Causes and effects of the worldwide decline in pollinators and corrective measures

by

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1. Pollination

1.1 Flowers and Their Pollinators

Pollination is the transfer of pollen from the stamen, or the male component of a flower, to the pistil, or the female part. The pollen grain reaches the ovary via the stigma to fertilize the ovules which produce the seeds and fruit. In higher plants, or spermatophytes, the reproductive system is external and visible. Several types of vectors may ensure fertilization of a flower: wind, water, and animals, especially insects.

In wind-pollinated plants, referred to as anemogamous plants, the stamens and pistils are often elongated in shape. Air movement picks up the pollen from these plants and carries it to other plants. Since pollinators are not required in this instance, the petals of these plants are often dull-coloured, small in size and even absent. In the case of certain aquatic, hydrogamous plants, pollen is transported primarily by water. This type of pollen is very elongated in shape and readily carried by the current from one plant to another.

Many flowers are zoogamous, that is to say, pollinated by animals. Over 1,000 vertebrate species are thought to be capable of performing this task. The major ones are mammals, especially bats, reptiles and hummingbirds, in the case of birds. Over tens of millions of years, plants and their pollinators have developed an evolving relationship enabling both parties to adapt to each other to ensure a service of mutual benefit.

Nectar-feeding bats are significant pollinators in tropical rain forests. They are also the main pollinators in the forests found in the isolated islands of the Pacific Ocean. With their long, narrow tongues, bats can reach the nectar deep within the flowers. In such locations, many flowers blossom at night and are equipped with large white petals that can readily be seen in relative darkness. Hummingbird-pollinated plants, on the other hand, are red, a colour that is easily perceived by these birds but not particularly visible to insects. Even when foraging on the wing, a hummingbird can reach the bottom of the corolla of a deep flower to obtain its reward in nectar. Since most hummingbirds lack a developed sense of smell, these flowers by and large are not strongly scented. There are five hummingbird species in Canada, only one of which, the ruby-throated hummingbird (*Archilochus colubris*), exists in Quebec. It is also the most common of all the hummingbird species occurring in Canada.

Entomogamous plants are those pollinated by insects which constitute the largest and most diversified group of all pollinators. As with mammals and birds, the mutualistic relationships between this category of pollinators and the flowers they visit are extremely varied and refined. Honey bees, bumble bees, butterflies, syrphid flies, and coleoptera are the most common of the insect pollinators. Insects forage in flowers in search of food and, in some cases, of partners, shelter or construction materials for their nests.

As may be seen, a wide range of animals seek out plants that reproduce sexually. Regardless of whether they gather pollen intentionally or accidentally when visiting flowers, if they transfer pollen as they go from one inflorescence to another, they are considered pollinators.

1.2 Wild, Native, Exotic or Introduced Pollinators

1.2.1 Wild Pollinators and Native Pollinators

It is important to make a distinction between “wild pollinators” and “native pollinators”. A pollinating species is termed “wild” when its habitat is located in a natural environment or an environment with no human interference. Wild pollinators include both native and exotic pollinators. A “native pollinator” refers to a species originating in, associated with, and established in a given habitat over a very long period or time. “Exotic pollinators” are those which were voluntarily or involuntarily introduced into an environment that was not originally theirs. A pollinator may be considered wild without necessarily being native. Introduced (managed) pollinators refer to species in which reproduction and survival are controlled by man.
1.2.2 Introduced Pollinators

Introduced pollinators designate species that have been raised by man to increase the commercial value of crops and, in the case of the honey bee, to produce honey. They share a basic characteristic in that they can be kept, raised and reproduced in large numbers.

Amongst the introduced species, the honeybee is the most commonly used worldwide for the pollination of various crops. Most honey bees nest in hives and the colony comprises four castes: a queen, inside worker bees, field bees, and drones. The second most commonly used pollinator is undoubtedly the bumble bee, *Bombus terrestris*, which is currently being raised on an industrial scale and gaining in popularity. A very small number of solitary bee species are increasingly being raised commercially for purposes of pollination. The most commonly known are the carpenter bee (*Xylocopa virginica*), the orchard mason bee (*Osmia lignaria*) and the hornfaced bee (*Osmia cornifrons*) and finally, the alfalfa leafcutting bee (*Megachile rotundata*), an easily managed species that can be raised year after year.

When pollinators are introduced in a crop, a distinction must be made between free pollination performed by wild pollinators already present in the environment and directed pollination performed by introduced pollinators.

1.3 Bees

Most entomophilous plants are pollinated by Hymenoptera belonging to the superfamily Apoidea. Six of the seven recognized bee families (Colletidae, Andrenidae, Halictidae, Melittidae, Megachilidae and Apidae) occur in Canada, and are primarily represented by the genera *Andrena*, *Perdita*, *Nomada*, *Dialictus*, *Halictus*, *Osmia*, *Megachile*, *Melissodes*, *Bombus* and *Colletes* (Krombein et al., 1979). The seventh family, the Stenotritidae, constitutes the smallest of the recognized families.

All bees feed on, collect and store pollen and nectar to nourish their brood. Some bee species favour a solitary lifestyle whereas others live socially.

1.3.1 Solitary Bees

Solitary bees are represented by females, all of which are fertile and generally live in a nest that they have built themselves. In these species, there is no worker bee caste. Most solitary bees dig a nest in an underground gallery while others use hollow reeds or twigs or even holes in dead wood. Some of these bees make their nests out of resin or mud mixed with gravel. Inside the nest, cell walls are made from wax secretions or else built with bits of leaves, petals or resin. The female creates a compartment or “cell” which is sealed once she has deposited an egg with pollen reserves to be used by the larva when it emerges. A nest may contain a number of cells. Nesting may be approached in a variety of ways, even within the same family. In general, solitary bees do not produce honey or beeswax. They do not suffer from acariasis and are not attacked by mites of the genus *Varroa* but they have their own parasites, diseases and pests.

1.3.2 Social and/or Gregarious Bees

In some bee species, several females live within the same nest, making and supplying their own cells in which they deposit their eggs. These bees are referred to as social bees. Some members of the Halictidae and Anthophoridae and many members of the Apidae live gregariously. For species that have adopted this type of social structure, the colony is divided into castes of fertile individuals responsible for reproduction and infertile individuals in charge of providing supplies and protection. Bumble bee (*Bombus* spp.) colonies, for instance, have three castes: queens, males and worker bees.
1.4 Food Preferences

1.4.1 Pollinator Efficiency: Pollen or Nectar?

Some insects collect only nectar from the flower’s nectar-producing glands. Others collect only the pollen from the stamens, while still others collect both pollen and nectar. Pollen is rich in proteins whereas nectar is rich in carbohydrates. These foodstuffs can be used for several purposes: consumption by the bees, building of the nest, preparation of food for the offspring and/or the production of honey and wax. Pollen is not harvested at random. Pollinating insects make a selection within the available local flora. The pollen is attractive because of its odour, and the presence of proline, an amino acid found in high concentrations in most pollen, is thought to influence their choice.

Nectar foragers include the honey bee as well as the male and female alfalfa leafcutting bee (Megachile rotundata) that have just emerged from their cocoons. Megachile rotundata bees collect only nectar in the first three days of life in order to gain strength prior to mating. Thereafter, they build their nests for their offspring in which they store a food supply consisting of 64% nectar and 36% pollen (Delaplane and Mayer, 2000). Within the group of pollen foragers, we find the female leafcutting bee at the nest-building stage, febrile queen and worker bumble bees (Bombus impatiens), and the queens of native species belonging to the genera Andrena, Halictus and Bombus.

1.4.2 Foraging Types

Every insect is often specialized to collect pollen from one or a few plant species in particular. The pollen thereby often benefits by being transported to another flower belonging to the same species. There may therefore be a hierarchy in the stimuli directing the choice of plants and even at times selective requirements on the part of some pollinators with respect to the host plant. In terms of these behavioural patterns, pollinators have been labelled monolectic, oligolectic or polylectic (Pekkarinen, 1998).

A polylectic pollinator may be considered a generalist since it forages in a wide variety of flower species. Most pollinator species, including the honey bee (Apis mellifera), bumble bee species (e.g., Bombus terrestris (L.), Bombus pascuorum (Scopoli) and Bombus lapidarius (L.), a few solitary bees and several butterfly species, fall into this category.

A pollinator that visits a very limited number of flower plants within the same family is considered oligolectic (Eickwort and Ginsberg, 1980). Very few species fall into this category although many solitary bees are oligolectic; namely, Bombus gerstaeckeri (Morawitz), which forages exclusively in species belonging to the genus Aconitum (Ponchau et al., 2002). An oligolectic pollinator will continue to forage in a single plant species even though other pollen resources may be available (Waser, 1985).

Lastly we have monolectic pollinators which forage only in a single plant species or in a few closely related species. Monolecticism is even rarer by far than oligolecticism. It may be observed in orchid-pollinating Hymenoptera, in the yucca-pollinating butterfly and in small figtree-pollinating wasps. The leafcutting bee Hoplitis adunca forages only in flowers of the common viper’s bugloss, the melittid bee Macropis fulvipes selects exclusively garden loosestrife flowers and Micropteryx calthella, a small nocturnal butterfly, forages only in buttercup flowers. It should be pointed out that a species may be oligolectic in its search for pollen but polylectic when looking for nectar. A flower is considered oligophilic, polyphilic or monophilic on the basis of its pollination by an oligolectic, polylectic or monolectic species.

Constancy and fidelity are two other concepts used to characterize the relationship between a pollinator and a floral species. Constancy is a behavioural characteristic linking a pollinator to the flower of a plant species, whereas fidelity designates temporal behaviour limiting the time a pollinator remains with a floral species before turning to other species (Wells and Wells, 1983).
1.4.3 Foraging Behaviour

Temperature, humidity levels and sunshine may all affect the time of day when pollen is available. Bees therefore collect pollen from different plants at different moments of the day. Pollen becomes available from the early morning hours to the end of the afternoon. In some plant species, pollen is available for the greater part of the day, whereas in other species, pollen can be harvested mainly at certain hours of the day. This may vary and tends to be characteristic of a given species.

1.5 Pollination of Plants

The different reproductive processes that occur in plants must be understood in order to grasp the importance of pollinators in angiosperm reproduction.

1.5.1 Types of Pollination of Flowering Plants

Two types of pollination are observed in plants that reproduce sexually: self-pollination and cross-pollination. Self-pollination occurs when the ovule of a flower is fertilized with pollen from the same flower on the same plant. Cross-pollination is more common and occurs with pollen from another flower on the same plant or from a different plant but belonging to the same species.

1.5.2 Types of Sexual Reproduction in Flowering Plants

So-called hermaphroditic plants have both male parts (stamens) and female parts (pistil). Roughly 70% of flowering plants are hermaphroditic. Single-sex flowers possess only stamens (male flowers) or a pistil (female flowers).

In the case of monoecious species, each plant has flowers that are exclusively male and others that are exclusively female. Pollination, and necessarily cross-pollination, may occur between two flowers on the same plant or else from two different plants. In the case of dioecious plants, a single plant has only male or else female flowers. Here again, cross-pollination is required.

Single-sex flowers can be produced by monoecious plants and even plants with hermaphroditic flowers. For instance, the flower may not open up at the same time as the anthers releasing the pollen. This staggered hermaphroditism, referred to as dichogamy, is a strategic evolutionary process in the reproduction of flowering plants aimed at preventing self-fertilization from occurring. In a fairly large number of species belonging to a wide range of families, the flowers are sterile unless pollinated with the pollen from another individual from the same species. This mechanism can be of great genetic significance. When fertilization occurs within the same flower or between two flowers on the same plant, the genetic make-up is very similar, if not identical. Cross-pollination promotes a mix of hereditary traits and adaptation of the species, in other words, natural selection. A genetic mix is extremely favourable in diversifying organisms and creating new lines. Cross-pollination of cultivated plants enhances the commercial value of agricultural production by improving the quality and quantity of fruit yields. Furthermore, the fruit is bigger and keeps longer, there is less misshapen fruit making marketing problematic, and the sugar and acid content of the fruit is greater than that found in poorly pollinated fruit.

Some insect-pollinated crops do not increase their yields or improve them only slightly. Other crops, on the other hand, show a considerable increase, and still others produce little or no fruits and seeds unless they are pollinated by insects. Thus, the value of pollination varies with the crop.

2. The Worldwide Decline of Pollinators

Over the past two decades, there has been much concern throughout the world over the apparent reduction in populations of pollinators of all kinds. Declines have been reported in no fewer than four continents. According to a committee of experts mandated to estimate the drop in numbers, the situation varies from one taxon to the next. Follow-up and conservation programmes have reported a drop in the numbers of several pollinating vertebrate
species, especially amongst bats, in at least part of their known range. According to John Karges, a biologist with Nature Conservancy, the population of the Mexican long-nosed bat (*Leptonycteris nivalis*) in the United States decreased from 10,000 individuals in 1967 to 1,000 in 1983. The species feeds on nectar from the agave plant which is used in the production of a sweetening agent and tequila.

Long-term studies carried out by researchers, individual investigators and regional Heritage Programs have also provided evidence of a decline and in some instances of the possible extinction of some populations of bumble bees, bees and butterflies. In addition, all throughout the planet, there has been a dramatic reduction in honey bee (*Apis mellifera*) populations.

### 2.1 The Loss of Honey Bee Colonies

At the end of the 1990s, the *Varroa* mite, a parasite found in honey bee broods in the United States and Canada and elsewhere in the world, was pinpointed as the major cause of bee colony losses. Various viral or microbial diseases with or without any link to the *Varroa* mite further aggravated the situation. There have been further problems, such as the presence of a single-cell fungus, *Nosema Cerema*, the improper use of pesticides which have proved toxic to foraging insects exposed to the chemicals and in the United States competition with Africanized honey bees. The beekeeping industry has been suddenly struck with the problem of major losses in the number of viable hives and honey production.

Scientific research and the pesticide industry quickly looked for solutions to destroy the *Varroa* mite in bee colonies. It was believed that the proper management of hives based on control of the parasite by means of planned applications of a represser would allow beekeepers to overcome the problem. It soon became clear, however, that the mites were developing resistance to the licensed products. Results were therefore mixed and the incidence of pathogens linked to the mites continued to rise.

At this time, another brood parasite, a coleopteran, *Athenia tumida*, appeared on the scene. Also known by the name of small hive beetle, it quickly became a new factor in losses in honey bee colonies in the United States. The parasite unfortunately made its way to Quebec in 2008 and its presence has been recorded, notably in the Montérégie region.

At the same time, another more serious problem was beginning to be observed in Europe and the United States: CCD or colony collapse disorder. The alert was given as early as 2000 in Europe and around 2006 in the United States. The distinguishing feature of this disorder is the disappearance of bees from their colonies. On opening a hive, the beekeeper finds only the queen, the brood and a few isolated bees. The others have simply disappeared. The phenomenon has quickly reached epidemic proportions and remains unexplained. Current studies suggest at present that several causes are at work together. In 2006, American beekeepers lost between 30% and 40% of their stock. Roughly two million hives are thought to have been lost and 27 states have been affected. The situation deteriorated further in 2007 and is thought to have resulted in up to a 70% loss of bees in the United States. In Canada, hive loss has been estimated at 40%, but according to the Canadian Honey Council (CHC), colony collapse as described for other countries has not yet reached our borders. In Quebec, colony loss for 2007 was estimated at 40%, whereas in Ontario losses of up to 70% have been reported.

All these devastating problems currently result in enormous losses for the beekeeping industry. Of greater concern, however, is the extent of the loss of honey bees in their capacity as pollinators in the environment. As a result of domestication of *Apis mellifera*, it is possible to calculate losses associated with that species. But what about the situation of wild bees?
2.2 The Decline of Wild Pollinators

Much less is known about the situation of wild insect pollinators with respect to conservation. This has been of concern to a number of scientists since insects are by far the largest of the many pollinating groups. Insect pollinator populations are often small and can quietly dwindle to the point of local extinction.

In the 1990s some scientists hypothesized that there was a generalized decline in the abundance of insect pollinators in North America. Other scientists (Buchmann and Nabhan 1996, Allen-Wardell et al., 1998) suggested a loss of diversity among species found in pollinating communities. Studies by Banazak (1995) and European researchers (Matheson et al., 1996) examined wild bee counts, notably in transects within agroecosystems.

European scientists reported serious loss of diversity among bee species, i.e., an estimated loss of 40% in Great Britain and 60% in Holland since 1980. According to Stephen Buchmann, Europeans have more detailed records of pollinating populations than the Americans, partly because they have more amateur taxonomists, who as a result of their contributions make it possible to ensure a good monitoring system.

2.2.1 Estimation of the Severity of the Decline

Experts in pollination ecology seem to confirm that the problems of honey bee colony losses in North America have resulted in a sharp decline in pollinator numbers below levels observed over the past 50 years. The management and protection of wild pollinators are therefore of vital importance for our food supply system. Certain data suggest that 1200 wild vertebrate pollinators could be at risk. The situation with respect to most invertebrate pollinators is unclear due to the lack of studies with pertinent data (Allen-Wardell et al. 1998).

In 1999, scientists from the United States and Canada met for a workshop at the National Center for Ecological Analysis and Synthesis (NCEAS), in Santa Barbara, California, to assess the possibility of a generalized drop in invertebrate pollinator numbers and a loss of diversity among species making up the pollinating community in North America, as reported by Buchmann and Nabhan in 1996 as well as Allen-Wardell and 17 of his co-workers in 1998.

The specialists at these workshops were of the opinion that not enough data were available to predict the extent of a possible disruption of pollinator activity. That said, the possibility of a significant progression in irreparable losses of biodiversity is real as a result of cascading extinctions. Furthermore, even though empirical evidence is not available at present to support the notion that pollination systems worldwide are being disrupted, well-documented observations of dwindling local populations may well be symptomatic of loss of biodiversity on a much larger scale.

Different surveying techniques have shown considerable year-to-year changes in population sizes as well as in community composition. On the whole, the conclusions of these studies were considered reliable despite the range of techniques employed. The fact that they all attempted, as effectively as possible, to take into account time/space variations in the populations, at least at a local level, lends a degree of validity to these studies (Roubik, 1996, Roubik, 1996 b).

Comparable changes were found in the size of three bee populations in a tropical setting and five populations located in a temperate zone. Short-term studies (carried out over 2 to 4 years) and longer-term studies (carried out over 17 to 21 years) showed that among 59 pollinating species including solitary, social and highly social bees there existed a variation in numbers in the order of 2.06 in the case of temperate-zone bees and 2.16 in the case of bees inhabiting tropical areas. The “usual” number of bees in a population could decrease or double in a year. Longer-term data are available for tropical regions only. Stochastic variations and the limitations of surveying methods indicate that monitoring should extend over at least four years to be considered valid. Longer-term studies are therefore required to provide a significant overview of natural changes within pollinator populations.
Researchers have pointed to a significant gap in follow-up data on wild bee populations. There is a lack of basic information on time/space and seasonal variations for several species in their natural habitat.

### 2.2.2 Examples of Local Studies: Contradictory Conclusions

Some studies have shown a drop in the populations of the species studied, whereas this problem has not been observed in other studies. By way of illustration, the study by Roubik (1996), conducted in the Parque Soberania, in Panama, clearly demonstrated that euglossine bee populations have not dwindled in over 20 years and that, on the contrary, their numbers seem to have increased. Four euglossine bee species suffered a statistically significant drop, whereas in 32 other species, numbers remained stable or else increased. In general, the euglossine bee population in Parque Soberania may be on the rise. Marlin and Laberge (2001) reported remarkable stability in bee population diversity in Carlinville, Illinois (U.S.A.) based on a survey conducted close to a century after the exhaustive inventory by Charles Robertson at the end of the 19th century.

In contrast, dwindling bumble bee (Bombus spp.) populations have been recorded in a number of Old World temperate zones. Despite their ecological significance, North American bumble bees have not been extensively studied and their situation with regard to conservation is largely unknown. Surveys conducted from 2004 to 2006 by Colla and Packer (2008) in southern Ontario were compared with earlier studies carried out from 1971 to 1973 at the same sites. Changes in the make-up of the community were examined. The extent of the decline of *Bombus affinis* was estimated by surveying 43 sites throughout the bee’s total known range in eastern Canada and the United States. The studies showed that bumble bee populations in southern Ontario had dwindled over the last 35 years. *Bombus affinis*, in particular, seems to have declined not only in southern Ontario but also throughout its range. These are troubling findings since the loss of even a single bumble bee species can have a ripple effect on fauna and flora and reduce agricultural production.

### 2.3 Repercussions on Plant-Pollinator Interactions

One of the concerns related to the decline of pollinator populations in a given environment is its potential impact on the plants that depend on them. The International Union for the Conservation of Nature (IUCN) predicts that 20,000 flowering plant species will have disappeared within decades. The drop in pollinator numbers is not exclusively responsible for extinction of these plants, but it is generally acknowledged that some plant-pollinator associations are in real trouble. The loss of flowering plants as well as the loss of pollinators may have a ripple effect damaging to both groups.

Bees are not the only pollinating invertebrates in decline about which little is known regarding their pollinating potential. According to Kearns (2001), dipterans (flies) of the family Syrphidae are pollinators that are not sufficiently valued for their ecological role in a particular environment. They forage relentlessly especially in flowers they can easily use and manipulate. Although they have relatively little hair, they can be significant pollinators of certain floral species in certain ecosystems. The relationship between syrphid dipterans and their host plants was examined in Great Britain and Holland at various sites according to different assemblages. It was found that pollinator decline occurred more frequently in a habitat with univoltine floral species and/or in the path of migratory species. Further, it was noted that plant species that depended on pollinators in decline were themselves in decline compared to other plant species. All of these findings strongly suggest a causal link between the extinction of some plants and the decline of species that pollinate them (Biesmeijer *et al.*, 2006).

### 2.4 Genetic Variation

A drop in the population of a pollinator species may accelerate its decline and even result in its disappearance. A decrease in abundance is often attended by loss of genetic variability due to genetic drift. This increases the probability that populations and even species will disappear. (Barrett and Kohn, 1991).
Packer and Owen (2001) compared genetic variations among the species of two higher pollinator invertebrate taxons: bees and lepidopterans. Bees are known for their limited natural genetic variability due, amongst other things, to their haplodiploid genetic system, grouping of their nesting sites, centralized feeding habits, the structure of their populations and perhaps too their social way of life. Packer and Owen have suggested that bee populations may be more genetically resistant to dwindling populations than diurnal and nocturnal lepidopterans.

2.5 Estimation of Decline by Means of Pollination Deficit

It is important to make a distinction between a lack of pollinators in a particular area and their decline. These are two distinct and not necessarily related phenomena. A lack means that there are not enough individuals to meet pollination needs, according to recognized norms. Decline refers to a tendency for a population or the diversity of the community to dwindle over time.

Examination of pollination deficits has been suggested as a new and less direct means of finding evidence of pollinator decline in an area.

This method relies on the following premises: research suggests that natural intact systems should reach an equilibrium with respect to the reproductive evolution of the plants. This balance would be determined equally by pollination and available resources in a site. In other words, plants should have evolved so that they can reach their potential pollination threshold. Serious pollination deficits could therefore indicate that the pollination service for a flowering plant population has deteriorated compared to a higher level available in the past. If pollinators are in decline, it should be possible to measure the effect of their absence, e.g., the production of fewer fruit or seeds in both natural ecosystems and agricultural areas.

Thompson (2001) is critical of this approach and of some of the studies used to support it. It was found, for instance, that in 62% of the cases studied, the natural production of fruit or seeds was at least occasionally limited by the absence of pollen. Because of random factors in the environment, allowance must be made for occasional inadequate pollination even when a balance has been achieved. Thompson concludes that optimal pollination is a more complex issue than one might think and that even though studies using pollination deficits to argue the case for pollinator decline may be informative if correctly conducted, they should nonetheless be interpreted with caution.

3. Pollinator Value and Services

3.1 Monetary Value of Crop Pollination

For several years, attempts have been made to calculate the shortfall resulting from a pollination deficit. (Robinson et al., 1989; Morse and Caldrone, 2000; Losey and Vaughan, 2006).

It has been estimated that 87 of the 123 main species grown for human consumption in 200 countries around the world rely to some extent on insect pollination (Klein et al. 2007). Pollinators are essential to 13 of these crops, 30 others rely heavily on them, whereas another 27 are only moderately dependent on insect pollination. In terms of production volume, however, only 35% (23 X 10^6 MT) of the food produced worldwide requires cross-pollination by insects since some important crops such as rice, corn and wheat are pollinated by the wind. An advantage of pollination services provided by introduced or wild pollinators is that it ensures optimal yields of crops that introduce variety to the human diet while adding a good supply of nutrients.

Insect pollination also ensures the production of seeds for fodder plants and large-scale crops such as hay, alfalfa and clover used to feed animals which in turn provide meat and milk products. Pollinators also play a significant role in the production of cotton, an essential component of the textile industry. Even self-fertilizing crops, such as canola, flax, beans, peas, soybeans, and peanuts, may well derive some benefit from pollination by insects.
A number of plants that depend on or benefit from insect pollination including several types of oilseed plants are likely to be of considerable economic value. By way of illustration, over half of vegetable fats and oils are derived from canola, sunflower seeds, peanuts and coconuts.

That said, the worldwide economic impact of potential losses due to inadequate pollination has not been clearly defined. Kevan and Philips (2001) concluded from a model they constructed that there was ample information available suggesting a decline in the number of pollinators affecting agricultural productivity. They also showed that when commercial ties existed among various countries, these declines economically impacted the producers and consumers of importing and exporting countries. In 2008, researchers set out to quantify the monetary value of insect pollination in one hundred plants used in the world for human consumption (Gallai et al., 2008). Their findings, involving essentially honey bees, revealed that the value of the service could be estimated at over C$239 billion (€153 billion). This would be equivalent to 9.5 % of the value of the worldwide agricultural production of human food in 2005. These calculations, however, are based solely on crops produced for human consumption and fail to take into account crops grown for animals, especially cattle. Also left out of the calculations were crops for biofuels or the production of seeds and ornamental plant crops. Had these other aspects been taken into account in the calculations, the total value of pollination services in the world economy would certainly be much higher (Gallai et al., 2008).

The shortfall due to pollination failure is much greater in the case of crops with a high economic value. A ton of crops not requiring insect pollination has an average value of C$236 (€151) whereas in the case of pollination-dependent crops, the average value has been estimated at C$1189 (€761). According to the calculations proposed by Gallai et al. (2008), cereal crops and corn, for instance, represent 60 % of agricultural production in the world but are not dependent on pollinators. They would not be affected therefore by the disappearance of the latter.

On the other hand, in some tropical regions, pollination of wild or cultivated graminaceous plants is a common phenomenon. Within areas with immense savannahs, these crops are the sole source of pollen for the bees. In Cameroon, Tchuenguem Fohouo et al., (2002) observed that each of the 35 species of native bees present in the corn crop transported pollen from this plant. In this context, the Apoidea as pollen vectors presumably have a positive impact on corn grain yields.

### 3.2 Worldwide Evaluation of Pollination

Gallai et al., (2008) set out to determine the vulnerability of various crops to pollinator decline and grouped crops by production categories. The categories that seemed the most affected by dwindling pollinator numbers were stimulants (coffee, cocoa) with 39 % vulnerability, nuts (31 %), fruit (23.1 %), oilseed crops (16.3 %) and vegetables (12.2 %).

A more detailed qualitative compilation of pollination-crop dependence was conducted by various authors for different countries or regions in the tropics. Roubik (1995), for instance, estimated the pollination value for 1 330 crops at 70 %. Within the European context, Williams (1994) found that 84 % of the 264 crops studied also depended on pollination.

A more in-depth analysis used pollination dependency coefficients to estimate the monetary value of pollination for various crops. The method employed involved multiplying the value of the crop by its dependency coefficient. This approach does not take into account the added qualitative value of aesthetically improved fruits and vegetables as a result of higher pollination rates. A wide range of dependency rates were found for several crops. Variation factors may be due to the different cultivars used in different regions of the world, the environmental conditions of the area and also the methods employed by the different researchers.
3.3 Estimation of the Pollination Value for Some Important Productions in Canada

According to Agriculture and Agri-Food Canada and the Canadian Association of Professional Apiculturists (CAPA), the value of bee pollination in Canada could be as high as $1-$1.2 billion or more a year. Morse and Caldrone (2000) have suggested a figure of over $15 billion for the United States. De Oliveira (2005) conducted similar analyses in Quebec using provincial data for crop values as well as Quebec studies, in part, to estimate the significance of pollination. According to his findings, 84% of the production of nine major crops in Quebec is pollinator dependent. In 2005, a shortfall in these crops could be as high as $103 million. The author attributed only 70% of this amount to honey bees and the remaining 14% to the services provided free by native pollinators.

By averaging the dependency coefficients calculated by various authors (Louvreau, 2004; Agriculture and Agri-Food Canada, 2001; Morse and Caldrone, 2000; De Oliveira, 2005) it was possible to determine the economic value of pollination services for Quebec’s major crops on the basis of planted crop areas and crop values in 2008. As may be seen from Table 1, the value calculated was over $166 million dollars.

In Quebec as well as in Atlantic Canada, fruit crops; namely, apples, strawberries, cranberries and low-bush blueberries, are the most heavily dependent on pollinators. Two-thirds of honey bee colonies leased for pollination purposes are used for these crops. In Ontario, cherry and pear crops also depend on insect pollination. Other crops requiring insect pollination include mainly the Curcubitaceae and a few other vegetable crops. The economic value of pollination for these crops will be examined in greater depth.

3.3.1 Fruit Tree Crops

Apples

A good apple production is totally dependent on insects for the transfer of pollen. Almost all apple varieties are self-sterile and require another variety to achieve an adequate yield. Most available varieties have overlapping flowering periods allowing for pollination of one variety by another. Apple blossoms produce more nectar than the blossoms of most other fruit species and are highly attractive to bees whose habitat is within the orchard or nearby. Several wild bee species have been identified as significant apple pollinators (Brault and De Oliveira, 1995). Since a large number of pollinators are required to pollinate all the flowers in an orchard, however, honey bee hives are usually leased to ensure good production. In Quebec in 2008, apple production attributable to insect pollinators was evaluated at $38.3 million (Table 1).
Table 1: Value of farm production for 11 Quebec crops that depend on pollinators, and calculation of the portion attributable to pollinating insects.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Pollinator dependency rate</th>
<th>Reference</th>
<th>Area, Quebec</th>
<th>Gross</th>
<th>Refs</th>
<th>Gross value ($)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apples</td>
<td>0.70</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.93</td>
<td>4 961</td>
<td>8 361</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>41 478 921</td>
</tr>
<tr>
<td>Blueberries</td>
<td>1</td>
<td>1</td>
<td>0.89</td>
<td>0.96</td>
<td>12 400</td>
<td>1 995</td>
<td>5 622 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>24 738 000</td>
</tr>
<tr>
<td>Canola/Rapeseed</td>
<td>0.10</td>
<td>0.20</td>
<td>0.46</td>
<td>0.25</td>
<td>21 000</td>
<td>982</td>
<td>5 622 000</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20 622 000</td>
</tr>
<tr>
<td>Cranberries</td>
<td>1</td>
<td>1</td>
<td>0.80</td>
<td>0.93</td>
<td>1 619</td>
<td>24 816</td>
<td>9</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>40 177 104</td>
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<tr>
<td>Cucumbers</td>
<td>0.90</td>
<td>0.60</td>
<td>0.33</td>
<td>0.83</td>
<td>809</td>
<td>10 636</td>
<td>5 622 000</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>8 604 524</td>
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<tr>
<td>Grapes</td>
<td>0.1</td>
<td>0.01</td>
<td>0.31</td>
<td>0.97</td>
<td>301</td>
<td>12 600</td>
<td>1</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td>3 792 600</td>
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<tr>
<td>Peppers</td>
<td>0.20</td>
<td>0.65</td>
<td>0.43</td>
<td>0.43</td>
<td>587</td>
<td>25 200</td>
<td>1</td>
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<td></td>
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<td></td>
<td>14 792 400</td>
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<tr>
<td>Pumpkins</td>
<td>0.90</td>
<td>1</td>
<td>1.00</td>
<td>0.97</td>
<td>647</td>
<td>12 150</td>
<td>5</td>
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<td></td>
<td></td>
<td></td>
<td>7 861 050</td>
</tr>
<tr>
<td>Raspberries</td>
<td>0.90</td>
<td>0.38</td>
<td>0.64</td>
<td>0.36</td>
<td>526</td>
<td>24 206</td>
<td>5</td>
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<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Strawberries</td>
<td>0.80</td>
<td>0.20</td>
<td>0.30</td>
<td>0.42</td>
<td>1 477</td>
<td>30 627</td>
<td>5</td>
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<td></td>
<td>45 236 079</td>
</tr>
<tr>
<td>Zucchini</td>
<td>0.90</td>
<td>1</td>
<td>0.95</td>
<td>0.36</td>
<td>647</td>
<td>20 930</td>
<td>5</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>233 576 744</td>
<td>166 143 599</td>
</tr>
</tbody>
</table>

5 Évolution des superficies cultivées en fruits et légumes au Québec de 2002 à 2008. New publication
6 CRAAQ economic references
7 La Financière agricole du Québec
8 Agdex 1987” Montreal market price, October 2008
9 Jacques Painchaud, MAPAQ, Central Quebec
Cherries

Two species of cherries are cultivated, those producing sweet cherries (Prunus avium) and those yielding sour cherries (Prunus cerasus).

Almost all sweet cherry varieties are self-sterile and cross-pollination is not only desirable, but essential. These varieties are in fact 100% dependent on cross-pollination. It is therefore crucial to plant compatible pollinating varieties and to introduce honey bees for the adequate pollination of the flowers.

Varieties producing sour cherries are in great part self-fertile and produce good yields when the blossoms are fertilized with their own pollen. It has been found, however, that pollination and yields improved when bees are present. The dependency rate of these varieties on pollinating insects has been estimated at 70%.

Bees forage in cherry blossoms for both the nectar and pollen. Bees constitute 75% of the insects foraging in these flowers, and they tend to revisit the same flowers during their different foraging flights. This phenomenon is referred to as “flower fidelity”. The degree of foraging honey bee fidelity varies with the crop. It was estimated that 43% to 53% of pollen loads transported by pollinators in contact with this crop contained pure sour cherry pollen. Cherries are scarcely grown in Quebec because the climate is not suitable for the trees.

Pears

Pollinator dependency for this crop ranges from 70% to 100%, depending on the variety. Virtually all varieties are self-sterile. Fruiting and yields are ensured by cross-pollination provided by good varieties of compatible pollinators. Pear blossoms are not as attractive to bees as the flowers of other fruits. A high pollinator-per-acre density is therefore required to achieve yields similar to those obtained with other fruits. Pears are not grown in Quebec because of the climate is not suitable for the trees.

3.3.2 Berry Crops

Strawberries

The strawberry flower is self-fertilizing and can be pollinated by the wind. In order to obtain full, regularly shaped fruit, however, all the carpels of the flower must be fertilized. A pollen grain must therefore be deposited on all the pistils. In the case of commercial cultivars, the anthodia of the first flowers are large in diameter and wind pollination is not always sufficient. Several visits by pollinating insects are therefore required to obtain well-developed fruit (Chagnon et al., 1989). It should be pointed out that the strawberry flower is not very attractive to bees because of its relatively low nectar production (0.6 to 0.8 mg) and sugar content (18 to 25%). It is therefore a poor source of nutrition. In strawberry fields protected from the wind, insect pollination can increase yields by at least 30%. In Quebec in 2008, the value of strawberry production attributable to insect pollinators was estimated at $18.8 million (Table 1).

Raspberries

Raspberries are considered self-fertilizing, but pollination is unpredictable with winds of less than 11 km/hr. Depending on weather conditions, the raspberry plant therefore requires some degree (35% to 90%) of insect pollination. Bees find raspberry flowers highly attractive because they are rich in nectar and pollen. Bees account for over 90% of visits to the flowers. The number and weight of the drupelets are significantly higher following insect pollination (Chagnon et al., 1991). The lengthy flowering period and pollen-rich flowers ensure successful cross-pollination. Fruit set may be increased by 20% if several varieties are planted. In Quebec in 2008, the value of raspberry production attributable to insect pollinators was estimated at $8.15 million (Table 1).
Blueberries

Blueberry yields may be limited by a paucity of pollinators, and the dependence of blueberries on insects for pollination has been calculated at 70% to almost 100%. Wild bees can ensure pollination but in large-scale operations, they are not sufficient in number.

Poor pollination of this crop translates into diminished fruit set and the development of fewer seeds (Aras et al., 1996). Yields will therefore be reduced since a large number of seeds must be developed to produce a large fruit. Well-pollinated fruit has been shown to ripen more quickly than fruit that has not been sufficiently pollinated. It was found that with 0 to 1 bee visit per flower, the fruit developed in 58 days, whereas with unlimited visits, it took only 53 days or a 28% decrease in development time. Bee species, other than the honey bee, have been raised and introduced into blueberry fields for pollination (Payette, 2004).

Mason bees (Osmia spp), bumble bees (Bombus spp.) and the alfalfa leafcutting bee (Megachiles rotundata) are considered more effective pollinators of blueberry flowers than the honey bee. In Quebec in 2008, the value of blueberry production that could be attributed to insect pollinators was estimated at $23.8 million (Table 1).

Cranberries

Bees have trouble gaining access to the pollen of cranberry flowers. They actively harvest the pollen from these flowers by tapping or stroking the anthers. Because of this behaviour, pollen harvesting insects are better pollinators than nectar harvesters (Cane and Schiffhauer, 2003). Honey bee queens may be genetically selected to promote the proportion of pollen-harvesting worker bees in a hive. Cranberry production is growing rapidly in Quebec. The areas under production have expanded from 87 hectares in 1990 with two producers to 1330 hectares in 2006 with 45 producers, including 13 engaged in organic production (Rioux, 2004; ACPQ, 2008). In Quebec the value of cranberry production attributable to insect pollinators is estimated at $37.5 million (Table 1).

Kiwi Fruit or Actinidia

The kiwi plant is dioecious which means that the male and female flowers are borne on different stems. At least one plant couple must therefore be planted. In large-scale operations, one male plant is needed for six female plants. Pollinators help in the transfer of pollen to and fertilization of female plants. Wind is an undeniable pollinating agent but fruit resulting solely from wind action is smaller and the setting rate is lower. It is thought that this crop is 90% dependent on pollinators. Palmer-Jones and Clinch (1975) demonstrated the preponderant role of insects, and the honey bee remains the pollinator best adapted to meeting the production needs of this crop.

3.3.3 Curcubitaceae Crops

The plants of this family (squash, cucumber, cantaloup, watermelon, pumpkin) all have the three types of flowers. Most cantaloup and melon varieties produce male and hermaphroditic flowers, whereas most cucumber and watermelon varieties have both male and female flowers. The pollen is heavy and sticky and there is virtually no pollination by wind. In these crops, insect pollination is essential for fruit production.

Inadequate pollination results in underdeveloped fruit. In cucumbers and other crops with separate-sex flowers, fruit would not develop without the presence of pollinating insects to ensure cross-pollination.

In most Curcubitaceae crops, the flowers open for only a brief period of time. Male flowers generally are the first to appear, followed by the female flower which develops into fruit. The act of pollination therefore requires perfect synchronization. In melons, the fruit produced closer to the plant’s crown is often milder, larger and better-shaped than that produced elsewhere on the same vine. In order to obtain the best fruit, it is essential to have a sufficient number of insect pollinators for the transport of pollen.
Wild bees play an important role in the pollination of these crops. Winfree et al. (2007) studied watermelon pollinators in 23 agricultural operations in New Jersey and Pennsylvania (United States). Simulation findings suggested that wild bees alone were capable of providing adequate pollination in 90 % of the operations studied. Pollen deposits on flowers correlated with visits by wild bees but not with visits by honey bees. In Quebec, the most commonly grown Curcurbitaceae are cucumbers (gherkins), pumpkins, squashes and zucchini. Studies conducted on cucumbers (Gingras et al., 1999) and pumpkins (Barrette, 1999) revealed an increase in these crops of 60 % and 100 %, respectively. The value of Curcurbitaceae production that can be attributed to insect pollination is estimated at a total of $27.6 million (Table 1).

3.4 Estimation of the Pollination Value for Some Worldwide Productions That Improve our Daily Lives

3.4.1 Stimulants

Coffee

Some coffee varieties are self-fertilizing, but 30 to 40 % of coffee bean production can be attributed to insect pollination. The main visitors are bees.

Tea (Camellia sinensis)

In this crop, 90 % of seed yields may be attributed to pollination by honey bees.

Cacao

Pollination of the cacao tree requires the active transport of pollen from flower to flower since the anthers and stigmas are separated by plant barriers within the flowers (Kaufmann, 1975). In addition, the flowers are often self-incompatible (Pandey, 1960). Cacao flowers are normally pollinated by flies, mainly by members of the families Ceratopogonidae and Cecidomyiidae (Young, 1986). In large-scale operations, it is common practice to resort to manual pollination to ensure pollen transfer. An individual can pollinate up to 250 flowers a day (Soria, 1981). This approach is necessary since under normal conditions under 5 % of flowers on mature trees are pollinated when insects are the sole pollinators (Alvim, 1984).

3.4.2 Other Crops

Almonds

All almond tree varieties are self-sterile, and as a result, cross-pollination is essential. Contrary to what has occasionally been advanced, bitter almond trees are not self-fertilizing.

Cotton

In the case of cotton, pollination is estimated to improve yields by 30 % and seed production by 20 %. Bees forage in greater numbers in sterile male flowers than in fertile male flowers. Most of the foragers in the fertile male flowers collect nectar rather than pollen.

3.5 Value of Native Pollinators

The most significant crop pollinators belong to the superfamily Apoidea, which at the planetary level includes some 17 000 species (Michener, 2000), roughly 3 500 of which are found in North America. At least 1 000 of these species are believed to occur in Canada (Goulet and Huber, 1993). The most commonly known crop pollinators are the honey bee (Apis mellifera), a half dozen bumble bee (Bombus spp.) species, a few solitary bee species and, on more fully open flowers, occasionally some flies, coleoptera, butterflies or thrips. Trying to assess the relative contributions of the various species to agricultural production can often prove challenging. When insect pollinators are not found in large numbers on crop flowers, it may become necessary to intervene to increase their numbers.
Native bee populations in an area may be increased in two different ways. The first involves reinforcing and maintaining local wild bee populations. The second involves breeding and managing species that have been selected for that purpose by means of developing habitat enhancement techniques. (Corbet et al., 1991).

3.5.1 Reinforcing Local Populations of Native Species

Native pollinators can provide a sort of “biological insurance” for the services currently provided by domesticated species (Winfree et al., 2007). However, bee species do not all display the same affinities for plants, nor the same ability to provide adequate pollination. In addition, they differ in their nesting requirements. These preferences are partly determined genetically. This also holds true for their physiological and behavioural constraints. This explains why some species are better than others in pollinating a specific crop (Free and Williams, 1973).

Each pollinator has its strengths and its weaknesses. The challenge is to determine precisely which natural pollinators in an environment are capable of providing additional pollination to achieve an economically optimal pollination rate for a given crop. Efficiency is the characteristic sought among pollinators. Javorek et al. (2002) identified three aspects of pollinator efficiency: 1) the number of visits to flowers, 2) the percentage of flowers visited with contact with the stigma, hence pollen transfer and 3) the amount of pollen deposited on the stigmas by the insect.

Torchio (1990) proposed a series of strategies and practices that could lead to the identification of efficient pollinators for a given area and to reinforcement of their population. He stated that it was essential to 1) observe the pollinators on the flowers of a crop, 2) study their biology, 3) estimate their pollinating efficiency, 4) determine their nesting needs to increase their reproductive rate and lastly, 5) conduct a follow-up of population numbers to evaluate the success of the measures taken.

3.5.2 Wild Pollinators in Quebec’s Agroecosystems

Observing native species on flowers therefore constitutes the first step toward reinforcing populations of pollinating species in a system. There have been reports of over 350 wild pollinator species in Quebec (Payette, 2003). Payette and De Oliveira (1989) demonstrated the importance of Apoidea diversity in Quebec’s agroecosystems (1989) in an inventory conducted in southern Quebec. The study resulted in the collection of 4,184 bees on 70 floral species and in five different biopes. Each of the 103 species (7 families, 25 genera) was identified according to its plant preference and its selected foraging time, i.e., spring, summer, fall or its tendency to forage over a lengthy period of time (spring to fall). The study was conducted over several years in different habitats, e.g., forests, wooded areas, hedgerows, road embankments, railways, the sides of ditches and streams, abandoned fields, grasslands, monocultures, and field borders. It was found that several bee species could complete a portion of their life cycle (foraging stage in the adults) during the flowering period of a particular crop. With other species, foraging extended beyond the flowering period of the target crop, and as a consequence, these bees had to forage in a wider variety of native or cultivated plants. It is of key importance therefore to know these botanical varieties and to ensure that they are available near crops (Payette, 2004).

This body of information provides evidence that an in-depth knowledge of the local pollinating insect fauna is required if the ideal target pollinating species is to be identified for population reinforcement. Subsequent to identification, suitable habitats near the crops must be provided and adequately managed to foster the reproduction and survival of the pollinators, particularly in intensive agricultural systems.

3.5.3 Management of Native Pollinators

Canadian agriculture depends primarily on four groups of bees which are managed commercially for crop pollination. These are the honey bee, the alfalfa leafcutting bee, the bumble bee and the mason bee. There are wild bee species that could be “managed” for pollination in Canada or elsewhere. These include pollinators of various...
legumes, apples, pears and cherries. These bees are more effective and reliable than domesticated pollinators. Some solitary bees are significant crop pollinators, but their commercial potential remains to be determined. The importance of their role is poorly understood and little effort has been made to try to estimate the value of the services they provide. Yet, the pollinating superiority of several bee species (Megachile, Nomia, and Osmia) compared to the honey bee has been shown particularly in alfalfa and fruit tree crops (Torchio, 1987; Parker et al., 1987).

In Europe efforts have been made to reinforce the number of individuals in natural populations (Heemert et al., 1990). In Japan, the population of Osmia cornifrons (Radoszkowski) was successfully bolstered on a commercial scale as an apple pollinator (Maeta, 1978). In North America, successful results were obtained with the alkali bee (Nomia melanderi) as well as with various mason bees (Osmia spp.), essentially Osmia lignaria used primarily as a pollinator for almond, apple, cherry, pear, plum and other crops (Torchio, 1987). Another native North American species, Osmia ribifloris, has more recently shown promise as a very effective and manageable means of pollinating blueberries. Mention should also be made of Osmia cornuta, an established apple and almond pollinator in Europe (Spain) which was tested with good results in the United States. The greatest success, however, has been with the alfalfa leafcutting bee (Megachile rotundata) (Richards, 1993).

The Alfalfa Leafcutting Bee (Megachile rotundata)

Species belonging to the subfamily Megachilines are both common and diversified and occur on every continent. The alfalfa leafcutting bee, Megachile rotundata, has been targeted for large-scale commercial rearing operations. It is the most commonly bred pollinator for pollination of alfalfa crops. It is used as a pollinator in the western United States and Canada as well as in several other countries. Canada is the largest worldwide producer and exporter of Megachile rotundata cocoons. The management system that has been developed enables farmers to collect the cocoons year after year and to sample them for an accurate estimation of the number of cocoons with females and the detection of parasites and diseases. A further advantage of the species is its ability to live in various man-altered habitats, such as landfills or roadsides where it finds food and nesting sites. Natural populations may therefore be reinforced by escapees from commercial breeding operations. The phenomenon was observed by André Payette in 2006 in cranberry bogs (Payette, personal communication). The author collected Megachile rotundata specimens several kilometres from the place where the species had been introduced for pollination the year before.

Because of its size and foraging behaviour, the leafcutting bee is well-adapted to Vaccinium (blueberry and cranberry) crops. In Quebec, the insect is kept commercially to pollinate blueberries, primarily in the Lake St. John region. It has also proved an efficient pollinator for cranberry crops in central Quebec, but problems in managing a hymenopteran parasite (Pteromalus sp.) within breeding operations have affected its popularity. The industry, however, is well-developed and has found ways of fending off parasites and diseases.

The bee has proved useful for crop pollination because of its short flight range, i.e., 200 m. Consequently it does not seek out competing plants, unlike the honey bee which can forage up to four km from the target resource. Megachile rotundata, however, is very sensitive to poor weather conditions. It does not fly under temperatures of 8˚C and ceases activity under 244 Watt/m2 of solar radiation (Girard, 2008). Several other native species have been identified on cranberry crops and they have often been found to exhibit a greater pollinating potential than the honey bee (Barrette, 2001).

Canada is home to 30 leafcutting bees such as Megachile rotundata as well to two other species that have been introduced but whose biology is still largely unknown (Kevan et al., 2008). These species may well harbour candidates with the same degree of efficiency for certain crops as Megachile rotundata, but with better adaptation to the local conditions prevailing at the time of target crops flowering.
Mason Bees (*Osmia* spp.)

In addition to species belonging to the genus *Megachile*, the subfamily Megachilines also includes the genus *Osmia*. Bees of this genus are also called mason bees because they make cells out of mud within the nests built in cavities (Payette, 2005). These wild bees may be bred and released in large concentrations on spring-flowering fruit crops. In our latitudes, the most common of the species is *Osmia lignaria*. It uses protected crevices and hollow stems for nesting. It is capable of efficiently pollinating several plant species and begins its activity at fairly low temperatures (15°-16°C). It is consequently well-adapted to cooler climates. It is used to pollinate very early flowering orchards. Some *Osmia* species arrive even before apple trees flower. A habitat can be created to keep these springtime species in an area. Surprising results are often obtained at the beginning, but unfortunately often after a year or two, the insects fall prey to parasites and diseases. This dampens grower interest. Furthermore, mason bees are not of any great value for pollinating vegetable crops because they are dormant at the time of flowering. Research is needed to overcome these problems before the bees can be commercialized in Canada.

Other genera of the subfamily Megachilines occur in Quebec. In addition to *Megachile* and *Osmia*, these include *Heriades*, *Hoplitis* and *Coelioxys* (Payette, 1989). The breeding potential of these species has not been elucidated.

Bumble Bees and Their Vibratory Pollination Behaviour

Bumble bees have morphological and behavioural traits that distinguish them from other pollinators. Anatomically they are bigger and hairier than other insect pollinator species. Also, when they visit flowers they vibrate their wing muscles at a frequency that releases pollen from the anthers. This phenomenon is referred to as buzz pollination. Very few species are capable of adopting this behaviour which in the case of numerous plants is essential for pollination.

Bumble bees are used in thirty or so countries to pollinate some 25 different crops. It is estimated that over 300,000 colonies are used in greenhouses in Europe and the United States (Henkes, 1997). They are superior to honey bees in pollinating flowers with deep corollas, e.g. red clover, because the tongues of honey bees are not long enough to reach the nectar. Bumble bees also forage at much lower temperatures than the other insect pollinators. According to Peat and Goulson (2005), the proportion of pollen and nectar harvested is temperature-dependent.

Bumble bees, however, are expensive to manage and in the fields and orchards requiring large numbers, this cannot be achieved at low cost. They have proved cost-effective in highly valuable crops requiring the specialized behavioural and physiological characteristics of this pollinator species. In Quebec, bumble bees are used in greenhouses for tomato and sweet pepper production and are introduced into the fields for blueberry and cranberry crops. In this case, they serve to complement the pollinating activity of the honey bee. They are capable of foraging under windy conditions and cloudy skies and at lower temperatures than the honey bee.

Quebec is home to twenty or so bumble bee species which can be found in various habitats including woodland, fields and peat bogs. The most common species are *Bombus impatiens*, *B. rufocinctus*, *B. ternarius*, *B. terricola* and *B. vacans* (Payette, 1996). They are often found in temperate habitats, in cool climates where nectar-producing plants flower.

Squash Bee (*Peponapis pruinosa*)

The squash bee is a solitary, terricolous species that is well adapted to Cucubitaceae crops (cucumbers, melons, pumpkins, squashes and gourds). It is generally not found, however, in a number of agricultural regions because of its high degree of sensitivity to the abusive use of pesticides. The species was identified on several floral species for the first time in Quebec in 2001 by André and Marc Payette (2003). There are no known breeding systems for
domestication of this bee. The development of a natural or semi-natural environment near Curcubitaceae fields could help increase their pollination and production.

3.6 Ecological Value of Pollinators in Natural Environments

3.6.1 Value of Ecosystemic Services

The services of ecological systems are essential for the functioning of land-based life support systems. The properties of different ecosystems and their mode of operation contribute both directly and indirectly to the well-being of the human race and represent a portion of the overall economic value of the planet.

By way of illustration of this concept, take the invaluable action of the long-nose bat which plays a key role in the ecological balance of the tropical rain forest. This small mammal is the main pollinator found in forests of the isolated Pacific islands. A large number of plants, including clove, banana, mango, avocado, eucalyptus, ebony, mahogany and cashew nut trees are solely dependent on bats for pollination and seed dispersal. The morphological adaptations of several plant species co-evolved to facilitate bat-specific pollination. Were these valuable bat species to disappear, no other pollinator could fill their role. The presence of bats on these Pacific islands also provides some control of malaria-carrying mosquitoes. We can therefore attribute to these animals ecosystemic services involving pollination as well as pest control resulting in improved human health.

Costanza et al. (1997) set out to place a price tag on various ecosystemic services which they grouped into 17 major categories, including pollination. According to their model, based on 1994 data, the economic value of bee pollination could be estimated at a total of US$117 per hectare per year (grasslands: US$26/ha/year and agroecosystems: US$14/ha/year).

The concept of ecosystemic service, as discussed by Ghazoul (2007), is important to make legislators, environmental professionals and the general public aware of what is at stake. It provides anthropogenic arguments demonstrating the importance of preserving pollinating species, but the concept does not necessarily take into account the complex interactions involved in saving an ecosystem so that it can operate on a long-term basis. The productivity of an ecological system that is beneficial to humans does not necessarily mean that it is always environmentally and ecologically valid.

3.6.2 Ecological Value

It is much more difficult to estimate the ecological value of pollinators and predict the consequences of their loss than to determine their economic value in agriculture. Estimations are complicated by the number of species involved and the relative lack of available information for most of these species, particularly those occurring in natural communities.

A large portion of the flora in uncultivated terrestrial communities in Canada, as elsewhere in the world, depends to varying degrees on pollinators for its survival. Many forest species rely largely or exclusively on wild bees for fertilization. By way of example, mention can be made of forest species such as maple, some Rosaceae e.g., mountain ash, dogwood, Ericaceae (blueberries) and other ligneous species as well as herbaceous plants such as orchids. By ensuring cross-pollination bees alone help to reduce the risks of population degeneration due to genetic erosion. Plants benefiting from pollination can provide shelter, food and reproductive sites for various animal species. Pollinators therefore ensure the survival of several plant species as well as of associated wildlife (birds, rodents, mammals). Pollination failure can affect all the links of the food chain. The Canadian black bear, for instance, requires blueberries in its diet, and blueberries in turn need the pollinating services of bees.
3.6.3 Importance for Biodiversity-Rich Environments (Hot Spots)

In a review of over 1000 studies of cases of limited pollination, Vamosi et al. (2006) found that botanical species in biodiversity-rich floristic communities (hot spots) might be less likely to receive pollen because of interspecific competition for pollinators. Reproductive success would therefore be reduced and these species could run a higher risk of extinction. A more limited access to pollen combined with habitat destruction represents a double risk for tropical plants that has still to be examined.

Biodiversity hot spots occur primarily in South America, Southeast Asia and in the rich scrublands and forests of South Africa. According to the WHO, up to 80% of people living in southern Africa use traditional drugs derived from wild plants. The value of these traditional plants for human use may therefore be linked to that of the pollinators ensuring their survival.

3.6.4 Intrinsic Value of Pollinators

While plants flower in order to attract pollinators and not to appeal to humans, men and especially women are very sensitive to the different types of inflorescences because of their visual beauty or their fragrance. The aesthetic and scent values of flowers, while widely commercialized, remain an inherent value offered up, free of charge, by nature. Over and above a species’ inherent value, there is its intrinsic value.

While the inestimable services provided by pollinators cannot be ignored, it is essential to respect the intrinsic value of these animals. Intrinsic value does not refer to any economic notion but rather to a philosophical position as described by Callicott (1989). Thus, a living organism is entitled to recognition in and for itself, independent of any usefulness it may have to humans. Because no price tag can be attached to this natural value, it is considered virtually worthless compared to the considerable material economic benefits derived from the development and exploitation of pollinators. While it may be true that there is no such thing as an objective intrinsic value in nature that is not anthropocentric, this value must be acknowledged for all pollinating species and the flowers they pollinate, irrespective of whatever use may be found for them.

4. Possible Causes of the Decline of Native and Introduced Pollinators

Several research projects, publications and public awareness campaigns have focussed on determining the possible causes of decline in introduced pollinator numbers, particularly among honey bees. Researchers and beekeepers have offered a number of hypotheses to explain the phenomenon. While several possible causes have been examined, none has yet been clearly identified as the main cause. Viral pathogens, parasites and fungi have all been accused along with various ecosystemic stress factors attributable to degradation of their environment: pesticides, pollutants, cell phone antennas, climate change and depletion of floral resources. In the case of honey bees, the consensus seems to be that the decline is due to a combination of these factors, exceeding the resistance capacity of the bees. This falls into the very definition of the bioindication principle: a living organism may become sensitive to an accumulation of various environmental stresses whereas it could withstand any one of these stresses taken separately. Thus, a pollinator could withstand the effects of a disease, poor nutrition or pesticide poisoning, but when these factors occur together, there comes a point when the pollinator’s resistance breaks down.

For some time the honey bee has been recognized as an excellent bioindicator of the quality of the environment in which it operates. We shall take a closer look at the different possible causes of honey bee decline. It must be remembered that the honey bee is an introduced species but is an observable indicator of environmental pressures and other anthropogenic stress factors affecting native pollinators. In addition, we shall try to determine the various causes for the specific decline of wild pollinating fauna.
4.1 Pesticides

Pesticides constitute a major threat to pollinators. It has been known for some time that the use of pesticides to control agricultural pests can have a negative impact on honey bee colonies (Johansen and Mayer, 1990). For decades, there have been massive losses in bee colonies wherever agriculture and beekeeping have co-existed. Losses in bee numbers are often the result of poor handling and application procedures for pesticides or else failure to follow the recommendations printed on the label. Even when the instructions are closely followed, the pesticide will inevitably constitute a serious risk for all the pollinators, regardless of whether they are wild or introduced.

The negative impact of insecticides on honey bee colonies suggests that wild pollinator populations may be similarly affected. If applied carelessly, the chemicals may be carried to non-targeted areas, thereby increasing their impact. In the case of applications from the air, for instance, a factor such as wind velocity could have a significant influence on the area covered by the pesticide, with the result that wild pollinators in areas adjoining the fields under cultivation could be endangered (Buchmann and Nabhan, 1996). This problem underscores the importance of providing buffer zones in agricultural areas not only to provide an essential habitat for pollinators but also to protect them from pesticide drift.

Pesticides are potentially able to harm a large number of pollinating species and even to eliminate a certain number of populations of species occurring in an ecosystem (Nabhan and Buchmann, 1997). Kevan et al. (1997), however, expressed the view that if the availability of wild flowers remained unchanged, wild bee populations could recover once pesticide applications ceased, except if populations were eliminated over a very large sector. The presence and abundance of suitable floral resources in an environment are therefore extremely important factors. Herbicide use may indirectly affect the pollinators of an area by eliminating or reducing the populations of plant species that are important for the maintenance of pollinator numbers (Kevan, 1975). In addition to their indirect effects, some herbicides, namely glyphosate, are toxic to bees and potentially harmful to other pollinators.

4.1.1 Use of Pesticides in Quebec, Canada and Elsewhere in the World.

In the early 1950s questions were beginning to be raised about the effects of pesticides on the population size of pollinating insects. Since then, over the last forty years, pesticide use in North America has doubled, and at the same time, in over 50 years of use, pesticides have found their way into every single country. Furthermore, the production capabilities of developing nations are in full expansion. The first major problems were observed in the United States in 1967 when 70 000 honey bee colonies were wiped out following applications of carbaryl in cotton fields. In the same year, 33 000 colonies in Washington State suffered a similar fate following applications of the same pesticide in wheat fields.

In Quebec as elsewhere in Canada and in the world, industrialization of agriculture favours a production mode requiring ever more pesticides to ensure a competitive edge. At the same time, a number of crops require pollination services to achieve higher yields. Beekeepers therefore place their hives in locations with the most intensive production but also with the most massive amounts of pesticides.

Quebec hives are also affected by pesticides, particularly in the Montérégie region where ever more acreage is given over to heavily pesticide-treated crops, e.g., corn. A large number of pesticides employed, including Furadan (a carbamate), are known to present a high risk for bees but are still freely used on corn, pepper, lettuce and other vegetable crops. Honey bees are not the only pollinators affected by insecticides. According to Plowright and Rodd (1980), populations of wasps (Vespidae), andrenids (Andrenidae), halictids (Halictidae) and bumble bees (including Bombus terricola) are considerably reduced after spraying with fenitrothion, an insecticide largely used in the past in fight against the spruce budworm, but still registered for minor use against other forest insects on areas of less than 500ha. In an attempt to reduce the problems resulting from spraying operations, use of these products...
has been restricted to periods when pollinators do not forage. This practice has been adopted in Canada, the United States and in several other countries (Adey et al., 1986; Johansen and Mayer, 1990).

In Quebec an agreement aimed at reducing honey bee loss resulting from chemical poisoning was signed between beekeepers and pesticide users (industry and farm producers) in the 1980s. The agreement emphasized the importance of restricting applications to periods when the bees did not forage, i.e., during non-flowering periods and outside of hours with high light intensity, in other words, during rainy days and early in the morning or late in the evening. Throughout Canada, thanks to the efforts of the federal and provincial ministries of agriculture, there has been a growing number of incentives aimed at reducing pesticide use in agricultural areas. At the same time crop pest detection networks and Agricultural Advisory Clubs have sprung up, providing users with the tools for a better assessment of the suitability of insecticide treatments and better management of these treatments. These initiatives to raise awareness among users have resulted in a considerable drop in the amounts of pesticides employed. Despite the recent trend in Canada to reduce the use of pesticides in agriculture and silviculture and to increase awareness of the impacts these substances have on pollinators, pesticide-induced poisoning of pollinators is far from having diminished. Pesticides constitute one of the components of the integrated fight against agricultural and silvicultural pests and will continue to be so in the predictable future.

4.1.2 New Molecules

The pesticides used today unfortunately have active ingredients that are far more potent and insidious than those used in the past. This is the case of a relatively new class of widely used systemic insecticides, the neonicotinoids. The insecticides in this group are highly toxic to insects, including bees, at very low concentrations. The group includes imidaclopride, thiamethoxam, clothianidine and several other compounds which are widely used to coat seeds. They are also applied according to standard dusting practices. These compounds can be taken up via the roots and then carried by the sap to all parts of the plant as it grows. This ensures protection against root pests but also against insects attacking the aerial portions of the plant. Since they are active until the flowering stage, they can be picked up by pollinators in the pollen and nectar.

Imidaclopride is used intensively to coat the seeds of horticultural and field crop species, mainly corn, sunflower and canola. In these crops, the pesticide has been detected in the soil, plant tissues and pollen. It is characterized by its persistent presence in the soil (half-life of 120 days or more). While this constitutes a decided advantage in terms of pest control, it also represents a risk for honey bees since the compound may reappear the following year and leach out at crop borders into the root systems of wild plants. Evidence suggests that the insecticide may have neurological effects on bees. The sublethal effects of systemic pesticides on the foraging behaviour of bees were described by Pham-Delegue et al. (2002). In Europe, researchers reported that exposure to imidaclopride inhibited the foraging and navigational skills of foraging insects. Although several studies have shown the harmful effects of imidaclopride on bees (Suchail et al., 2006), other studies have reported only negligible effects or none whatsoever (Maus et al., 2003). In a number of these studies, however, the researchers concentrated only on the LD50 in a laboratory setting (Bailey et al., 2005). They failed to take into account the impacts on the overall operation of the colony. The impacts of imidaclopride and the other neonicotinoids on bees are still the subject of some debate. These chemicals were marketed in France under the brand name of Gaucho and were banned in the treatment of sunflower seeds in 1999 after having killed off massive numbers of bees. Five years later, France banned them also in the treatment of corn. Bayer, which manufactures imidaclopride and other neonicotinoids, claims that these compounds are safe for bees if properly applied.

A few years ago, approval was granted for the marketing of corn seed treated with a new systemic neurotoxic insecticide containing clothianidine (or Poncho 600) as its active ingredient. This compound is also a neonicotinoid with the same molecule and mode of action as imidaclopride. In France, Bayer’s application for licensing of clothianidine was turned down by the authorities. In Germany, Italy and other countries, the use of clothianidine,
as in the case of the other neonicotinoid, was banned or suspended. According to the Pest Management Regulatory Agency (PMRA) of Health Canada and the Environmental Protection Agency (EPA) of the United States, clothianidin is “highly toxic” to bees. Yet in 2008, over 95 % of the corn grown in Quebec was treated with the product.

More recently, the PMRA approved an application for licensing for thiamethoxam (or Cruiser 350FS) as a seed treatment to control flea beetles in canola and mustard crops. This neurotoxic insecticide is produced by Syngenta, a Swiss agrichemical group, and acts on the nicotinic receptors of insects. It is also marketed for use on corn seed but in this case to control click beetles (Agriotes spp.), underground coleopterans that attack root systems. Neonicotinoids are also used on berries (strawberries and raspberries), i.e., crops that are highly attractive to insect pollinators.

The most recently approved systemic pesticide does not belong to the family of neonicotinoids. Bayer has replaced the latter, which lost many of the licenses that had been granted, with a molecule likely to prove far more damaging to pollinators. This new systemic pesticide, Movento (Spirotetramat), is far more robust in that it can move in all directions in the plant’s vascular system. It can be found in the pollen and nectar. Not only is it toxic to adult bees, it also affects larval development and the fertility of the queen. The impact of this new pesticide on other pollinating species is not yet known, and few data are available on effects on the immature stages of various bee species.

According to several researchers, pesticide toxicity to honey bees is a good indicator of the risks for other bee species (Johansen and Mayer, 1990). The mode of action and route of entry of pesticides vary with the bee species. The ability to detect these products is complicated by the absence of homogeneous detection methods.

### 4.1.3 Transgenic Crops (GMOs)

Transgenic plants were developed specifically to reduce some of the undesirable and involuntary effects of pesticides. There are concerns, however, about potential impacts the direct effects of insecticide proteins in the pollen may have on non-targeted species, including some pollinators (Losey et al., 1999). These concerns focus on the lack of information on the lethal threshold of transgenic insecticide proteins and the sublethal effects of the proteins on the physiological and reproductive behaviour of the insects feeding on them. Malone and Pham-Delégue (2001) reviewed the limited literature on the subject and concluded that in some cases, there were negative effects but that these were sublethal. They ascribed these effects to the consumption of transgenic pollens. These effects vary with the transgenic agent and the extent of its expression. During foraging activities, bees come in contact with genetically modified crops. A literature review published by Brodsgaard et al. (2003) indicates that genetically altered organisms are potentially hazardous to bees. Up to now published results suggest that the impacts of transgenic plants on bees should be examined case by case and depend on the portion of the plant that is ingested (Malone et al., 2001). In Quebec, no method has been developed to assess the impact of genetically modified organisms on pollinators under natural conditions.

Concerns regarding the effects of transgenic crops on non-targeted species have focussed primarily on butterflies. Special attention has been paid to the effects of Bt corn used to control the European corn borer (Ostrinia nubilalis; Minorsky, 2001). In 1999, over 20 million acres (9.6 million hectares) of Bt corn were planted in the United States, i.e., over 20 % of the total area planted in corn (CNRC, 2000), and greater concern was expressed over the consequences for non-targeted organisms. These concerns were expressed by both the scientific community and the public at large and gave rise to several studies to evaluate the risks associated with Bt corn for the monarch butterfly (Danaus plexippus). The studies showed that the risks of a negative impact were low. A combination of factors has been cited, e.g., the genetic transformation of corn (Hellmich et al., 2001; Zangerl et al., 2001), behaviour of the monarch larva (Anderson et al., 2005), pollen persistency failure (Pleasants et al., 2001). Sears et al. (2001) evaluated...
the risks based on laboratory data and findings from the field. They concluded that replacing 80% of conventional corn with Bt corn would prove hazardous to only 0.05% of monarch butterflies. This estimated risk would be significantly lower than the risk caused by the pesticides used traditionally to control the European corn borer (Stanley-Horn et al., 2001).

It should be pointed out that genetically modified crops – corn, canola, cotton and soybeans - are generally grown from neonicotinoid-coated seeds. By way of example, Herculex corn, which contains Bt genes to control the corn rootworm, and Yieldgard corn, a European corn borer-resistant variety, are grown from seeds coated with a neonicotinoid insecticide and a fungicide. http://www.dowagro.com/herculex/.

In addition, Moradin and Winston (2005) noted that a variety of genetically modified canola (B. rapus) exhibited a repellent effect not observed in traditional varieties. Similar findings were reported by Sabbahi et al. (2005). The latter found significantly fewer bees in transgenic fields than in conventional fields. While a repellent effect may protect pollinators from the harmful action of transgenic proteins, it deprives the local pollinators of a floral resource which would otherwise be available to them and which covers vast areas in landscapes transformed for purposes of agriculture.

According to statistics published in 2006 (Statistics Canada), Ontario’s farmers planted 995,000 acres in genetically modified corn, i.e., 47% of the area planted in grain corn in the province. In Quebec, farmers planted 580,700 acres in genetically modified grain corn, i.e., 52% of all the grain corn planted in the province.

4.2 Fragmentation and Habitat Loss

Fragmentation and habitat loss are two types of disruption that have been recognized as important factors in loss of biodiversity on a local as well as worldwide scale. Habitat loss refers to the loss of a natural environment arising from a primary succession, i.e., a natural landscape. Fragmentation of a habitat refers to the break-up of a habitat into fragments that are often too small to ensure the viability of populations of all species. Pollinators and pollination-dependent plants are not protected from this type of disruption (Kearns and Inouye, 1997; Kevan, 2001; Kevan et al., 1990). According to the Canadian Nature Federation, over the last ten years, close to one-third of the territory covered by the Canadian boreal forest has been given over to various initiatives resulting in the loss and fragmentation of the mature forest cover, thereby affecting large numbers of plant and animal species. That said, disturbances such as cuts should not be considered total losses since some floral species can proliferate in areas bordering cutover sites and provide habitats for pollinators (Leopold, 1987).

The extent to which habitat loss influences pollinator abundance and diversity is a more complex issue than a simple relationship between area loss and pollinator loss. While examination of data on pollinators and land fragmentation does point to a decline in insect pollinator numbers and diversity as habitats dwindle in size (Rathcke and Jules, 1993), it is essential to understand the mechanisms producing losses for a proper assessment of the extent of different types of environmental disruptions on the equilibrium of a local pollinating community. Cane (2001) emphasized the importance of examining habitat needs for nesting in accurately determining the effects of landscape fragmentation on local populations.

4.2.1 Impacts of Agriculture

Throughout Canada, forestland and natural prairies are disappearing in zones of human expansion, giving way to intensive agriculture that is particularly poor in terms of biodiversity. The introduction of new cropping practices and intensive farming in general have resulted in a significant loss of forestland in southern Quebec. Close to half of the Regional County Municipalities in southwestern Quebec have lost more than 50% of their forest cover. Considered an obstacle to expansion, wetlands, which are subject to flooding, have been drained in favour of agriculture (Conseil de la conservation et de l'environnement, 1990). Between 1950 and 1978, over 685 km of coastal marshland bordering the St. Lawrence corridor disappeared as it was drained for agricultural purposes.
As a result, Quebec’s agricultural landscape is now characterized by a mosaic formed by areas of intensive farming separated by parcels of natural and semi-natural habitats. This means a decline in the types of habitats that could provide nesting sites for pollinators and flora needed for pollinator survival. Furthermore, different types of non-sustainable farming practices further aggravate the problem of deforestation, i.e., loss of herbaceous borders, abandoned use of crop rotation and green manures employing leguminous plants (practices that have been replaced with chemical fertilizers) and a reduction in native plant diversity in fields and pastureland (subsequent to the use of herbicides).

Corn fields have replaced vast stretches of forestland and logging is conducted under new conditions. The mechanical removal of brush, for instance, has become a widespread practice and destroys the flora found in the undergrowth. The massive supply of Ericaceae pollen has consequently been substantially reduced if not altogether eliminated. With respect to the quality of available food, regression of Ericaceae plants has been attended by a highly significant progression of sorrel (Polygonaceae). Insect pollinators are therefore obliged to use pollen sources of poorer nutritional quality.

Monoculture practices not only reduce natural and semi-natural habitats, they also cause loss of diversity among cultivated plants, further impoverishing the range of floral resources available to the natural pollinators in the area.

**Pastureland**

A study conducted by Richards (1995) showed that bumble bees and floral resources suffered a decline in diversity and abundance in zones with more extensive pastureland for cattle. In a large portion of British Columbia and in some parts of eastern Canada, the overpasturing of farm animals (cows, sheep and llamas) has a negative impact on pollinators and floral biodiversity (Kevan, 2002).

**Transition Zones (Buffer Zones)**

In some instances, wild areas bordering on farmland may act as buffer zones for crop pollinators. These are transition zones between the natural environment and cultivated areas (Morandin and Winston, 2006). Agroecosystems must therefore be considered habitats in which agriculture plays the dominant role but which also make provision for fragments of natural habitats, e.g., forests, grasslands, etc.

Ricketts et al. (2008) summarized the findings of 23 studies examining 16 crops on five continents. The general relationship between pollination services and the physical distance of semi-natural habitats from field crops was scrutinized. A significant exponential drop was found in the number of pollinators and the rate of visitation to crop flowers as distance increased. The visitation rate was reduced by 50% of maximum values when natural habitats were 0.6 km from the crops, while the variety in species declined by 50% with distances of 1.5 km.

In a study conducted on sunflower monocultures in California, Kim et al. (2006) concluded that wild bee species reacted differently to soil conditions created by agricultural practices. After examining the environmental variables needed for the nesting requirements of different bee species, they found more nesting sites and greater diversity in bee species in farm operations close to natural habitats than in farms that were some distance away. These findings suggest that most bee species are affected negatively, but to varying degrees, by intensified agriculture. The authors expressed the view that natural habitats could serve as buffer zones against biodiversity loss in bee communities existing in the agricultural landscape.

The evidence indicating a general drop in fruit and seed production proportional to distance from natural habitats is less clear. A more pronounced reduction in crop visitation was recorded in tropical zones compared to temperate regions. The drop was slightly more pronounced for social than for solitary bees.
Tropical crops which depend mainly on social bees could therefore be more sensitive to habitat loss. Quantifying these general relationships could help in predicting the consequences of changing land use on pollinator communities and the productivity of nearby crops.

4.2.2 Importance of Floral Resources

Habitat fragmentation and loss affect pollinators in two ways. First, they reduce the availability of the range of plants capable of meeting all food needs throughout a season (Kearn, 1997). Loss of access to resources could increase competition among local species for the limited resources. Secondly, habitat loss could also disrupt nesting among a number of bee species that dig their nests in burrows.

Availability of Flowers

Pollinators rely exclusively on pollen for their source of protein (Jump and Penuelas, 2006). By reducing the availability of pollen, habitat loss can affect pollinator species and communities but in different ways since the various species do not have the same needs and requirements (Kevan 1975, 1999, 2001; Tommasi et al., 2004; Cartar, 2005). Even when a field has been abandoned, the first floral species to colonize it are rapid growing with a short cycle and do not require pollinator insects for sexual reproduction. They develop very small flowers with little nectar and they are virtually never visited by bees. This underscores the importance of abundant and diverse floral resources and of floral quality in terms of pollinator food needs.

Migrating pollinators require a landscape providing continuous corridors of nectar supplies to satisfy their energy needs during migration. In some agricultural or other operations, habitat damage or destruction may cause disruption or breaks within these traditional corridors. The pollinators are then obliged to change their migratory path or else suspend migration. A good example of this is the lesser long-nosed bat (Leptonycteris curasoae), which used to be the main pollinator of a number of cactus species in the southwestern United States, but its numbers have substantially dwindled partly due to disruptions in the nectar corridors used by the species. The monarch butterfly and different hummingbird species are other types of migrating pollinators which may well see their migration corridors disappear or else suffer fragmentation following the disappearance of herbaceous spaces containing appropriate food resources.

The floral composition of a site therefore determines its suitability as a habitat for certain more specialized pollinators. According to Rasmont et al. (2006), the loss of taxons of long-tongued bees in Belgium and France could be the result of the disappearance of certain floral resources, especially of plants with deep corollas (Fabaceae, Lamiaceae, Scrophulariaceae, Borraginaceae). The loss of the latter also provides an explication for the decline of at least three bumble bee species that used to be common in England (Goulson et al., 2005).

Floral Composition

Studies of floral composition may prove important in gaining insight into changes in the composition of pollinating species in a region. In Canada, Gritix and Packer (2006) examined the changes in a community of wild bees, repeating a bee biodiversity study conducted in Ontario a few years earlier. They compared the findings of an inventory of bee species that was carried out in 1968 and 1969 with those obtained during a new sampling of bee fauna in 2002 and 2003. The same habitats and sampling techniques were employed. The richness of bee species, the diversity and equitability of their distribution were significantly greater in the more recent census. A total of 150 bee species were found in 2002 and 2003 while only 105 had been counted in 1968 and 1969. However, only 7.5 % of the communities were found to be similar in make-up. Changes in the bee community, especially the higher proportion of forest tree pollen specialists, could be attributed to habitat changes resulting from plant successions over the 34 years separating the two studies. A breakdown in habitat quality may occur even if floral diversity is unchanged or greater in range since the ecological succession of vegetation can result in the natural replacement of plants in a habitat.
Risks of Extinction

Following habitat loss, it becomes more difficult for pollinators to maintain a metapopulation structure, i.e., involving an assemblage of populations separated in space but interconnected through a flux of individuals. The loss or reduced access to corridors with floral resources may hinder or prevent contact with source populations providing possibilities of recolonization and genetic renewal. Bumble bees seem to be especially susceptible to these effects and over half the number of bumble bee species in Great Britain are thought to have disappeared or could face extinction in the coming decades (Goulson, 2003a). The apparent loss of two species in the United States over the past few years suggests that North American bumble bees are likewise threatened due to the combined effects of a number of anthropogenic factors resulting in the degradation, conversion or loss of habitat. Consideration should also be given to other factors, such as pesticide use, pollution and pathogen transfer from commercial bumble bee breeding operations (Thorp, 2003, 2005).

Hedgerows, road sides, embankments and other areas unsuitable for cultivation provide a nesting habitat for some bees (Kells et al., 2001). Since 1960, a spectacular decline in wild bees in Germany has been associated with the often ill-considered suppression of these habitats. (Westrich, 1989). Conversely, in some agricultural landscapes in Poland, maintenance of these habitats has been associated with the persistence of pollinating insect fauna of great richness (Banaszak, 1995, 1997).

4.2.3 Urbanization

Negative Effects

Urbanization can cause habitat fragmentation and loss for a number of pollinators with subsequent undesirable and harmful effects. Transforming the rural landscape (levelling off slopes, pulling out hedges and removing groves, filling ditches and pools of water, asphalting roads, resizing streams, etc.) in favour of urbanization, major infrastructure operations (roads, highways) and the development of industrial zones also cause serious disruptions with deleterious ecological effects resulting in the disappearance of a number of floral species-specific biotopes and plant-pollinator imbalance. Road sides and highway embankments are often refuges where rich, varied plant life can develop. Unfortunately, the plants in these sites are often contaminated with lead residues. It has been shown that insects visiting road sides are highly contaminated with lead and that they may be affected by road traffic (McKenna et al., 2001).

In addition, pollinator populations may be reduced by exposure to city lights and other sources of artificial light (Frick and Tallamy, 1996) which interfere with the navigational ability of a number of species. Moths are important pollinators for night flowering plants, and disorientation of the moths could reduce or eliminate the reproductive capabilities of the plants. This would have long-term harmful ecological effects.

Positive Effects

Some researchers, however, have reported positive effects from urban and periurban expansion for some bee species with access to floral resources and nesting sites (Cane et al., 2006; Frankie et al., 2005). Thus, anthropogenic habitats, e.g., urban developments, could support a greater abundance and richness of species than was initially believed. Godefroid and Koedam (2007) reported that the city of Brussels in Belgium was home to half of the plants identified in the country. During an inventory of bee abundance and diversity in an urban setting, Matteson et al. (2008) recorded a total of 54 species in New York City. Säure (1996) counted 262 species in the city of Berlin (Germany). He considered that the large diversity of bees in Berlin was probably due to the variety of landscapes providing a wide range of suitable nesting habitats.

An inventory of bee abundance and diversity in the urban areas of Vancouver in British Columbia showed that urban areas could support several bee families (Tommasi et al. 2004). The habitats examined included botanical
gardens, wild urban areas and flower gardens. A total of 56 species were inventoried. The authors concluded that urban zones were potentially important reservoirs of pollinators, particularly if flowering and a range of habitats were maintained and reinforced through sustainable urban planning.

### 4.2.4 Habitat Loss Associated with Recreational Activities

Outdoor recreational activities may prove harmful to pollinating insects. Some species of flowers suffer if overpicked. Trampling of the soil can break the floristic balance or have a destructive effect on the entrance to burrows of insect pollinators (colletids, andrenids, halictids, etc.).

### 4.3 Exotic Species

#### 4.3.1 Honey Bee

The honey bee, also known as the domestic bee, is a pollinator that originally came from Asia, Africa and Europe. Over 20 geographical races of the bee are known. The main races occurring in Western Europe are the European dark bee (*Apis mellifera mellifera*), the Carniolan bee (*A. m. carnica*), the Italian bee (*A. m. ligustica*) and the Caucasian honey bee (*A. m. caucasica*). For at least three centuries, these races of honey bees, like other pollinating insects, have been imported from one part of the globe to another (Sheppard, 1989).

Because of intensive breeding by humans, the honey bee has become the dominant introduced pollinator in a number of habitats. The history of the spread of this bee throughout the world constitutes an example of an invasive exotic species. It will be recalled that an invasive exotic species is by definition a species that is alien to the ecosystem in which it is found but which is capable of reproducing in the ecosystem and of competing with wild species for various resources.

The literature dealing with the economic consequences of pollination, however, considers the honey bee essentially in terms of the positive effects its introduction had on modern beekeeping. Virtually nothing is known about the role it played in reducing the diversity and upsetting the stability of ecological systems.

In Canada, very little information is available on the impact of introduced bees and the significance of their role in dispersing the pollen of wild plants. In some countries, e.g., Australia, it has been shown that the honey bee has a negative impact on wild bees (Paton 1993; Goulson 2003b; Paini, 2004; Paini and Roberts, 2005).

#### Competitive Effects

Honey bees are highly polylectic which means that they collect pollen from a large number of different plant species and families. Because a handful of colonies can collect hundreds of kilograms of nectar and dozens of kilograms of pollen per year (Buchmann, 1996), they can reduce the amount of nectar and pollen available in different natural plant communities (Paton, 1996). The behaviour of native species that use the same flowers as the honey bee, e.g., wild bees, hummingbirds and ants, may therefore be altered.

The study by Schaffner et al. (1983) has often been cited to explain the phenomenon. The study, conducted in the state of Arizona in the United States, focussed on agave pollinators, which were inventoried on the flowers before, during and after the introduction of honey bees. A change was observed in the number of native insect foragers (bumble bees and ants). A more recent experimental study was recently carried out in California by Thomson (2004) who examined the competitive effects of *Apis mellifera* on the feeding behaviour and reproductive success of the eusocial bumble bee *Bombus occidentalis*. When in competition with the honey bee for nectar, the bumble bee produced fewer larvae in its colonies.

More recently, Thomson (2006) reported that in the presence of scarce resources, there could be up to an 80% overlap in honey bee and bumble bee activity, but the overlap seemed to affect the bumble bees adversely for only one month out of the seven months of the study. From observations collected in a transect, the same author...
recorded a significant decline in numbers of foraging bumble bees as they approached colonies of introduced honey bees. It could be that competition between the honey bee and some bumble bees is due to the fact that the tongue (proboscis) of some bumble bee species is as long as that of *A. mellifera*, and proboscis length determines to some extent the range of plants that can be used for collecting nectar (Harder, 1982, 1983, 1986).

Subsequent to a literature review on the subject, Butz Huryn (1997) concluded that the presence of honey bees altered not only the abundance of pollinating fauna on flowers but also its foraging behaviour. However, she noted that there had not been any studies indicating that the honey bee had a harmful effect on the abundance of flora and associated pollinating fauna. While the short-term effects of interspecific competition between the honey bee and native pollinating fauna seem to be fairly well documented for some areas, little is known about the long-term impacts on native populations.

When additional pollinators are introduced into an area, there may be greater competition for floral resources, particularly if a plant community is close to its limit for supporting pollinators. In the light of these findings, there is some concern regarding the competitive effects of honey bees or other commercial pollinators in regions where these insects do not yet exist, but where there is some question of introducing them, e.g., in Australia, where commercial bumble bees have not yet been used.

Findings from studies conducted in Europe where honey bees are native to the area and in other parts of the world where the bees have been introduced suggest that several factors interact to determine the extent of the impact on the flora and fauna. These factors include the degree of habitat fragmentation and disruption, the degree to which floral resources overlap in time and space, and the presence of other introduced species capable of facilitating the presence of honey bees (Kato *et al.*, 1999; Schwarz and Hogendoorn, 1999; Barthell *et al.*, 2001; Roubik and Wolda, 2001).

There have also been cases of swarms of honey bees leaving their hives to form colonies in nature. When this occurs, the honey bee often finds a hollow tree to rebuild its colony. Soderquist (1999) reported that honey bees and wild fauna overlapped in their use of hollow trees. The latter are also adopted by a number of microchiropteran bats and small arboreal mammals (Lumsden and Bennet, 2000).

The overall conclusion would be that the reproductive success of native species is in all likelihood affected, through competition, by introduced pollinators, but the phenomenon is not easy to detect.

Is the incidence of honey bees sufficiently great for the current decline in colonies to prove beneficial in restoring an ecosystemic balance in certain landscapes? And if honey bee colonies should increase again in North America following, for instance, the development of disease-resistant strains, might there not be a subtle, involuntary but significant effect on wild bee populations relying on the same floral resources? And if visitation and subsequent pollination rates among native plants were to be altered, might there not also be consequences for these pollinating populations? All of these questions remain unanswered, but the impact of the honey bee on the natural balance of an area can prove of real ecological concern.

Abe *et al.* (2008) examined the question of the honey bee’s competitive effect in a study conducted in the Ogasawara islands in the Pacific 1 000 km south of Japan. Once they had rejected hypotheses involving honey bee competition, reduction in forestland and the impacts of agricultural pesticides, they found that the decline in native fauna was due to the presence of an invasive exotic species, the anole, which preys on pollinating insects. The authors concluded that if the network of native pollinators on the Ogasawara islands was to be preserved, attention should first be paid to the eradication of the anole before considering eradication of the honey bee.

Caution is therefore required before flatly stating that the honey bee, as a competitor, is harmful to the survival of an area's native pollinators. Morphological traits such as tongue length and specific behavioural reactions of different pollinators to environmental conditions may minimize the competitive effects among species.
Furthermore, commercial pollinators such as the honey bee and the bumble bee are often introduced in an agricultural setting at the time of flowering of the target crop. During this period, there are abundant, albeit monospecific, floral resources. Competition for food resources could consequently be reduced.

**Supplementary Effects**

On the other hand, it has been shown by other studies that the presence of the honey bee could even have a beneficial supplementary effect on pollination, particularly in agroecosystems. Chagnon *et al.* (1990) observed that honey bees and other native strawberry pollinators exerted a supplementary effect when it came to foraging activities. Bees differing in size display a distinct foraging behaviour in their visits to flowers. Large bees forage in the anthodium of the flower whereas small bees adopt a circular movement around the periphery. Different parts of the stigma-bearing anthodium are therefore touched. Flowers that have been visited by both types of pollinators produce fruit with a greater number of fertilized achenes and consequently larger fruit.

Similar findings were recorded by Greenleaf and Kremen (2006) in sunflower crops. They observed that the behavioural interactions between wild and honey bees resulted in up to a five-fold increase in the efficiency of bee-mediated pollination of hybrid sunflowers. These indirect contributions caused by interspecific interactions between wild and honey bees were over five times as great as the contribution made by wild bees alone.

These findings emphasize the economic importance of interspecific interactions in the production of some crops. The protection of native populations is therefore vital even if honey or bumble bees are introduced into a crop since the action of the wild bees can supplement that of the introduced pollinators.

4.3.2 Other Introduced Pollinators

In addition to the honey bee and other species of the genus *Bombus* that have been introduced into most continents, other introduced species have now become established in Canada and the United States.

To-date there are 25 exotic bee species currently established in Canada and the United States. Twenty of these were accidentally introduced, while five were intentionally brought into North America. Fifteen of these species are polylectic, that is to say, they are capable of foraging several plant species and families and could consequently compete with native species.

Our understanding of the interactions that may become established between introduced and native bee species is limited, however, because of their subtle lifestyle (hibernation, behaviour, reproduction), which makes them difficult to study. It may be supposed, nonetheless, that introduced pollinators cause damage essentially by competing with native species for floral resources and nesting sites when they escape from commercial shelters (Barthell and Thorp, 1995; Barthell *et al*., 1998; Thorp *et al*., 2000). Introducing alien pollinators may also be inadvertently responsible for introducing natural enemies, e.g. pathogenic agents, into native pollinator populations (Butz Huryn, 1997; Dupont *et al*., 2004; Kato *et al*., 1999; Roubik, 1978).

4.3.3 Pathogens

Propagation of pathogenic agents from commercial breeding operations, known as spillover, may occur when heavily infected commercial pollinators interact with the host plants of wild populations. The phenomenon has been observed in some wild bumble bee species (*Bombus* spp.). Bumble bees from commercial operations used for pollination in greenhouses often carry greater amounts of various pathogenic agents than wild bumble bees. Propagation of pathogenic agents within wild bee populations occurs when commercial bees escape from greenhouses and interact with their wild counterparts near the flowers. A study conducted in southern Ontario by Colla *et al.* (2006) examined the presence of four pathogenic agents within wild bumble bee populations near and far from greenhouses in which introduced bumble bees were employed. It was found that bumble bees collected
near the commercial greenhouses were more often infected with pathogens likely to have been transmitted by flowers (*Crithidia bombi* et *Nosema bombi*) than bees collected in more distant sites.

In a more recent study (Otterstatter and Thomson, 2008), using a model based on laboratory experiments and scientific documents, it was possible to quantify the propagation of *Crithidia bombi*, a highly harmful pathogen commonly found in commercial Bombus breeding operations. The model predicted that during the three months following transmission of the pathogen from commercial mating hives, 20 % of the wild bees present within a radius of 2 km from the greenhouse would be infected. A wave of infection involving up to 35 % of the wild bees could spread at a rate of 2 km per week. The authors concluded that it was likely that the escape of pathogens from bumble bee breeding operations into wild populations contributed to the decline recorded among wild bumble bees in North America.

The following explains the mode of operation of the best known wild bee pathogens.

*Nosema bombi* is a protozoan that causes nosema disease in bumble bees. Once it infects the organism, spores develop in the tissues of the midgut and in the Malpighian tubules, then are found in the intestine proper. The disease may occur in young queens even before they leave their maternal nest. Some queens die even before hibernation, whereas others, also infested, may survive for several weeks after they have emerged from hibernation in the spring. Symptoms include an inability to fly, reduced activity and death.

*Crithidia bombi* is a flagellate protozoan (Trypanosoma) that may be found in all adults in a bumble bee colony. The parasite also develops in the intestine. *Mattesia bombi*, a gregarine parasite of the fatty tissues of bumble bees, may also occur in the mid- and hind-gut. Another gregarine, *Gregarina quenui*, has been reported in the wild bee, *Halictus scabiosae.* (Pouvreau, 2004).

In addition, a pathogenic fungus of the family Ascomycetes has virtually destroyed the production capacity of the alfalfa leafcutting bee (*Megachile rotunda*) in the United States.

Over and above parasites attacking individuals directly, there are some pathogenic organisms that cause deterioration of the food stored in the nests, thereby resulting in death from lack of food. This is the case of parasitoid flies of the family Phoridae, mites and infections due to a parasitic fungus (Pouvreau, 2004).

### 4.3.4 Effects of Exotic Plants and Pollinators on Native Pollinator-Plant Interactions

While exotic bees may suppress native bees through competition, they may also affect the workings of an ecosystem through their preference for certain floral species. When visiting flowers, many exotic species mark a preference for adventive plants that colonized disrupted sites (Goulson, 2003a; Roubik, 1983; Thorp, 1996). As a result, it is less likely that they will provide pollination services for the area’s native plants.

It has been shown that interactions can occur between plants and non-native pollinators within a community. These interactions are potentially capable of lessening the natural ecosystem’s ability to operate. The distribution of a plant or pollinator could become so fragmented as a result of its decline within its natural population that the dynamics of the metapopulation is disrupted. Genetic erosion could then lead to an even greater decline, which in turn could result in the local extinction of the species, creating gaps to be filled by exotic species. When an ecological gap is filled by an exotic plant, the impacts on native species increase, especially if the exotic and native species vie for the same pollinators (Richardson et al., 2000; Bjerknes et al., 2007). Pollinators can therefore exert an influence on the establishment and propagation of exotic species and contribute to their potential to become invasive (Hanley and Goulson, 2003). Furthermore, the intraspecific distribution of pollen from native plant is reduced in the presence of exotic plants.
The introduction of exotic pollinators can potentially increase pollination of exotic competing plants in an area and consequently enhance their propagation by seed (Barthell *et al.*, 2001; Goulson and de Derwent, 2004). Some native plants could also suffer from disruption of the pollination process following deposition of heterospecific pollen on their stigmas by exotic pollinating insects (Brown and Mitchell, 2004).

There are a good many examples of the accidental or deliberate introduction of plant species that subsequently became invasive weeds. In North America, exotic plants introduced accidentally or for purposes of cultivation, notably forage crops for cattle, have been known to spread quickly (D’Antonio and Vitousek, 1992; Larson *et al.*, 2001; Zavaleta *et al.*, 2001). Exotic grasses introduced in the southwestern United States and northern Mexico, i.e., compact brome (*Bromus madritensis*) and buffelgrass (*Cenchrus ciliaris*), rapidly choked out the other flowering plants. They are also highly combustible and run the risk of causing intense forest fires. The manner in which they occupy the land, however, is favourable to the creation of nesting sites for ground-nesting solitary bees (Buchmann, 1996). These advantages could be offset by the increased risk of forest fires and reduction in floral species available for foraging (Asner *et al.*, 2004).

It has also been demonstrated that the introduction of exotic pollinators can occasionally prove beneficial to plants. Dick (2001) found that the Africanized bee, which is generally considered a dangerous exotic species, could prove to be an important pollinating agent for ensuring the genetic diversity of certain species in fragmented or degraded tropical forests. In this instance, the Africanized bee would ensure the transport of pollen over vast distances, thereby providing a continual genetic flow.

### 4.3.5. Effects of Invasive Plants on Pollinators

Invasive plant species affect not only pollinators but also plant pollination by disrupting the structure and function of ecosystems. Invasive plants can alter the composition of the floral community in natural habitats, causing a loss of available resources (food, shelter, etc.) for all fauna species. Many pollinators co-evolved with the plants they visit with the result that their physiology is adapted for the efficient use of the nectar and pollen provided by the floral resources for which they are specialized.

Native pollinators are often adapted to and specialized for certain plant species. Exotic plants may have floral structures rendering nectar resources physically inaccessible to native pollinator species. In this case, the pollinator adapts by means of various strategies and robs the plant by seeking a reward but without the subsequent transfer of pollen grains. Pollinators that are poorly adapted to the flowers do not return any advantage to the ecosystem.

Furthermore, in their search for food, pollinators transport pollen on their bodies. Plant pathogens may be transmitted from one plant to another by means of this vector. Hybrids may also be involuntarily created via the genetic mix that occurs.

### 4.3.6 Africanized Bees

Propagation of the Africanized honey bee from South America to North America is one of the most spectacular examples of biological invasion (Roubik, 1989; Schneider *et al.*, 2004). The Africanized honey bee is a hybrid of the European honey bee (*A. mellifera*) and the African honey bee (*A. mellifera scutellata*). The latter was intentionally introduced into Brazil in the early 1950s, while the European races were introduced at the time of colonization in the 17th century (Winston, 1993).

**Impacts on Native Pollinators**

The Africanized bee displays a considerable capacity to dislodge native pollinators. The experimental introduction of Africanized bees into a community of neotropical wild bees resulted in reduced numbers of native bees and their decreased use of floral resources (Roubik, 1978, 1980; Roubik and Wolda, 2001). Roubik (1978, 1980)
demonstrated the impact of introduced Africanized bees on native wild bee populations in Central America. These studies emphasize the importance of considering an exotic species’ potential to affect native populations before introducing it into an area.

Factors Facilitating Propagation of the Africanized Honey Bee

Several factors have facilitated the propagation and establishment of the Africanized honey bee. Its colonies develop more rapidly than those of European races, and certain genetic incompatibilities of hybrid strains favour the loss of European traits. Africanized drones also have also an advantage when it comes to mating since Africanized bees can establish their nests in a greater variety of sites and are better able to appropriate other nests than European bees (Schneider et al., 2004). The invasion of the Africanized bee into the United States began several years after the abrupt decline in honey bee populations. The Africanized bees therefore cannot be considered one of the causes of dwindling domestic populations.

According to some researchers, the Africanized bee has not yet made its way into Canada because the border between the United States and Canada has been closed to bee transport ever since the tracheal mite was detected in the United States. If the border were to open again to bee transport, Africanized bees might well find their way into Canada. It is more than likely, however, that the Africanized bee would not be able to overwinter in Canada because of prevailing weather conditions, at least not with the genetic make-up it currently displays in the United States. A watering-down of its genetic make-up might allow its survival, but its aggressive characteristics as currently known, would probably be weakened.

Disadvantages of the Africanized Bee

The Africanized bee is less desirable than European bees for pollination of plant crops. Compared to European bees, Africanized honey bees forage over relatively short distances (Danka et al., 1993), and are consequently not suitable for certain plants grown on a large scale. They are also more likely to abandon their colonies completely when food is scarce (Danka et al., 1987). Furthermore, Africanized bees may cause a shortage of nectar in areas where they are used in high densities for pollination of orchards or fields.

4.4 Climate Change and Pollution

It has been predicted that climate change will have a decided effect on certain aspects of pollinator behaviour and ecology, influencing thereby ecological relationships with other organisms. Furthermore, different groups of pollinators could react differently to changes in temperature.

According to some specialists, behavioural changes linked to the species’ physiology have already been observed in some pollinators. Over the past two decades, British butterflies have made their first appearance of the season earlier and earlier and the peak period has also been brought forward. Similar changes have also been observed in California’s butterflies (Forister and Shapiro, 2003). The average period for the first flight of 16 species studied tended to occur earlier. An average difference of 24 days for four of them represented a statistically significant trend. On the other hand, seven species tended to appear later in the season. The average flight dates for some Spanish butterflies (eight of the 19 species studied between 1988 and 2002) were also statistically earlier (Stefanescu et al., 2003).

Different species of pollinators are consequently going to react differently to climate change, which will affect the diversity and abundance of their populations in varying degrees. In terms of physiology, some factors like the photoperiod and temperature exert a control on endocrine activity and can modify fertility, the mode and rate of reproduction as well as the rate of development. These physiological reactions may differ from one species to the next. The underlying causes for changes within a pollinator community are therefore highly variable.
Weather prediction models point to changes in temperature and precipitation patterns as well as in other areas. It is anticipated that there will be increases in levels of carbon dioxide (CO₂) and tropospheric ozone in the atmosphere and a decrease in stratospheric ozone, which would lead to an increase in ultraviolet (UV) light. We shall first examine how these abiotic changes may alter pollinator behaviour. We shall then examine the relationship between pollinators and their biotic environment with respect to changes that are likely to occur in the ecosystemic balance.

4.4.1 Abiotic Factors

Weather conditions play a major role in controlling pollinator populations. Several studies have shown that pollinator phenology (development) may be influenced by worldwide changes in temperature. Any modification of the abiotic conditions of an area can have a disruptive effect on the manner in which bees function in an ecosystem.

Migratory pollinators, such as hummingbirds and monarch butterflies, are particularly at risk of disruption since predicted climate change will not be uniform in altitudinal gradients (gradients of height in mountains) and latitudinal gradients (north-south gradients). Ambient weather conditions (temperature, precipitation, etc.) have a direct effect on pollinator physiology and behavioural reactions, such as reproduction and flight. The pollinators will therefore react differently to changes in climatic conditions, depending on each species’ ability to adapt.

Temperature

The action of the outdoor temperature on honey bee flights has been examined in a number of studies. According to Heinrich (1979), temperatures inducing the first flights should reach a minimum threshold of 14° to 15°C. These values may vary from 12° to 14°C in April and from 16° to 18°C in May (Pouvreau, 2004). The influence of temperature may differ with the race. The same applies to luminosity, wind and rain (Winston, 1993). Honey bees considerably reduce their activity or even cease foraging when the wind velocity exceeds 30 km/hour. In areas that are often wind-swept, the bees fly close to the ground to reduce the effects.

Bumble bees, in general, satisfactorily resist the various difficult climatic conditions encountered in Canada’s latitudes (Heinrich, 1979; Plowright and Laverty, 1987; Free, 1993; Stubbs and Drummond, 2001; Desjardins and de Oliveira, 2006). They are endothermic (Willmer, 1983) and are endowed with a thermoregulatory system that allows them to forage in colder temperatures than the honey bee, even in the rain. Temperatures of under 10°C, however, generally bring a halt to or definitely slow down their foraging activities. Foraging bees also undertake fewer flights in the middle of the day when temperatures exceed 35°C. Optimum foraging temperatures vary somewhat with the species. Bumble bees are less likely than other insects to be inhibited in their flights by rain.

In the case of wild bees, a drop in temperature particularly at the beginning of the season when the bees are making their nests can prove especially detrimental. For queen bumble bees and solitary bees abrupt changes in temperature can be fatal. Premature emergence from hibernation can occur when frosty weather gives way to abnormally high temperatures at the end of winter. Microclimatic factors, especially temperatures at ground level, influence solitary bee activity. The degree of a nest’s exposure to sunlight may cause variations in temperature influencing daytime and seasonal activity. In France, it was observed that Sand bees (Andrena vaga) with nests on southeastern slopes are active in the morning and cease foraging in the afternoon, before colonies established on western slopes. Since bumble bees and most solitary bee species nest on the ground, abundant rainfall can cause flooding of the nests. This could disrupt their life cycle which occurs partly or completely in this environment (Pouvreau, 2004).

In studies conducted in Alberta, the alfalfa leafcutting bee was found to need a minimum temperature threshold of between 16° and 17°C to initiate foraging flights. Once this threshold was reached, the degree of radiation from the sun was a greater determinant in how activities proceeded. Activities ceased at a minimum threshold of 200 W/m² (Lerer et al., 1982). While relative humidity had a significant inverse relationship with pollination, the relationship was minimal when the influence of the temperature was incorporated into the equation (Bailey et al., 1982).
alfalfa leafcutting bee is often introduced for crop pollination, but is more sensitive to heat and light conditions than the honey and bumble bee, the two other pollinators used commercially.

**Luminosity**

Naturally, climate change will not influence the photoperiod. The periods of light and dark will not be affected. Having said that, an increase or decrease in the intensity and duration of the cloud mass may alter the intensity of the light and consequently affect the behaviour of insects sensitive to the sun’s rays. This is true of the alfalfa leafcutting bee. Several other pollinators such as butterflies and some flies (syrphids) are also less active in cloudy weather. Primitive bees (Colletidae, Andrenidae and Halictidae) generally prefer an open sky, and when it is cloudy, they become active later in the day. A loss of light intensity also decreases bumble bee activity, but clouds do not limit their foraging activity. In the case of the honey bee, activity is normal as long as the light intensity exceeds 500 lux. Below that intensity, activity decreases and halts at 10 lux. When the sky becomes overcast with the threat of rain or a storm, the foragers return *en masse* to their hive.

**Wind**

Wind generally influences insect flight but if it is not too strong or too cold and the sun is shining, most solitary bees will continue to fly. A strong wind will also make the flowers sway on the plant rendering access difficult for the pollinators. A wind force greater than six on the Beaufort scale interferes with bumble bee flight. Some bumble bee species (*B. hortorum* and *B. pascuorum*) are less sensitive to wind action and visit flowers closest to the ground or else growing on rigid stems. The direction in which bumble bees forage is also influenced by the aerodynamics of upwind flight or the dispersal of floral scents. In this instance, the wind makes it easier for the insects to detect and visit the flowers.

**4.4.2 Atmospheric Pollution (CO₂ and UV Radiation)**

In addition to climate change, increases in greenhouse gases such as CO₂ and in UV radiation resulting from loss of the ozone layer in the atmosphere may have impacts on plant communities and consequently on the pollinators that visit them.

Several botanical taxons were studied to determine the potential effects on floral traits and nectar production that might arise from an increase in CO₂ levels and UV radiation. According to a review by Davis (2003), an increase in atmospheric CO₂ could alter nectar production in cultivated as well as wild plants such as *Betonica officinalis*, *Centaurea jacea* (Rusterholz and Erhardt, 1998), *Ipomoea purpurea* (Rathcke, 1992), *Scabiosa columbaria* (Rusterholz and Erhardt, 1998) and *Tropaeolum majus* (Lake and Hughes, 1999). As a rule, it was found that high CO₂ concentrations could alter the volume of nectar produced and the plants’ secretion rate. Changes were at times negative, but in other cases, positive. The sugar concentration and composition, however, were apparently not affected (Lake and Hughes, 1999).

Lower levels of stratospheric ozone in the atmosphere may cause an elevation in ultraviolet B (UVB) radiation, delay the period and duration of flowering in some plants, diminish flower production and affect the reproductive success of their pollinators. Such changes were recorded by Sampson and Cane (1999) in two annual plants. Stephanou *et al.* (2000), on the other hand, found the opposite in another species as a result of increased UVB radiation. They noted that this type of radiation could increase nectary size, thereby leading to an observable increase in pollination. Collins *et al.* (1997), for their part, did not observe any differences in the number of honey bees foraging in Brassicaceae exposed to UVB radiation compared to numbers recorded in radiation-protected plants.
An increase in CO₂ levels may exert a range of effects on plant communities visited by pollinators (Bradley and Pregitzer, 2007). The same applies to UVB radiation. It is therefore difficult to predict the long-term effects of these factors on pollinators.

The presence of atmospheric pollutants (sulfur dioxide, nitrogen dioxide, etc.) usually causes floral decline and indirectly affects pollinator insects. At present, we do not know if exposure to sublethal doses of atmospheric pollutants influences the fertility of female pollinators and larval development.

Roadsides and highway embankments are often sites where an abundance of a variety of plants can develop. Unfortunately lead residues have made their way into plant tissues. It has been shown that insects visiting roadsides are highly contaminated with lead.

Bees and plants tend to bioaccumulate heavy metals. In British Columbia, bees are tested for arsenic. They serve as bioindicators of atmospheric pollution from smelters in the neighbouring city in Washington State. Analysis of pollen loads harvested by honey and other bees can even confirm the presence of a known concentration of heavy metals in the soil (Sawidis, 1997).

Researchers from the University of Virginia reported that air pollution from cars and power plants could inhibit the ability of some bees and butterflies to detect the scent emanating from flowers (Fuentes, 2008). Pollutants like ozone, hydroxyl and nitrate radicals rapidly bond with the volatile molecules produced by flower scent. The result is a vicious circle in which pollinators travel ever-greater distances to find nectar in flowers and the flowers close by do not benefit from pollination to reproduce and diversify.

### 4.4.3 Climate Change and the Plant World

At every stage of their biological cycle, pollinators are affected by other organisms in the animal kingdom with which they maintain relationships of competition, predation, parasitism and commensalism. As a consequence, any changes in the way of life of these organisms resulting from climate change could also affect the survival of pollinators in an area. However, in terms of evolution and ecology, it is with the plant world that pollinators maintain the closest relationship.

Climate change can alter or disrupt the relationships between plants and their pollinators both locally and regionally. These changes may be the result of changes in the floral biology of a plant or else in its phenology and geographical distribution.

**Floral Biology**

Rainfall, soil moisture and sunlight are important factors in the secretion of nectar (Hocking, 1953). Changes in the abundance and concentration of nectar in a flower could alter pollinator feeding behaviour. The visitation of flowers could be modified and this in turn could influence the rate of pollen transport and subsequent fruit set. Furthermore, the pollen transferred from one flower to another or from one plant to another could be increased or decreased. There could also be changes in the distances covered in the transport of pollen. These factors could have significant consequences for plant reproductive systems and the genetic mix. Other types of consequences resulting from changes in the nectar secretion rate of flowers have also been reported. For instance, there could be impacts on the recruitment dance of bees which is dictated by the attractiveness of a floral species in terms of its reward in nectar.

**Flowering Phenology**

The interactions between plants and their pollinators may be disrupted if changes in the flowering sequence and pollinator activity are not synchronized. Plants could flower before or after the pollinators’ period of seasonal activity.
Throughout the world major changes have been observed in the time of flowering of several plants. Using herbarium specimens from the Arnold Arboretum in Boston, Primack et al. (2004) compared the flowering dates of different species between 1885 and 2002. They found that plants collected between 1980 and 2002 flowered eight days earlier than those collected between 1900 and 1920. Flowering of agricultural species is also influenced by the warming of the planet. A 40-year study on white clover (Trifolium repens) revealed that since 1978, flowering has progressed earlier and earlier, by as much as 7.5 days per decade (Williams and Abberton, 2004). Further north, in Washington State, Abu-Asab et al. (2001) reported that flowering on average was 4.5 days earlier in 89 species of plants, whereas it was later in 11 other species.

Changes in the flowering dates of some plants are the source of considerable concern since evidence indicates that the pollinators of these plants may not emerge and behave accordingly. A long-term study of the biological cycles of Mediterranean plants and animals indicated that differential variations could be observed in the phenological development of the plants (leaf fall, flowering and fruit set). These variations were not synchronized with the changes observed in the emergence dates of butterflies and the arrival of migratory birds (Penuelas et al., 2002). The authors stated that these changes could alter ecosystem structure and mode of operation.

4.4.4 Migrators

Migratory pollinators rely on the different habitats over which they travel to carry out their reproductive cycle. The ruby-throated hummingbird, for instance, spends the winter in Mexico and returns to the United States or Canada to reproduce. It depends on flowering plant corridors in spring as well as in the fall. If the migration calendar no longer coincides with the flowering period, the plants could eventually lose some of their pollinators, and the latter could be compelled to undertake migration under conditions requiring great expenditure of energy with little opportunity for renewing their metabolic fuel. Some scientists have advanced the view that if fragmentation continues at its current rate, a number of migratory corridors will soon no longer be functional (Withgott, 1999).

4.4.5 Plant-Pollinator Interactions

A combination of different environmental changes could prove highly prejudicial to a large number of plant-pollinator interactions. As mentioned above, climate change could at more or less long term affect the survival of pollinators that are essential to certain plants, with a subsequent decrease in fruit set. Changes in the abundance and distribution of these flowers could in turn influence the abundance and distribution of pollinators. We could be witnessing a decline in certain historical mutualistic relationships or, on the other hand, the creation of others.

In their paper, Mermott et al. (2004) reported the findings of an ecological simulation of the impacts of climate change on the balance of plant-pollinator interactions in a given environment. They concluded that in the absence of compensatory mechanisms, climate change-induced alterations in phenology were potentially able to disrupt the temporal overlap between the presence of pollinators and the availability of their floral food resources. The simulation predicted that a substantial portion of the pollinators, particularly the most highly specialized feeders, would be vulnerable to these changes. The few studies available on the life histories of pollinating insects provided with a limited food supply in adulthood indicated that fertility and/or longevity were reduced (Boggs and Ross, 1993). This ultimately decreases the density of the population or its rate of growth (Bijlsma et al., 1994) and means a greater risk of extinction particularly at the local level. Even pollinators suffering minimal losses in terms of the plants they rely on for food, could undergo a population decline since they would have a smaller number of plant species to provide nourishment. The authors explained that while the plants would not “starve” if they lost some pollinators, there would be fewer new individuals or perhaps none at all from sexual reproduction. This would mean a decline in plant populations which would be accelerated depending on individual longevity, the capacity to propagate by cloning and to self-fertilize and the viability and fertility of the products of self-fertilization. (Bijlsma et al., 1994).
The authors acknowledged that the loss of a more specialized pollinator was unlikely to cause the immediate extinction of the plants it visited due to the complex nature of the networks of plant-pollinator interactions. Thus, plants are protected, in part at least, from the loss of more specialist-type pollinators by the presence of other, more generalist species (Memmott et al., 2004). Nevertheless, while the decline in specialist networks does not seem to affect pollination, and adaptation to a certain level of variability in the environment does occur, this is no guarantee against a possible decline in more generalist-type species and breakdown in the ability of pollination services to function. (Memmott et al., 2004; Fontaine et al., 2006).

4.4.6 Altitude

Changes in environmental variables (temperature, humidity, rainfall, wind) may also alter the phenological development of plants and their pollinators as well as their distribution along altitudinal gradients (mountain setting) and latitudinal gradients (north-south). Such changes may alter the composition of both types of communities and disrupt their mutualistic relationships, thereby causing local extinctions. The latitude and altitude at which certain plants and their pollinators occur have changed over the last 30 years, probably in response to climate change (Walther, 2004). Some British and North American butterflies, for instance, have extended their range further north (Crozier, 2003; Hill et al., 1999; Parmesan et al., 1999), whereas other species in Montana (Lesica and McCune, 2004), Spain (Wilson et al., 2007) and Norway (Klanderud and Birks, 2003) are now observed at lower altitudes and latitudes.

4.5 Causes of Hummingbird population Declines

When discussing pollinators, it is important to acknowledge the invaluable contribution of hummingbirds, which are essential for the pollination of several floral species. In fact, hummingbirds are the only pollinators for some plants with specialized flowers. There are 330 known hummingbird species in the world but these colourful birds are found exclusively in the Americas.

In western Canada, the rufous hummingbird (Selasphorus rufus) is found in several regions of British Columbia. During their annual migration, a certain number of birds overwinter in Mexico, whereas others prefer the Gulf coast of the United States. A decline in numbers has been recorded in several areas of the species’ range in North America. In Quebec and all of eastern Canada, only one species can be found: the ruby-throated hummingbird (Archilochus colubris), which is at the northern limit of its geographic distribution. There is a flagrant absence of information on the species in Quebec. In 2006, a team of volunteers began gathering information for a better understanding of how these birds used their territory. http://www.projetcolibris.org/

As with wild bees, drops in the population of these small birds are caused by multiple factors. These include first of all habitat destruction due to human activity (urbanization, agriculture, conversion of grasslands for pasture). Another important threat that has been identified involves the presence of invasive species that are crowding out the native plants on which hummingbirds depend. Mention has also been made of changes in habitat due to the spraying of herbicides as well as the direct effects of spraying on nesting birds (MacKinnon and Freedman, 1993).

Hummingbirds like most birds migrate from the north to the south in the fall and return in the spring. They often travel over vast distances. Some habitats along migratory corridors are considered critical for some endangered species (Calder, 2004). Climate change within these corridors could pose a serious threat to hummingbirds. Abnormal weather conditions, primarily cold winters or drought, in the desert along the migratory corridors are responsible for a high mortality rate within the populations.

Climate change is also responsible for synchronistic failure between the phenological development of hummingbirds and that of the plants they favour. As a result, the birds do not reproduce at the time when food is at its most abundant. Both et al. (2006) recorded the consequences of this absence of coordination for the migratory
pied flycatcher, *Ficedula hypoleuca*. The authors compared nine Dutch populations and found that populations had dwindled by roughly 90% over the last two decades in zones where the food supply for the nestlings had peaked at the beginning of the season. There was a lack of synchronism. In zones where the food supply peaked at the end of the season, the decline in population numbers was much lower.

5. **What Can Be Done to Halt Pollinator Decline and Improve the Situation?**

Urban sprawl, the use of pesticides as well as the emergence of other pressures arising from agricultural and forestry practices make it difficult to support pollinator populations that are essential for maintaining a balanced ecosystem. Pollination services require stable habitats and ecological systems that support pollinators. It is therefore important to develop strategies to protect and maintain habitats that are vital to the survival of pollinating species and to restore degraded habitats.

Conservation, prevention and ecological restoration are needed to reduce or reverse the problem of declining pollinator populations. The solutions lie as much at the political level as at the professional, community and individual levels. A proper understanding of pollinator diversity and pollinator interactions with plants within the framework of a range of disturbances will enable us to act at every level to halt the current decline.

5.1 Government Responsibility

5.1.1 Legislation

A report by Tang *et al.* (2007) gives the conclusions of a study on federal and provincial laws conducted by The International Network of Expertise for Sustainable Pollination at the request of the North American Pollinator Protection Campaign (NAPPC). The study set out to determine the extent to which existing laws had the capacity to ensure the protection of native and wild pollinators.

The analysis focussed more on strict, enforceable laws passed by federal and provincial legislatures than on proceedings that are not legally binding such as agreements, conventions and strategies.

Insect pollinators could be covered by federal jurisdiction since the latter applies in all national parks and national wildlife reserves. Some provincial laws could also provide a better protection of pollinators since they apply in the other regions of Canada. However, there is no explicit provision for insect pollinators in either federal or provincial law.

According to the recommendations outlined in the report by Tang *et al.* (2007), legal provision could be made at the federal level by modifying the Parks Act, for instance, to allow pollinator insects to be acknowledged for the essential ecological services they perform and for the vital role they play in ensuring ecosystem integrity. The authors recommend replacing the term "Lepidoptera" with "Insecta" in the federal Species at Risk Act. Protection would thereby be potentially granted to all pollinating insect species in Canada.

The Pest Control Products Act, administered by Health Canada’s Pest Management Regulatory Agency (PMRA), could be amended to include a specific reference to wild and managed pollinators, particularly with the licensing of new pesticides. Studies to examine the toxicity of these products to wild bees could be required under this Act. Several contentious pesticides should be submitted to a new battery of assessment tests that are applicable to bees (lethal and sublethal effects) and their broods (larvicidal and ovicidal effects). These tests should be designed using rigorous experimentation protocols drawn up by a committee of qualified, independent experts, including wildlife ecotoxicologists. Provision should also be made for a continuous post-licensing survey of these populations and their environment. It should be mentioned that the Agency has begun considering pollinating insects in the light of the significant agricultural services they provide (Tang *et al.*, 2007).
Despite these efforts, regulations should include stricter measures regarding the conditions for use. The labels could provide fuller information on the conditions for use during pollinator activity depending on the time of day and year and on weather conditions.

Similar changes could also be made in provincial legislation, along with decisions to protect the habitats of wild insect pollinators. Pollination by wild species must be given its full due not only because of the ecological services rendered, but also because of the important role it plays in the survival of certain rare and/or endangered plant species as well as of the insects they support in exchange.

Finally the report by Tang et al. (2007) states that the two levels of government should adopt the legal measures needed to protect and preserve native pollinators and should make sure that their ecological and agricultural services are maintained.

5.1.2 Conservation Areas

According to national databases on conservation areas, Canada has approximately 3500 identified protected areas. These areas are managed by different levels of government. They include national or provincial parks and conservation or wildlife management areas. A number of parks have also been created at the municipal level.

While the creation of natural reserves is effective in protecting habitats for pollinators, simply setting space aside is not enough. For long-term conservation, it is also important to make sure that necessary resources are available and that the areas set aside are as large as the vital habitats of the species targeted. Because of the diversity of the species involved, not all pollinators can be preserved in parks and natural reserves. Conservation and protection programmes must therefore include not only reserves but also other types of habitats that are important for ensuring pollinator biodiversity. This means woodlands, the margins around clearings, hedges, grasslands, old orchards, canals, abandoned gravel and sand pits, wet ditches, gardens and other green spaces suitable for adequate flora.

In the German state of Baden-Württemberg, for instance, several hundred natural reserves have already been established. They represent a wide variety of habitats, such as peat bogs, marshlands, barrens, inland dunes, screes, grasslands, former pastures and fallow land. Most of these sites were selected because they represented good examples of natural catastrophes or semi-natural habitats. Some of them have acquired the status of natural reserves, mainly because of the presence of large populations of rare or endangered bee species (Westrich et al., 2000). The role of natural reserves in the conservation of the bees of Baden-Württemberg remains under a special supervisory programme. Similar initiatives could be undertaken in Quebec to ensure the survival of species representing our regional pollinators.

A fine example of species preservation in Quebec is found in the Monts-Valin National Park in the North Saguenay-Lake St. John district. Two wild bumble bee species that were formerly extremely common in the Saguenay–Lake-St. John district disappeared in the 1990s with the increased commercial introduction and acclimatization of the species Bombus impatiens. The high summits of the Monts-Valin National Park constitute a refuge for Bombus terricola, one of the species that disappeared locally, since Bombus impatiens has not yet become established within park limits. The creation of the Monts-Valin National Park was the result of a regional initiative involving the municipalities of the northern sector of the Saguenay, the Le Valinouët ski resort, and the Monts-Valin development initiative.

The entire area of Quebec’s national parks must surely harbour other species of rare and endangered insect pollinators. It is therefore of vital importance to protect the types of habitats used by these species when planning and making decisions regarding the choice of conservation areas.
5.1.3 Communication and Establishment of Action Plans

In order to protect wild pollinators, it is essential to establish concrete action plans that will promote local, national and international coordination. Projects focusing on research, conservation, restoration, public awareness or education require partnerships, with the creation of strategic coalitions and mobilization of existing resources. It is important to facilitate communication between the parties concerned to ensure the success of these types of partnerships.

5.1.4 Financing Local Initiatives

The financing of structured local initiative programmes for the conservation and restoration of habitats to promote the preservation of plants and wildlife is crucial if the intended goals are to be achieved. Governments cannot act alone.

5.2 Urban Initiatives and Municipal Responsibilities

Increased urbanization is partly responsible for the disappearance of a number of wild flower species, which are sources of nectar and pollen for many pollinators. That said, the conservation of pollinators should not be viewed as incompatible with urban development. Cities are capable of supporting a greater abundance and diversity of species than might be thought. For instance, it was found that the city of Brussels in Belgium was home to half of the country’s native plants (Godefroid and Koedam, 2007), whereas Maguran et al. (2004) found a greater variety of ground beetles (Carabidae) in the urban regions of Central Europe than in the suburbs. Closer to home, at least 54 different species of pollinators were counted in New York City (Matteson et al., 2008)

Habitat restoration programmes can be set up as part of land-use planning. For such programmes to be effective, it is essential to implement planning policies.

5.2.1 Encouraging Native Diversity by Promoting Gardens and Habitats

Encouraging the growth of native plants in open spaces fosters the protection of pollinator habitats. At the municipal level, pollinator biodiversity may be promoted by planting flowers in public spaces, such as parks, playgrounds, schools, roadsides, and areas around public buildings. Planting trees, bushes and melliferous plants as well as creating hedges out of shrubbery in parks and gardens can help improve the living conditions of honey bees, bumble bees and butterflies.

All the green spaces in urban and suburban areas, such as city parks and golf courses, constitute precious habitats capable of meeting the basic needs of insect pollinators. Provision can be made for these insects as part of the routine maintenance of the green spaces, making it possible to conserve both the pollinators and perennials of the site but also to ensure a food supply such as berries for other wild species, including bird species in particular.

Close-cropped lawns are a feature of many parks and gardens. Appropriate measures should be taken to limit, even prevent, the systematic destruction of adventive plants, often considered “weeds” or “competitive plants”. They include a number of floral species used by pollinators for their nectar and/or pollen. Rather than a systematic elimination of these plants, it is advisable to examine each occurrence on a case-by-case basis to determine the quality of the diversity provided by these plants and the animal species they sustain.

5.2.2 Habitat Restoration

Over and above political decisions, the preservation of biodiversity calls for concrete action. Pro-active conservation measures must be adopted. These could include investing in the restoration and management of habitats to encourage pollinator diversity in disused or abandoned sites.
An avant-garde scheme has been initiated by the City of Guelph in Ontario in collaboration with the University of Guelph. The city is working on creating the first "pollinator park" in the world. The objective is to transform a 40-hectare (100 acres) abandoned dump site so that it can be used for educational and recreational purposes. Plans include using the park to create an urban habitat adapted to all the stages of the life cycle of pollinator insects. Furthermore, there will be activities for the public focusing on pollinators with the goal of arousing awareness on the issue of pollination.

5.3 Individual and Community Initiatives

While the problem of pollinator reduction is of worldwide significance, a number of simple things can be done at the community as well as individual level to stave off the decline. The total area covered by community and private gardens throughout the regions of Québec is such that amateur gardeners can clearly play an important role in the preservation and protection of local pollinators.

5.3.1 Gardening

Citizens can help protect pollinators in their own yards through their gardening practices. Insofar as possible, each home owner should set aside a section of his property to let it develop naturally and allow native plants to grow and reproduce. This would promote the development of local species. In urban areas, such measures could provide sites for reproduction and islands of resources along corridors taken by pollinators as they move from place to place.

It is not enough to let native plants grow. Pollinator-friendly ornamental plants should also be selected. If a wide variety of species is to be encouraged, provision must be made for a wide variety of habitats. The plants selected should flower at different times, display an array of colours with different heights and flower shapes. To create diversity, it is important to grow plants that flower from early spring to late fall. There are several horticultural concepts that are often easy to introduce and help promote plant biodiversity which in turn supports pollinator species. One should not hesitate to request the necessary information from nurseries and local and national support groups. Financial contributions can also be made to organizations to help support their efforts in promoting pollinators and plant communities.

5.3.2 Insecticides

Naturally pesticide use should be reduced or completely eliminated whenever possible. This means carefully judging whether pesticide treatment is absolutely necessary and if so, carefully reading the label and correctly applying the standard guidelines. Insecticides should never be applied when a plant is in flower. The least harmful formulation should always be selected. There are a number of ways of chasing harmful insects without endangering pollinators. Information on these alternatives may be obtained from support and information organizations such as the Coalition for Alternatives to Pesticides (CAP).

5.3.3 Learning to Recognize and Encourage Pollinators

If pollinators are to be protected and managed, they must first be identified. There are guides to identification and other types of information for the layman which will allow anyone to recognize the pollinators in his neighbourhood. It is also possible learn how to create habitats that will promote their presence and reproduction.

The successful creation of a pollinator habitat requires supplies of food and water and an appropriate site for nesting. The ideal site depends on the requirements of each species. For instance, for certain species such as leafcutting bees (Megachilidae) and carpenter bees, all that is needed is to leave the occasional dead stalk or even a few dry branches on the ground. Andrenids and halictids prefer warm, sandy sites.
Nesting sites for bumblebees and *Osmia* may be created by making holes 7 to 10 cm deep in a piece of old wood placed with a southern exposure on a pole or a roof. Additional food supplies may also be provided for butterflies and bees. Nectar feeders may also be installed for hummingbirds.

Creation of new habitats, however, does not replace protection of the original habitat.

### 5.4 Intervention in Agroecosystems

Commercial pollinators, especially the honey bee (*Apis mellifera* L), are not always the most efficient pollinators when it comes to the proper pollination of crop flowers. Most cultivated species are receptive to a wide range of pollinators.

Furthermore, honey bees introduced into a crop are not always present on crop flowers at the onset of flowering, especially if the flower is not rich in nectar. In this case, the wild pollinators in the agri-food environment become essential for these first flowers to set fruit.

Unfortunately populations of these native species may be very small or even absent from an environment. It is possible to promote the development of these populations and facilitate their domestication in regions beyond their natural range and generally where they do not occur.

In the agricultural landscape, there are many shelters for pollinators resulting from favourable environmental practices, such as the use of grassy strips to protect water courses and fallow land. Everywhere on farms there are important refuges capable of sheltering a wide range of these insect allies. Hedgerows, embankments and bushes serve as windbreaks and shady places during periods of intense heat. To enrich these habitats, it is far more preferable to plant native trees and shrubs which grow wild in the region, since they have adapted to the climate and soil types and are consequently more resistant. These plants have also evolved along with the fauna and provide food and shelter for a great many species of insects and birds which, in turn, play a role in pollination of the flowers and seed dispersal.

Mowing edges and grassy spaces can result in the direct death of insects, particularly of the eggs and larvae which are unable to escape from a mower. Ideally, this type of operation should be done in the fall or winter when the flowers are dead. Sequential mowing in a mosaic pattern is preferable to eliminating all of the plants on a site. Reducing mowing operations by adopting a two-year schedule would allow for diversification and the maintenance of grassland flora (dandelions, field bindweed, clover, birdsfoot trefoil, etc.) from year to year.

The same holds true for controlled burns. Fire can have devastating effects on the existing populations. Ideally, small sections representing no more than 30% of a site or less should be burned in rotation every two years, giving pollinators the chance to colonize properly and to find shelter.

The transformation of an intensive monoculture system into a more attractive landscape for pollinators would provide continual pollinating services, ensuring thereby continual agricultural production. Restoring habitats for pollinators near cultivated land could encourage and stabilize pollinator populations with a resultant improvement in crop yields. It is important to be able to develop methods for restoring adequate habitats to preserve pollinators which play such an important role in agricultural ecosystems.

#### 5.4.1 Knowing and Diversifying Crop Pollinators

Reinforcing pollinator populations by means of habitat management is a potentially effective option. It may even become essential should honey bee colonies become less readily available (Corbet *et al.* 1991). In the case of some crops and many plant species with flowers that are not adapted to the honey bee, pollination by wild species remains the only viable option.
If a farmer intends to exploit the free services of native pollinators in his crops, he must be able to recognize and protect the habitats of these insects on his farm. He must find the areas on and around his farming operations that are capable of supporting these allies. Measures can be taken to bolster these habitats in order to increase populations.

Various approaches aimed at increasing pollinator numbers in an environment have been examined (Parker et al. 1987; Southwick and Southwick 1992; Torchio 1990,1991; Corbet et al. 1991; Williams et al. 1991). The most logical approach seems to be preserving and managing wild bee habitats including appropriate resources and nesting sites (Westrich, 1996). Habitat management programmes could be introduced, especially in intensive farming systems.

Insect pollinator communities and populations vary widely both in abundance and diversity. Long-term monitoring of the species present in an environment will indicate population trends, shedding light on the suitability of a habitat and its value for ecosystemic services in terms of pollination. This type of detection, however, requires regional coordination of sampling strategies covering a period of a number of years.

Technical support clubs could develop this type of competence by including a section on pollinators in their services.

5.4.2 Knowing the Sources of Honey

In some rare plant populations that are of exceptional value to pollinators, it might be necessary to make provision for pesticide-free buffer zones. Implementing a measure of this type requires a good knowledge of melliferous plants.

For a plant of this type to be considered of apiarian interest, it must regularly produce large amounts of nectar, grow in rich stands and provide good-quality honey (Louveaux, 1978). Such plants are also favourable to wild pollinators. There are not many of these plants, but they represent a wide floral variety, and their flowering period spreads out over time. Their presence provides insects with nourishment in periods when crop plants do not produce nectar. These stands may also include plants, such as fruit trees, alfalfa, sunflowers, clover, etc., which in the absence of herbicide treatment can prove of great importance.

Many plants fertilized by insects provide both nectar and pollen. Large amounts of pollen may be supplied by typically entomogamous plants but there are other plants as well. Insect pollinators may also use plants in which the pollen is dispersed by the wind (anemogamous plants). This is the case of trees with catkins, such as willows.

We do not yet have a guide on melliferous plants specific to Quebec, but the Flore Laurentienne contains a great deal of information. (Brouillet, 2006). The “Guide d’identification des mauvaises herbes du Québec” published by the CRAAQ is also a practical source of information, listing the characteristics that are most useful in identifying some 120 plants frequently found in crops. It also contains close to 650 colour photographs.

5.4.3 Control of Pesticide Use

Herbicides

Herbicides are designed to eliminate plants competing with cultivated species and can thus be a significant management tool. The use of non-selective herbicides, however, can result in a decline in the floral resources essential to pollinators. In addition, some herbicides, especially glyphosphate, are known to be directly toxic to bees. These products should therefore be applied with the utmost caution. The suitability of their use should be assessed especially when it comes to the elimination of melliferous plants.

Insecticides

The application of chemical insecticides may have harmful effects on wild and introduced pollinators with a resulting reduction in wild and cultivated plant pollination. If agricultural practices and regulations are to improve, there must be stricter education and information on the subject for all participants in the agricultural domain.
Agronomists and those involved in farming should be required to be trained in the importance of pollination and the hazards connected with the use of pesticides. Such training should be provided by independent experts and representatives of the beekeeping sector. Regulations should be more rigorously applied. In case of non compliance, sanctions would be in order.

5.4.4 Improving Management of Bumble Bee (Bombus impatiens) Parasites

In view of the importance of bumble bees as pollinators of crops and wild flowers, measures must be taken to prevent a further decline in numbers. In North America, the catastrophic drop in the populations of some bumble bee species since the 1990s is probably due to the accidental introduction of exotic parasites from Europe. This is the result of the worldwide trade in bumble bees for the pollination of greenhouse crops. In Quebec, the commercial bumble bee is also used for the field pollination of blueberry and cranberry crops. Improved management of bumble bee parasites could help reduce or even eliminate these pathogenic agents. It would also be advisable to take proper precautions so that introduced species are not released into nature at the same time as the wild species take flight to avoid transmission of the parasite.

6. RECOMMENDATIONS FOR RESEARCH AND THE ADVANCEMENT OF UNDERSTANDING

Gaps in our understanding of how to protect and promote populations of bees that are significant for the pollination of agricultural crops as well as wild plants must be properly identified. Further work is needed on studies that have already been initiated and additional research is required on topics that have already been addressed if we are to be able to fill the gaps in our understanding of a wide range of issues dealing with pollinators.

Several research topics relating to these issues will be recommended here. The topics logically deal with the concerns expressed in Chapter 4. Several recommendations also come from other sources, the most important of which are the Canadian Pollinator Initiative (CANPOLIN) (Kevan et al. 2008), the North American Pollinator Initiative (NRC, 2007) and The Forgotten Pollinator (Buchmann and Nabhan, 1996).

6.1. Developing Expertise in Pollinator Taxonomy

A number of recommendations aimed at halting pollinator decline require knowledge of the species found in an environment. Documentation and assessment of the number and diversity of pollinator groups are advised. However, when it comes to furthering our understanding at the species level, it is often difficult to find an expert for the identification or validation of specimens. The decline in specialists in insect pollinator taxonomy is cause for as much concern as the decline in the insects themselves.

Some species are on the list of endangered species drawn up by the International Union for Conservation of Nature and Natural Resources. It is important to recognize these species so that appropriate measures can be taken to ensure adequate conservation of their habitat, but as O’Toole (2002) pointed out, without more sustained funding in the area of bee taxonomy, we run the risk of not really knowing what we are trying to preserve.

Recommendation: train a new generation of experts in pollinator insect taxonomy and support their advancement with funding and some form of mentoring.

6.2 Identifying Native Pollinating Species of Use in Agricultural Production

In agricultural ecosystems, good management of insect pollinators can provide a complement to pollination of some crops. At present the quality and extent of these pollination services are not fully understood. The first step is to identify the different species found on a crop’s flowers, followed by identification of species with a valuable potential for pollination. Lastly, the contribution of these species to agricultural production should be quantified.

Recommendations: acquire a better understanding of the role played by wild species in crop pollination.
Identify the insects on crop flowers and determine their pollinating efficiency

Identify the economic importance of plant pollinators.

6.3 Identifying Native Pollinators That Could Be Commercialized

Some wild bee species could be managed for pollination, as is the case with bumble and honey bees. Some natural pollinators of various legumes, apples, pears and cherries, for instance, are both efficient and reliable. Some solitary bee species, such as the squash bee (**Peponapis pruinosa**), play an important role in the pollination of pumpkins. There could be a considerable advantage in extending the use of pollinators found on the flowers of one cultivated plant to other crops. Care should be taken, however, that a prospective introduced (or managed) pollinator does not have the potential to become an invasive exotic species.

**Recommendation**: develop new commercial pollinators.

- Examine the possibility of mass breeding for purposes of commercialization of species identified for their marked potential as pollinators of the flowers of certain crops.
- Study the competition that might exist between native pollinators and potential candidates for commercialization.

6.4 Studying Plant-Pollinator Relationships

Several plant-pollinator interactions are already well understood. It would be advisable to make sure that the state of our knowledge concerning rare and keystone species from an ecological or commercial point of view is complete and properly interpreted.

Botanical species differ in the way they respond to disruptions. We do not know how a disturbance in the landscape can influence the beneficial effects resulting from the co-evolution of plants and their pollinators. It is important to know the relationship that might exist between dwindling pollinator populations and the potential for the cascading disappearance of plant species that shelter these insects and depend on them for reproductive purposes.

**Recommendation**: acquire a better understanding of pollination systems in natural environments.

- Obtain an in-depth scientific understanding of the dynamics of pollination in different ecosystems and the consequences of a decrease in pollinating insects or host plants.
- Study the relationships between the morphological traits of native plant flowers, pollination mechanisms and the visitors to these flowers, for different ecosystems.
- Study fruit set in native plants in relation to the number of visits by natural pollinators and determine the consequences of fewer or no visits at all.

6.5 Developing a Viable Agricultural Landscape

The preservation or restoration of wild plants in an agroecosystem could prove beneficial for crop pollination by attracting surplus pollinators to the crops and the environs. In return, these pollinators could serve to complement the activity of pollinators introduced to improve yields. On the other hand, the presence of wild plants could provide competition and exert a negative influence on production by attracting introduced pollinators away from the target crop.

A proper understanding of the importance of plants in an environment for the maintenance of pollinators is essential. A good grasp of the phenology of the flora and pollinating fauna found in an agricultural landscape could help determine positive or negative outcomes and the extent of influence these plants have on crop pollination.
**Recommendation:** acquire a better understanding of the ecological and commercial value of agricultural ecosystems harbouring wild pollinators and the impact of different agricultural practices on these environments.

- Study the consequences of habitat fragmentation in an agricultural environment on pollinator populations.
- Assess the repercussions of farm practices on the food sources available to pollinators.
- Estimate the presence of a competitive effect between native pollinators and pollinators introduced into various crops.
- Assess the effects of amending agricultural practices, restoring habitats or creating foraging plots on wild pollinator densities in a crop.

### 6.6 Protecting Foraging Sites and Restoring Degraded Habitats to Promote Pollinator Presence

There is a positive correlation between the diversity and abundance of pollinators in wooded land with the size of these wooded areas. A loss of pollinators in these areas is followed by a reduction in total flower seed production.

Urban sprawl and agricultural development have cut into the areas available as habitats for wild bees. Research on native bees should focus not only on conservation of the species. It should also be concerned with conservation of habitats and ecosystems. A better understanding of the dynamics of pollinator migration is needed. If the insects are to be protected, it is also important to be able to identify foraging sites along the migration corridors taken by the pollinators.

**Recommendation:** identify the characteristics of habitats that are essential to native pollinator survival, reproduction and population increase.

- In different ecosystems, identify the areas needed to ensure a viable habitat for the pollinators.
- Study the flowering phenology of species selected as part of an ideal mix of floral resources intended for habitat restoration.
- Assess the effectiveness of restoring an area in terms of the conservation of targeted species.
- Conduct follow-up studies on pollinator populations following implementation of a management or restoration plan.
- Study the relative specialization and morphological compatibility of different pollinator species with respect to certain botanical families as regards the harvest of pollen and nectar.

### 6.7 Acquiring a Better Understanding of the Impact of Pesticides

It is well established that the improper use of agricultural pesticides adversely affects the development of honey bee colonies. A better understanding of the impact of pesticides on wild bee species as well is of crucial importance. The development of a tool to measure this impact would make it possible to provide these populations with greater protection. With a better management of pesticides, it would be possible to reinforce natural pollinator populations which contribute to improved crop yields.

**Recommendation:** reduce pollinator mortality resulting from the excessive use of pesticides.

- Study the lethal and sublethal effects of pesticides (insecticides, herbicides) on wild pollinators.
- Conduct research on the long-term impact of pesticides on natural populations.
6.8 Studying the Pathogens of Wild Insect Pollinators

If the use of introduced pollinators for crop pollination is to be encouraged, continued efforts must be made to control diseases and parasites.

Several avenues of research have already been explored in the case of the honey bee (Apis mellifera) to study the different pathogens (diseases and parasites) attacking the species. Less work has been done on the parasites of other introduced species. These pathogens are potentially capable of being transmitted to wild populations of the same species.

Recommendations: design and implement a management programme for pathogenic agents (parasites and diseases) to prevent a negative spillover effect on wild populations.

− Study the pathogens attacking alfalfa leafcutting bees (Megachile rotundata) and develop methods aimed at improving the viability of these populations when introduced for crop pollination.

− Conduct research on contamination of wild bumble bees by species introduced for pollination in greenhouses.

6.9 Using the Honey Bee as a Bioindicator

The honey bee (Apis mellifera L.) is recognized throughout the world as an effective environmental indicator. It is used on a planetary scale as a tool for biological monitoring to assess the environmental risks of harmful products (NRC, 1991; Warren-Hicks et al., 1989; Bromenshenk, 1992; Bromenshenk et al., 1995). A honey bee hive is a complex, organized living organism which is highly sensitive to a number of chemical pollutants at extremely low levels, sometimes as low as 2 to 3 ppm, as in the case of systemic insecticides.

The impacts of treatments with pesticides and other contaminating products on the mortality rate and development are more difficult to assess in natural pollinators than in honey bees since the latter return to a hive where their populations can be more readily monitored. There is therefore good reason to use the honey bee as a sentinel for the protection of these non-targeted organisms. Thus, the assessment of the environmental health of an environment for the health of the pollinators it harbours as well as the biological monitoring of exceptional regions, like watersheds, could be the focus of future projects using the honey bee as a bioindicator.

Recommendation: conduct studies on the impacts of different types of environmental stress on native pollinators using the domestic bee as a bioindicator.

6.10 Studying and Following Changes in Hummingbird Populations

An irregular trend has been observed in the abundance of some hummingbird populations. Some populations seem stable year after year, whereas in other cases, there is a dramatic drop in the number of birds returning each year. There is an urgent need to understand hummingbird population trends and the factors that might be responsible for population decline.

Recommendations:

− Study how habitat loss and fragmentation in migration corridors can affect populations.

− Determine, for different latitudes, whether climate change can be the cause of a lack of synchronism between hummingbird reproduction and the peak period when plants in reproduction sites provide food.

6.11 Creating New Research Positions

Lastly, if all of these research objectives are to be achieved, new research positions must be opened up in entomology.
In agriculture, especially in the fruit and vegetable sector, it is important to work on identifying pollinators that display a potential for commercial use. Similarly, work should be done on developing and implementing protocols for the management and mass production of these species.

In the area of ecology, the emphasis must be placed on improving our ability to identify wild pollinators and to understand their life cycles and ecological requirements (nesting sites, host plants, competitors...) in different types of natural environments.

7. CONCLUSIONS

The reproduction of over 80% of plant species on the planet depend on cross-pollination provided by animals. Several of these precious species are threatened with dwindling populations. Various factors may be at play. Whereas the reduction in honey bee and domesticated bumble bee colonies is evident and well documented, the scientific community is somewhat divided when it comes to the fate of wild bees. Some studies clearly show a long-term persistence of some members of complex bee communities. However, specialists agree that well-documented local reductions in wild bee populations are probably symptomatic of a far more extensive loss of biological diversity. There is a need for standardized inventory-taking techniques and longer-term studies to shed light on the problem.

A lack of temporal/spatial and seasonal data on pollinator abundance and variety, especially in the case of bees, seems to hinder our understanding of the current situation. It is therefore necessary to fine-tune the methods of investigation and sampling used to assess the situation among pollinator communities in general.

To maintain their populations, bees and other pollinating insects require nesting sites (loose soil, abandoned mouse nests, dead wood, burrows, etc.) and floral resources (providing nectar and pollen). Some environmental resources are becoming rarer because of modern agricultural practices such as row harvesting, pasturing, and breaking up habitats into fragments that are too small to sustain the various communities of pollinators. (Kearns et al., 1998; Kevan, 1999, 2001; Kevan et al.,1990). Excessive anthropogenic disruptions, such as mowing embankments, roadsides, and public spaces could result in the loss of host plants and their specialized pollinators. Most bees found in temperate zones are polylectic (Minekley and Roulston, 2006) and can use a wide range of plant species in different types of habitats. Bees and other pollinators can consequently survive in urban and suburban settings if they are provided with suitable nesting sites and the floral diversity needed to supply nectar and pollen throughout the growing season (Cane et al., 2006; Frankie et al., 2005). Measures taken to preserve a landscape should strike a balance between the needs of humans and those of native pollinating species.

With the introduction of new pollinators into an environment, regardless of whether it is voluntary or involuntary, there is the risk of disrupting local communities. The extent of the disruption depends on a myriad of factors, the most significant being the phenology of the plants and the insects (seasonal calendar of their development), the abundance of native and introduced pollinators and their competition for the use of resources. Because of the complexity of the interactions between these factors, the potential ecological impacts of introduced pollinators on native species are uncertain and difficult to quantify (Goulson, 2003b; Schaffer et al., 1983). Researchers are of the opinion, however, that these impacts are in all likelihood minor compared to major disruptions, such as habitat loss and pesticide use. At the same time, it is important not to overlook the effects of pollinators introduced into an ecosystem since they are potentially able to compete with native pollinators which often play an essential ecological role (Paine, 1966; Thorp and Gordon, 1992; Thorp et al., 1994).

Weather conditions have a direct influence on pollinator flight and an indirect effect on pollen and nectar production by the flowers selected by the pollinators for foraging. Temperature constitutes an important factor potentially limiting insect flight and pollen availability, but light intensity, rain and relative humidity also play a role.

Estimating the impact of climate change on pollinators poses a problem since it is very difficult to assess the effects due to each one of the factors involved and impossible to predict the damage to plant/pollinator interactions that
might result from extreme weather conditions (Harrison 2000; Meehl and Tebaldi, 2004). Furthermore, the effects of climate change on other stages in the life cycle of pollinators, such as, for instance, the larval and migratory stages, must not be overlooked.

Regardless of the cause, pollinator decline potentially reduces pollination services in natural and developed areas. This decline also impacts cultivated plants which rely on pollination to produce seed and fruit.

Over and above the value associated with an increase in agricultural production, there is the established or potential value associated with leasing certain pollinators for purposes of crop pollination. Ecosystemic services are much harder to estimate. We can only acknowledge their incalculable importance.

The key points in pollinator conservation in urban, semi-urban and agricultural areas are the following:

1. Identify wild pollinators and their established habitats
2. Create nesting sites for bees
3. Supply a range of native flowers that blossom throughout the growing season
4. Make changes in the management practices involving existing fields to avoid harming the pollinators that are already present
5. Improve, restore or create habitats for butterflies and bees
6. Avoid using pesticides
8. References


Canadian Wildlife federation. Quebec Regional Office. 55


Canadian Wildlife federation. Quebec Regional Office.


