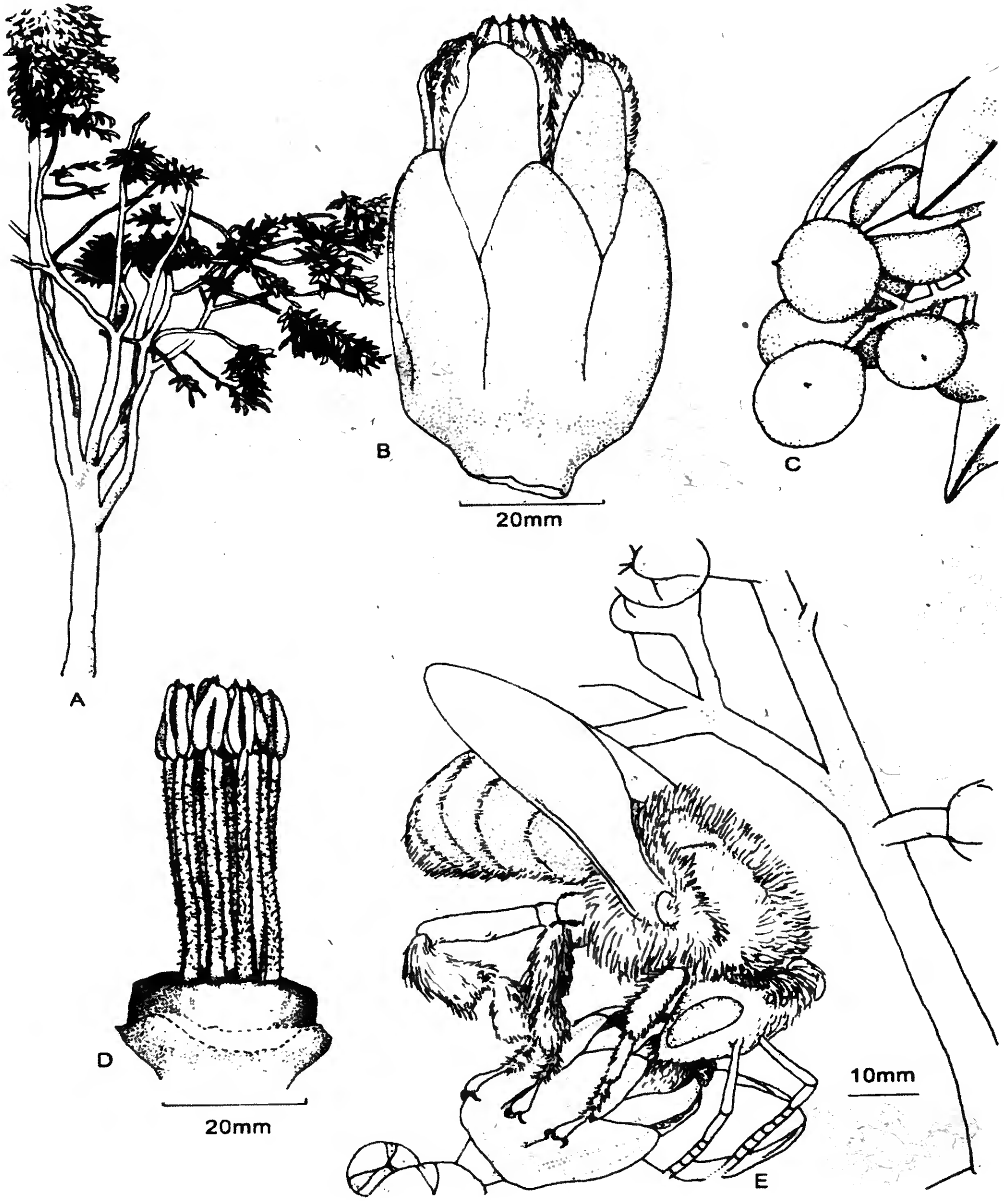
Special programs are needed to improve:
1 - the heterogeneity of agricultural landscape;
2 - the control of pesticides in agricultural areas;
3 - the knowledge on the role of tropical forest fragments to the maintenance of pollinators.

FIGURE 3 - Some studied fruit flowers. (Drawings from Ivan Castro).



A- Diospyrus kaki *B - Diospyrus discolor* *C - Averrhoa carambola* *D - Macadamia integrifolia*
E - Persea americana *F - Psidium guajava* *G Clausema lausiun* *H - Grewia asiatica*

FIGURA 4 – *Talisia esculenta* Radlk. ((Drawings from Ivan Castro).



A - Habit B - Male Flower C - Fruit D - Nectari disc E - Uruçu (*Melipona scutellaris*)

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TABLE 1: List of fruits and their potential pollinators (Bahia, Northeast - Brazil) (12°45' s ; 39°11' w)

FRUIT SPECIES	**FRUIT FAMILY**	**COMMON NAME**	**APOIDEA FAMILY (relative abundance - - diversity)**	**POTENTIAL POLLINATORS (Abundance - > 5%)**
Averrhoa carambola L.	Oxalidaceae	Starfruit (Carambola)	Apidae (56..3% - 8) Anthophoridae (28.6% - 17) Halictidae (11.3% - 9) Megachilidae (3.7% - 4) Andrenidae (0.1% - 1)	*Apis mellifera scutellata (50%)* *Exomalopsis (Phanomalopsis) sp1 (11%)* *Exomalopsis (Exomalopsis) auropilosa (5,5%)* *Augochloropsis (Augochloropsis) calicroa (8.1%)*

FRUIT SPECIES	**FRUIT FAMILY**	**COMMON NAME**	**APOIDEA FAMILY (relative abundance - - diversity)**	**POTENTIAL POLLINATORS (Abundance - > 5%)**
Blighia sapida Koen	Sapindaceae	Akee (Castanheiro da Africa)	Apidae (97.6% - 3) Halictidae (2.4% - 1)	*Trigona fuscipennis (63.4%)* *Apis mellifera scutellata (33.8%)*
Citrus sinensis Osbeck	Rutaceae	Orange (Laranja)	Apidae (90.7% - 4) Anthophoridae (6.8% - 7) Halictidae (2.5% - 2)	*Trigona spinipes (60.2%)* *Apis mellifera scutellata (26.7%)*
Clausena lansium Skeels	Rutaceae	Wampee (Uampi)	Apidae (97.2% - 7) Halictidae (0.4% - 1)	*Apis mellifera scutellata (92%)* *Trigona spinipes (6.4%)*
Cocus nucifera L. (*)	Asteraceae	Coconut (Coco)	Apidae (76.9% - 2) Halictidae (23.1% - 2)	*Apis mellifera scutellata (76%)* *Auglochlora (Augochora) sp. n. Moure (22.8%)*
Diospyros blancloi A.DC	Ebenaceae	Mabolo (Mabolo)	Apidae (82.1% - 4) Anthophoridae (11.3% - 5) Halictidae (5.7% - 3) Colletidae (0.9% - 1)	*Euglossa securigera (52.8%)* *Apis mellifera scutellata (19.8%)* *Xylocopa (Neoxylocopa) gricescens (5.7%)*
Durio zibethinus Mill	Bombacaceae	Durian (Durião)	Apidae (100% - 4)	*Trigona spinipes (61.7%)* *Trigona fuscipennis (28.6%)* *Melipona scutellaris (7.5%)*
Syzygium aqueum Alst.	Myrtaceae	Watery rose apple (Jambo Branco)	Apidae (91.8% - 4) Anthophoridae (8.2% - 2)	*Melipona scutellaris (55.1%)* *Apis mellifera scutellata (24.5%)*
Syzygium cumini Skeels	Myrtaceae	Jambolam plum Java plum (Jambolão)	Apidae (96% - 2) Halictidae (3% - 2) Megachilidae (1% - 1)	*Apis mellifera scutellata (92%)*
Syzygium jambos Alst.	Myrtaceae	Rose apple (jambo rosa)	Apidae (97.2% - 6) Anthophoridae (2.4% - 3) Halictidae (0.4% - 1)	*Trigona fuscipennis (50.5%)* *Apis mellifera scutellata (26.6%)* *Melipona scutellaris (13.1%)* *Trigona spinipes (5.6%)*
Syzygium malaccense Mem.& Peny	Myrtaceae	Malay rose apple (Jambo)	Apidae (100% - 3)	*Apis mellifera scutellata (95.8%)*
Eugenia uniflora L.	Myrtaceae	Brazil cherry (Pitanga)	Apidae (99.4% - 4) Anthophoridae (0.3% - 1) Halictidae (0.3 - 1)	*Melipona scutellaris (40,2%)* *Apis mellifera scutellata (33,6%)* *Trigona spinipes (22.9%)*

FRUIT SPECIES	FRUIT FAMILY	COMMON NAME	APOIDEA FAMILY (relative abundance - - diversity)	POTENTIAL POLLINATORS (Abundance - > 5%)
Grewia asiatica L.	Tiliaceae	Phalsa (Falsa)	Apidae (64.4% - 6) Anthophoridae (31.6% - 14) Halictidae (3.4% - 8) Megachilidae (1% - 1) Andrenidae (1% - 1)	*Apis mellifera scutellata (32.5%)* *Melipona scutellaris (28.1%)* *Exomalopsis (Phanomalopsis) sp1 (18.1%)* *Xylocopa (Neoxylocopa) suspecta (6.6%)*
Litchi chinensis Sonn	Sapindaceae	Lychee (Lichia)	Apidae (88% - 5) Halictidae (12% - 3)	*Apis mellifera scutellata (70%)* *Nannotrigona punctata (10%)* *Dialictus (Chloralictus) opacus (8%)*
Macadamia integrifolia Maiden & Betche	Proteaceae	Macadamia (Macadamia)	Apidae (90.2% - 5) Anthophoridae (4.7% - 2) Halictidae (4.7% - 5) Megachilidae (0.4% - 1)	*Trigona spinipes (44.1%)* *Apis mellifera scutellata (28.6%)* *Nannotrigona punctata (9.4%)* *Trigona fuscipennis (7.7%)*
Malphighia punicifolia L.	Malphighiaceae	Barbados cherry Acerola (cereja das antilhas)	Anthophoridae (90.8% - 17) Apidae (8.9% - 4)	*Centris (Centris) aenea (42.6%)* *Centris (Hemisiella) tarsata (11.6%)* *Trigona spinipes (7.6%)* *Centris (Centris) nitens (6.6%)* *Centris (Centris) cfr. rufiventris (6.6%)* *Epicharis (Epicharis) flava (5.3%)* *Centris (Heterocentris) analis (5%)*
Nephelium lappaceum L.	Sapindaceae	Rambutan (Rambutão)	Apidae (79% - 7) Halictidae (18.9% - 5) Anthophoridae (1.2% - 3) Megachilidae (0.2% - 1) Colletidae (0.2% - 1)	*Nannotrigona punctata (23.9%)* *Trigona spinipes (25.6%)* *Apis mellifera scutellata (23.1%)* *Augochloropsis (Augochloropsis) calicroa (17.2%)*
Persea americana Mill.	Lauraceae	Avocado (Abacate)	Apidae (99.0% 7) Halictidae (1% 2)	*Apis mellifera scutellata (85.8%)* *Melipona scutellaris (5.6%)*
Psidium guajava L	Myrtaceae	Guava (Goiaba)	Apidae (82.8% 11) Anthophoridae (12.9% - 5) Halictidae (3.4% - 1) Colletidae (0.9% -1)	*Apis mellifera scutellata (21.6%)* *Nannotrigona punctata (19.8%)* *Trigona spinipes (19%)* *Melipona scutellaris (12.9%)* *Centris (Centris) aenea (6%)*

FRUIT SPECIES	FRUIT FAMILY	COMMON NAME	APOIDEA FAMILY (relative abundance - - diversity)	POTENTIAL POLLINATORS (Abundance - > 5%)
Talisia esculenta Radlk.	Sapindaceae	Pitomba	Apidae (92.8% 7) Halictidae (6.2% - 2) Anthophoridae (0.4% - 2)	*Apis mellifera scutellata* (54.6%) *Melipona scutellaris* (32.2%) *Augochloropsis (Augochloropsis) calicroa* (6.2%)
Tamarindus indica L.	Fabaceae	Tamarind (Tamarindo)	Anthophoridae (79.2% - 8) Apidae (10.3% - 5) Megachilidae (6.6% - 4) Halictidae (3.9% - 2)	*Centris (Centris) aenea* (18.1%) *Xylocopa (Neoxylocopa) suspecta* (14.3%) *Centris (Paremisia) fuscata* (11.7%) *Centris (Centris) analis* (11.7%) *Trigona spinipes* (7%) *Epicharis (Xanthepicharis) bicolor* (6.5%) *Centris (Centris) spilopoda* (5.2%) *Xylocopa (Neoxylocopa) nigrocincta* (5.2%)

(*) Observations from "Praia do Forte" beach (North of Bahia State) (Castro and Viana, 1997).

Anacardium occidentale L.	Anacardiaceae	Cashew apple (Caju)	Apidae (100% - 1)	*Apis mellifera scutellata* (100%)
Artocarpus integer (Thunb.) Merr.	Moraceae	Champedak (champedaque)	Halictidae (100% - 1)	*Augochoropsis* (*Paraugochloropsis*) sp. n. Moure & Castro (100%)
Carica papaya L.	Caricaceae	Papaya (Mamão)	Apidae (100% - 1)	*Trigona spinipes* (100%)
Casimiroa edulis Llave. & Alex.	Rutaceae	White sapote (sapota branca)	Apidae (95.7% - 1) Colletidae (4.3% - 1)	*Trigona spinipes* (95.7%)
Diospyros kaki L.	Ebenaceae	Kaki, Japonese persimmon (Caqui)	Apidae (85.7% - 1) Anthophoridae (14.3% - 1)	*Apis mellifera scutellata* (100%) *Centris* (*Paremisia) fuscata* (100%)
Eryobotrya japonica (Thumb.) Lindl.	Rosaceae	Loquat (Nespera)	Anthophoridae (66.7% - 2) Apidae (33.3% - 2)	*Xylocopa (Neoxylocopa) suspecta* (55.6%) *Trigona spinipes* (22.2%) *Epicharis* (*Epicharis*) *flava* (11.1%) *Melipona scutellaris* (11.1%)
Flacourtia indica (Burm. F) Merr	Flacourtiaceae	(cereja forasteira)	Apidae (40% - 1) Anthophoridae (13.3% - 2) Halictidae (46.7% - 3)	*Apis mellifera scutellata* (40%) *Dialictus (Chloralictus) sp* (26.7%) *Augochloropsis (A)* prov. *leucotricha* (13.3%)
Mammea americana L.	Clusiaceae	Abricot (Abricó)	Apidae (100% - 1)	*Trigona spinipes* (100%)
Mangifera indica L.	Anacardiaceae	Mango (Manga)	Anthophoridae (100% - 1)	*Exomalopsis* (*Phanomalopsis)* sp (100%)
Passiflora edulis Sims	Passifloraceae	Passionfruit (Maracujá)	Anthophoridae (100% - 1)	*Xylocopa (Neoxylocopa) suspecta* (100%)
Terminalia kaernbachi Wart	Combretaceae	Noz Okari (okari)	Apidae (100% - 1)	*Apis mellifera scutellata* (100%)

Session V

Other Contributions by Abstract

27. Aizen, M. "Habitat fragmentation, pollinator decline, and plant pollination"

28. Ayala, R. "Bee diversity in Mexico"

29. Buchmann, S. "Estimation, conservation and sustainable uses of native bees for pollination of agricultural and wildland plants in the United States, with implications for the tropics"

30. Dafni, A. "Fire, *Bombus terrestris*, invasion and the threat to solitary bee diversity in a Mediterranean ecosystem"

31. Raw, A.; Boaventura, M.C. and Freitas, G.S. "The diversity of a bee fauna: the species of the cerrados of Central Brazil"

HABITAT FRAGMENTATION, POLLINATOR DECLINE, AND PLANT POLLINATION

Marcelo A. Aizen

Many insect pollinators are vagile animals that can fly relatively long distances during single foraging bouts. This trait alone would imply that pollinator faunas as a whole should not be particularly susceptible to habitat fragmentation and other forms of habitat degradation. Evidence from regions as disparate as the Argentine Chaco, Sweden, Florida and Amazon, however, indicates that pollinator faunas are strongly affected by habitat disruption, becoming markedly depaupurate with increasing fragmentation. Pollinator assemblages show great variation at scales of a few meters because of their responsiveness to microscale changes in environmental conditions and to plant-plant differences in availability of nectar or pollen. Presence or absence of pollinator species may also be determined by exploitative competition among "weedy" and "habitat-restricted" flower visitors, and abundance of specific plant resources.

In addition, habitat degradation, which usually accompanies fragmentation, can greatly decrease the availability of nesting sites for ground- and tree-dwelling pollinators. Because all these effects are likely to be most intense near borders of habitat fragments, changes in species diversity and composition with fragmentation might be a classic expression of "edge effects". In the Chaco, for instance, small fragments (~1ha) sustain not only poorer pollinator communities than larger fragments but also faunas that converge on those thriving in the surrounding agricultural matrix. In general, habitat alteration in the Americas favors the invasion of opportunistic flower visitors such as exotic honeybees (*Apis mellifera*). Likewise, in the south Andean temperate forests the only native bumblebee (*Bombus dahlbomii*) appears to be replaced by a recent European immigrant (*Bombus ruderatus*) with increasing habitat disturbance.

Although the actual mechanisms underlying all these patterns are poorly understood, I suggest that, because of pollinators' fine-grained perception of their resource landscape, processes occurring at a local scale are important to understanding large-scale patterns in the diversity and composition of pollinator assemblages. Because of redundancy characterizing plant-pollinator interactions in general, habitat fragmentation does not necessarily lead to the total disruption of this mutualism. Nevertheless, simplification may have subtle but important consequences on the quality of the interaction, hindering the capacity of plants to adapt further to a changing environment.

BEE DIVERSITY IN MEXICO

Ricardo Ayala

The known bee fauna of Mexico is the result of 240 years of taxonomic work during which 95 authors have contributed to the description of species. The known apifauna de Mexico is composed of seven families, 144 genera, and 1,800 species and subspecies. The bee fauna of Mexico appears intermediate between those of the United Stated and Central America. The northern Mexican states with xeric vegetation are the richest in species, specially Chihuahua (396) and Sonora (359). The peninsula of Baja California (states of Baja California and Baja California Sur), with 445 species, is the area of greatest richness. The poorest regions of Mexico are the Yucatan Peninsula and montane regions above 3,000 m.

Other vegetation types have not been analyzed, but it is possible that pines, pine-oak, and tropical evergreen forests have relatively low diversity. In 1985 a group of scientists from Mexico and the U.S. met at the "Estacion de Biologia Chamela", to discuss and organize long-term cooperative studies that they called "Programa Cooperativo sobre la Apifauna Mexicana (PCAM)". The objective o the PCAM is 1) investigation of the taxonomic diversity and distribution of the bees in Mexico, 2) establishment and enhancement of permanent collections of bees in Mexico. The principal accomplishments of this project are 1) a computerized relational database, 2) a collection of approximately 22,500 specimens. The specimens represent 950 species from 120 genera, 169 species not previously recorded from Mexico, and approximately 178 species that are apparently undescribed.

ESTIMATION, CONSERVATION AND SUSTAINABLE USES OF NATIVE BEES FOR POLLINATION OF AGRICULTURAL AND WILDLAND PLANTS IN THE UNITED STATES, WITH IMPLICATIONS FOR THE TROPICS

Stephen Buchmann

Worldwide, taxonomists have described 25,000 species of bees. If they were known completely, it is likely that 35,000 or 40,000 species are actually extant. With a few exceptions (portions of Europe, Mexico and several U.S. sites) we have a poor understanding of our local, regional and national bee faunas. This lacuna is especially troubling as habitat fragmentation, pesticides and competition with honeybees have depressed some local populations and likely caused undocumented extinctions of native bees. Several *Bombus* spp. In Britain are likely already extinct. Sampling bees is not difficult (sweep samples at flowers, trap-nesting for stem-nesters, light traps, Malaise traps, and floral volatiles for euglossine bees). Several new types of bee-sampling techniques (yellow pan traps, PVC pipes, and attractants) are also discussed. Once captured and prepared as museum voucher specimens, however, most ecologists or land managers cannot find the expertise to get authenticated generic and specific level determinations. This will continue to be an ever-worsening problem.

Conservationists, ecologists and land managers charged with the responsibility of protecting biological diversity, including bees, on various lands do not have a coherent set of guidelines for the protection/conservation of existing bee populations, nor specific recommendations for habitat restoration for bees and other pollinators. Often, these can be as simple as allowing dead trees and branches (containing beetle emergence holes) to remain, or the creation of stable banks or attractive bare ground patches where other species may nest. Often, supplemental "drilled boards" may be placed and used to attract and rapidly build up populations of native bees especially in habitat restoration studies, or for pollination of agricultural crops. Land managers are often unaware that prescribed burns to control invasive weedy plants may have profound deleterious effects on native stem and shallow ground-nesting bees. These and other methods are reviewed along with comparison of their utility for temperate and tropical habitats.

FIRE, *BOMBUS TERRESTRIS* INVASION AND THE THREAT TO SOLITARY BEE DIVERSITY IN A MEDITERRANEAN ECOSYSTEM

Amots Dafni

Bombus terrestris, which is native to the northern region of Israel, invaded massively at the last two decades, into natural habitats. It is a an integrated result of intensive gardening, escape from greenhouses and the availability of postfire open habitats. The main points are as follows:

1.Pollen analyses of the *Bombus'* loads indicate that the foraging range of an individual bee may be at least 5km. The nectariferous ornamental plants subsidise the maintenance of the *Bombus'* wild population along the dry season, in which resources are scarce.

2.There is a massive escape of queens from greenhouses (commercial hives were introduced to Israel as late as 1991) and the establishment of feral colonies even in a distance of 30km. from the closest introduction site.

3.Under conditions of limited resources *Bombus* bees exploit almost every available nectar source and are more efficient than solitary as well as hones bees. There are indications that *Bombus* limit the other bees by competitive exclusion.

4. Nine years after the fire (at Mt. Carmel) the solitary bee diversity is very low and 95% of all the bee's visits (on several key plant species) are performed by *Bombus* . In conclusion, the alarming , man made as well as man-promoted , invasion of *B. terrestris* in Israel , combined with high frequency of fires , posed a threat on one of the world richest bee's fauna – the *Mediterranea phrygana.* The Israeli lesson may serve as warning light against any attempt of introduction of *B. terrestris* or commercial pollination in areas in which solitary bees are common e.g. as South Africa -solitary bees are less vulnerable than valuable.

THE DIVERSITY OF A BEE FAUNA: THE SPECIES OF THE CERRADOS OF CENTRAL BRAZIL

Anthony Raw
Marcelino C. Boaventura
Geusa Simone de Freitas

The vegetation of some two million km^2 in central Brazil is Cerrado.This type of savanna ranges from herbaceous to tree savanna with ribbons of evergreen gallery forest lining the courses of rivers and streams. Some areas bear semideciduous forest.The annual rainfall of much of the region is high, though there is a severe winter drought. Cerrados are very rich in species of flowering plants and small animals. For example, in the Federal District of Brasília an area of 5,822 km13,500 species of flowering plants, 8,000 of moths, 1,250 of butterflies and 503 of bees have been recorded. Brasília lies at an altitude of 1,000 m and a latitude of 15oS and its vegetation is solely cerrado.To date, 821 species (121 genera) of bees have been recorded from the Cerrado region. Apparently, 420 species (51 %) are restricted to the region and various of them seem to be endemic to small areas. Species richness is high at a local level, for example, 206 species of bees have been collected in an area of 2km^2 in Brasília. About 60 % of the 821 species are solitary and many of them are ground nesters. Up to 29% are social or semisocial of which 17 % are Halictidae and 7 % are Meliponini. Some 10% (86 species) are predatory species. To date, 18% of the species are apparently confined to open cerrado, 37 % to gallery forest, and 38 % to semideciduous forest.There are two difficulties in assessing the numbers of species of bees in the Cerrado region; surveying and taxonomy.To date, bees have been surveyed in only 6.4 % (60) of the region's 921 municipalities - and only 11 of them at what can be claimed a satisfactory intensity. Species vary considerably from place to place which indicates that additional collecting in different areas will reveal substantial additional numbers.The level of taxonomic knowledge of the region's bees is insufficient. Of the total of 821 species, 58 (7 %) are new to science and 81 (10 %) may be new.

Session VI

INTERNATIONAL POLLINATORS INITIATIVE: THE SAO PAULO DECLARATION (PRINCIPLE RESULTS AND PROPOSALS FOR ACTION)

[excerpts from " Report on the recommendations of the Workshop on the conservation and sustainable use of Pollinators in Agriculture with Emphasis on bees" .Brazilian Ministry of Environment, Brasilia, December 1999.]

INTERNATIONAL POLLINATORS INITIATIVE: THE SÃO PAULO DECLARATION ON POLLINATORS

Excerpts from the **Report on the Recommendations of the Workshop on the Conservation and Sustainable Use of Pollinators in Agriculture with Emphasis on Bees**

Brazilian Ministry of Environment, Brasilia, December 1999

EXECUTIVE SUMMARY

One-third of the world's crops demand pollination to set seeds and fruits and the great majority of them are pollinated by many of the estimated 25,000 species of bees. The annual value of this service in the U.S. is calculated at US $6-8 billion and the estimate worldwide is US $ 65-70 billion. The most widely used species in crop pollination is the honeybee (Apis mellifera). A major problem is emerging for the world's agricultural production reflecting the risk involved in relying on a single pollinator species. Honeybees in many parts of the world have contracted a serious disease and the numbers of honeybee colonies have decreased dramatically. Fruit and vegetable growers in the U.S. and Europe are complaining about poor fruit sets despite good blooming. As the disease has spread throughout most of the world, specialists consider all countries will become seriously affected. Farmers and growers now wish to use native of bees. Many species of native bees are known to be efficient pollinators of crops and a few species have been managed for this purpose. However, the numbers of native bees are dwindling; some species seriously so. Declines in numbers have been reported in North and Central America and Europe. The losses are due mostly to the use of agrochemicals and monocultures, to deforestation, and possibly to the introduction of exotic pollinators.

The emergence of a serious and widespread disease has made it clear that native pollinators need to be protected and sustainably managed for the pollination service they can provide and that agricultural practices be designed to incorporate the protection and sustainable management of bee populations. The pollinator crisis exemplifies the intimate relationship existing between the welfare of natural environments and their biodiversity and the needs of sustainable agriculture.

As a contribution to the development of the CBD work program approved by Decision III/11 on the "Conservation and Sustainable Use of Agricultural Biological Diversity", which identified pollinators as one of the initial priorities, the Brazilian Government held an international workshop of experts to propose a framework for an International Initiative on Pollinators as a key element in this program. The workshop was attended by 61 scientists from 15 countries and four international organisations (CBD Secretariat, FAO, IBRA and ICPBR). Six groups of specialists discussed: 1- Reducing theTaxonomic Impediment on Pollinators, 2- Monitoring the Decline of Pollinators, 3- Identifying the Causes of Pollinator Decline, 4- Quantifying the Economic Value of Pollinators to Agriculture, 5- Conservation of Pollinator Diversity, and 6- Sustainable Use of Pollinators.

The recommendations of the Workshop include a proposal that COP5 formally establish an International Pollinators Initiative based on the framework for action contained in this report and request SBSTTA to co-ordinate, with support from the Executive Secretary, the preparation of a first Global Diversity Outlook Report on Pollinators. The Workshop participants also requested that COP5 call for international co-operation to develop the International Pollinators Initiative and request the financial support of GEF for this initiative and, furthermore, propose the creation of a Pollinators Specialist Group within the Species Survival Commission of the IUCN.

The recommendations produced by this workshop should help foster support from agencies to enhance initiatives on all continents on pollinator conservation and sustainable use. This would help to mainstream the issue of biodiversity in our society and to direct the conservation movements to promote the maintenance of biodiversity as an essential component to ecosystem functioning.

The workshop participants concluded that there is insufficient reliable data on the reported declines in the numbers of pollinators and their effects on agriculture, but that the necessary expertise to collect such data is available. Furthermore, they agreed that such an effort is viable provided the institutional support is available. However, the difficulties in obtaining reliable identification of pollinators (especially of bees), which are vital for the success of both the monitoring programme and pollination research, was also stressed. They also emphasised that the pollination requirements of relatively few crops are known. The experts spoke of the need to produce manuals and catalogues and agreed that the creation of websites with databases of specialists, publications and reports and information on the pollination requirements of crops and on their pollinators is vital and that success of the proposed actions will be greatly enhanced with public awareness of the problem.The spread of successful pollinators for some cultures should be regulated, in order to avoid their introduction in areas outside their natural distribution and avoid competition with local pollinators.

The proposals for action of this Workshop are varied, and many are concerned with the collection of reliable information and its dissemination. The predominance of these two subjects demonstrates the participants' desire to have access to standardised extra data. Some of this information already exists but is not readily available, while much additional data need to be collected. An international training program was suggested, with standardised methodology and well-defined goals in order to create a worldwide network of experts capable to develop appropriate actions for the conservation and sustainable use of local pollinator diversity.

SUMMARY OF MAJOR FINDINGS

1. All the participants remarked that we have insufficient reliable data on the reported declines in the numbers of pollinators and their effects on agriculture worldwide.
2. Some experts have clear evidence demonstrating that numbers have declined, while most stated their data only suggest that pollinators are declining, but all considered the information to indicate emphatically that an impending crisis exists.

3. They stated that reliable methods are available to collect standardised data worldwide, on the status and trends of pollinators, provided that institutional support is given and more experts are trained.
4. All stressed the need to have access to reliable data on the reported declines to:
   a. explain why they are occurring,
   b. make confident evaluations of their expected effects on agricultural production,
   c. select the necessary action to resolve the question.
5. The experts agreed on the difficulties in obtaining reliable identification of pollinators (especially of bees) which are vital for the success of both the monitoring programme and pollination management.
6. They emphasised the need to expand the understanding of pollination requirements of crops worldwide.
7. All recognised the need to produce manuals on methods and catalogues of species of species and interactions.
8. The need for better public awareness of the problem was recognised, as well as the dissemination of best practices on native pollinators conservation and sustainable use.
9. The major tasks are to:
   a. monitor the numbers and diversity of pollinators ot target crop systems and landscapes;
   b. determine the pollination requirements of crops and their effective pollinators
   c. refine the estimates of the economic worth of pollination and the cost of itsdecline;
   d. test and recommend pollinator management and restoration strategies;
   e. appraise methods to increase the sizes of pollinators' populations and diversity, stimulate public awareness of the role of pollinators in their lives.

LIST OF PROPOSALS FOR ACTION

TAXONOMIC IMPEDIMENT:

1. Assess the scale of the Taxonomic Impediment
2. Maintain continuity of existing taxonomic and reference collections of bees
3. Establish Centres of Excellence in Bee Taxonomy
4. Train bee taxonomists
5. Train parataxonomists

6. Repatriate data [Capacity building and benefit sharing]

7. Stimulate taxonomic output
8. Hold a Workshop on motivation and training of parataxonomists
9. Hold a Workshop on automated systems for bee identification

MONITORING THE DECLINE:

1. Establish a committee to co-ordinate a global monitoring plan and network
2. Refine plans and methods for implementation of a global monitoring plan
3. Assess methods, prepare manuals for monitoring pollinators and train participants
4. Implement a pilot global monitoring program in selected areas worldwide
5. Assess the potential impact of exotic pollinators on native pollinators
6. Establish a network of websites with databases for all pollinator monitoring data
7. Prepare a Global Biodiversity Outlook Report on the status and trends of pollinators
8. Promote follow up activities to ensure continuity and improve the proposed program

CAUSES OF DECLINE:

1. Assess pollinator diversity and pollinator efficiency in representative agroecosystems and adjacent natural and seminatural environments
2. [This issue needs further attention, as workgroup report was not submitted]

ECONOMIC IMPORTANCE:

1. Establish a network of experts and a network of databases
2. Determine the pollination requirements of each crop species
3. Determine best pollinators for each crop species
4. Determine impact of pollinator presence/absence on fruit and seed yield
5. Establish pollination models for selected crops
6. Develop a generalised economic method for evaluation of crop-pollinator-pollination systems
7. Conduct cost/benefit analyses for different crop and pollination systems, at the farm level
8. Conduct total crop production cost analyses for different crop-pollinator-pollination systems, at the national level, including externalities
9. Conduct cost analyses for changes from one crop-pollination system to another, at the international level, including infrastructure maintenance
10. Disseminate information generated by various means

CONSERVATION AND RESTORATION:

1. Establish an international advisory group on pollinator conservation
2. Establish an international information network on pollinator conservation and a global directory of pollinator experts
3. Assess the state of scientific and indigenous knowledge on pollinator conservation
4. Develop and update global and national lists of threatened pollinator species
5. Develop model-testing protocols for the introduction of non-native pollinators and to assess impacts of agrochemicals on pollinators
6. Develop an international communication outreach capacity
7. Produce multilingual manuals on pollinator conservation and restoration for farmers
8. Create "bee smart" certification labels for "pollination friendly" products

SUSTAINABLE USE:

1. Disseminate information on pollination in agricultural environments through data bases, websites, and networks
2. Establish a roster of existing pollination and pollinators experts to serve as a pool for consultations in technology transfer
3. Promote applied research on pollination in agricultural ecosystems through training of post-graduates to work on gap issues
4. Protect natural habitats, within agricultural landscapes, as sources of wild pollinators for crop improvement
5. Evaluate positive and negative effects of alternative practices and technologies in agricultural production on pollinator conservation and effectiveness
6. Evaluate impacts on pollination of practices and technologies used in agricultural production
7. Improve the knowledge on the real needs of pollination of tropical crops and forest trees
8. Gather and disseminate/exchange information of best practices
9. Conduct risk/impact assessments of main causes of pollination decline
10. Develop guidelines for policy makers and for farmers

FOLLOW-UP RECOMMENDATIONS

The participants of the workshop proposed follow up activities to promote the initiative which needs to be developed:

1. Propose that COP5 formally establish an International Pollinators Initiative based on the framework for action contained in this report.
2. Request that COP5 call for international Co-operation to develop the International Pollinators Initiative. It is suggested that this initiative be supported by existing organisations, particularly the relevant organs of FAO, and IUCN, IBRA, ICPBR and Apimondia.
3. Recommend that COP 5 request the financial support of the Global Environment Facili-

ty - GEF for this initiative.

4. Recommend that COP 5 request SBSTTA to co-ordinate, with support from the Executive Secretary, the preparation of a first Global Biodiversity Outlook Report on Pollinators – GBO-P.
   a) It is suggested that a first GBO-P be prepared for 2002 based on published and other existing data.
   b) A second GBO-P could be prepared for 2005 based on standardised monitoring of pollinators and pollination worldwide. This will depend on establishing the monitoring programme with a functioning network of agreed selected sites and proven methods.
5. Propose the creation of a Pollinators Specialist Group within the Species Survival Commission of the IUCN.

CONVERGENCE OF PROPOSALS

The proposals for action of this Workshop are varied, but many are concerned with the collection of reliable information and its dissemination. The predominance of these two subjects demonstrates the participants' desire to have access to better data. Some of this information already exists but is not readily available, while much additional data need to be collected.

Need to collect reliable data:

1. Standardised monitoring of the numbers of pollinators (particularly bees) over a worldwide network of selected sites is essential for identifying patterns of change in their numbers.
2. The monitoring programme would entail substantial improvements in the services of the identification of pollinators and there is a serious limiting taxonomic deficit in this respect.
3. Assessment of the pollination requirements of agricultural crops and of the roles of pollinators will permit improvements in pollination and thus of crop production.
4. Assessment of the economic worth of crop pollinators should be feasible once the data from # 3 are available.
5. Identification of the means of conserving and increasing the numbers of pollinators is a subject for multidisciplinary approach.

Communication:

Suggested publications:

Manuals on monitoring techniques

Manuals for measuring pollinator decline

Manuals for promoting pollinator recovery

Web site:

A co-ordinated network of web site is required with lists of researchers, crops, pollinators, pollination, publications, crop losses and all the data from the monitoring programme. It should be organised at local and global levels and with Internet access. This might be organised and run by FAO and IBRA.

Education:

Educational programmes for the public, for schools and for post-graduate courses.

Training programmes for entomologists and parataxonomists.

Use of post-docs in long-term studies, to disseminate knowledge and in regional training programs, with the standardised methodologies established in this programme, emphasising regionally important pollinators.

Further specialist meetings:

Another international planning workshop like the São Paulo workshop should be organised and aimed at specialists from Asia, Australasia, Eastern Europe and Africa (regions under-represented at the São Paulo workshop) to complement the recommendations of the São Paulo workshop, from the perspectives of these regions. This event could provide an opportunity to further detail the proposals for actions recommended in São Paulo, as well as consolidate the support of international and national agencies to the proposed International Initiative on the Conservation and Sustainable Use of Pollinators.

Regional meetings should be organised in each continent, similar to the one that discussed the European perspectives held at the Linnean Society, London, 8 April 1995. Nevertheless, international participation and guidelines are important for helping in the establishment of new and stronger joint projects, emphasising a general improvement of the pollinators' use on a global scale.

(The full text of São Paulo Declaration on Pollinations is available in the internet at http:/ www.mma.gov.br/biodiversidade/doc/pollinas.pdf);

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