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

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ABSTRACT

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

INTRODUCTION

Canada is committed to sustainable development; bringing together economic, social, and environmental goals and ensuring that Canadians' needs are met today and in the future while we live in balance with other components of the earth's ecosystems. Achieving environmentally sustainable agriculture is a process of continuous improvement, energised and carried out by members of the agriculture sector and supported by government. Canada is also committed to preserving biodiversity, as it is the key activity in sustaining the earth's resources and productivity for the future. In December 1993, Canada became one of the first industrialised countries in the world to ratify the international Convention on Biological Diversity. Extensive discussion on agricultural biodiversity has occurred since that time and a review of the biodiversity of pollinators in agriculture and the environment was undertaken. This topic is an excellent example of the value added by a forum such as the Convention on Biological Diversity, which brings agriculturists and environmentalists to work together on common problems. Thus, the aim of our review is to summarise the relative risks of the major crop pollinators in Canada, and discuss important aspects of pollinator biodiversity and crop pollination, factors affecting pollinator biodiversity and general trends in Canada as they relate to the agriculture/environment interface.

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

Environmental sensitivity

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

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

Canadian pollinator biodiversity

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

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

Honey bee (*Apis mellifera)*

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

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

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

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

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

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

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

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

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

Alfalfa leafcutter bee (*Megachile rotundata)*

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

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

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

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

Bumble bees

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

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

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

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

Mason bees

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

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

Other native solitary bees

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

Relevance of pollinator biodiversity to crop pollination

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

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

The agronomic and economic value of bee-effected pollination has been an internationally contentious issue since at least the turn of the century. Attempts to value the pollination activity of bees have ranged from "guesstimates" of no empirical substance, to informed estimates (largely by apiculturists) to a few concerted efforts by economists (Gill 1991; Southwick and Southwick 1992). Estimates by Canadian researchers on the value of pollination to Canadian agriculture have ranged from C $443 million to C$1.2 billion (Winston and Scott 1984; Charest and Hergert 1992; CAPA 1995). Others have estimated Australia's benefits at A$156 million (Gill 1991), USA at US $1.6 billion to US $40 billion (Levin 1983; Robinson *et al.* 1989; Southwick and Southwick 1992), and the European Community at 5000 million ecus (Borneck and Merle 1989). The estimates have been used to justify continued public financing of honey price support schemes (USA), increase public funding of bee related research and extension programs, enhance the efficiency of the policy making process, and to recognise the contribution beekeepers make to the well-being of society. The estimates are derived primarily for honey bee pollinated crops. Honey bees have often been credited with pollination services that are actually performed by other bee species (Parker *et al.* 1987; Richards 1996; Kevan 1999). There are few estimates of the value of non-*Apis* pollination, and these insects are generally not appreciated. The benefits we derive from native pollinators are believed to be increasing as the honey bee industry experiences continued difficulties from mites, Africanised bees and diseases, and as crops that are better pollinated by bees other than honey bees are grown more intensively.

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

Pressure indices affecting pollinator diversity in Canada

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

Agriculture and Forestry

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

Pesticides

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

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

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

Habitat modifications

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

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

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

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

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

Pollution

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

Exotic species

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

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

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

Environmental factors

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

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

Remediation or trends in pollinator biodiversity in Canada

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

Protected area index

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

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

CONCLUSIONS

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

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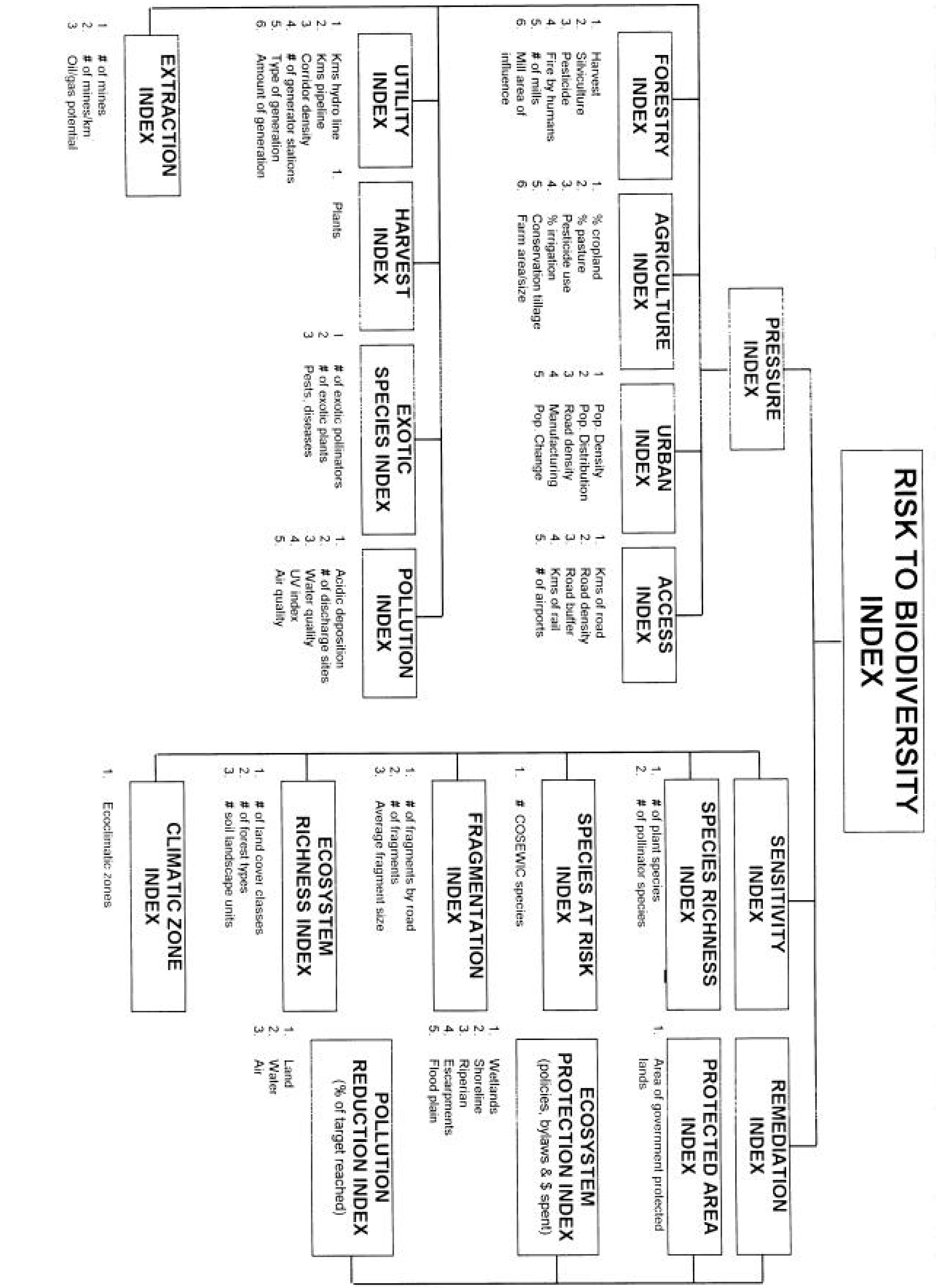
RISK TO BIODIVERSITY INDEX
PRESSURE INDEX
FORESTRY INDEX
1 Harvest
2 Silviculture
3 Pesticide
4 Fire by humans
5. # of mills
6 Mill area of influence
AGRICULTURE INDEX
1. % cropland
2. % pasture
3. Pesticide use
4. % irrigation
5. Conservation tillage
6. Farm area/size
URBAN INDEX
1 Pop. Density
2 Pop.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

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