Present and Potential use of Bees as Managed Pollinators in Mexico

Author(s): Alfonso Torres-Ruiz, Robert Wallace Jones and Ricardo Ayala Barajas
Source: Southwestern Entomologist, 38(1):133-148. 2013.
Published By: Society of Southwestern Entomologists
DOI: http://dx.doi.org/10.3958/059.038.0102
URL: http://www.bioone.org/doi/full/10.3958/059.038.0102

Present and Potential Use of Bees as Managed Pollinators in Mexico[1]

Alfonso Torres-Ruiz[2,5], Robert Wallace Jones[3], and Ricardo Ayala Barajas[4]

Abstract. A diversity of crops is grown in Mexico. Of the plants that produce fruits and/or seeds for human consumption, 85% depend to some degree on pollinators for efficient production. Mexico also has a great diversity of native bees, some of which have been recognized as having potential for use as managed pollinators; defined as a semi-domesticated species, produced in large quantities, and bought and sold commercially. The objective of the present work was to review the species of bees presently commercially available in Mexico as managed pollinators and to analyze in particular: 1) their commercial availability, 2) crops for which they are used, and 3) the perspectives for their sustainable use and conservation. Presently, only two species of bees are used commercially in Mexico: the honey bee, *Apis mellifera* L., and the common eastern bumble bee, *Bombus impatiens* Cresson. Mexican native bee species have been used experimentally, but at this time, none is commercially available. The principal threats to the conservation of native bees in Mexico are the elevated rate of deforestation combined with intense use of agrochemicals and particularly insecticides for control of pests in extensive monocultures. Continued research and conservation programs considering native bee species are needed to ensure the survival of as many species as possible to provide a wide array of biological characteristics with potential for use as managed pollinators in Mexico. This is critical to ensure the future necessities of the wide diversity of Mexican crops with unique agronomic characteristics within the diversity of habitats where they are cultivated.

Resumen. México es un país con alta diversidad de especies vegetales cultivadas. El 85% de las especies de plantas que producen frutas y/o semillas para consumo humano, dependen en algún grado de los polinizadores para una producción eficiente. Alternativamente, México tiene gran diversidad de abejas nativas y algunas de ellas se han señalado con potencial para ser usadas como polinizadores manejados. El objetivo de este trabajo es revisar las especies de abejas que están comercialmente disponibles en México como polinizadores manejados, analizando en particular: 1) disponibilidad comercial, 2) cultivos donde se utilizan, y 3) las perspectivas de su uso sustentable y su conservación. Actualmente, sólo se cuenta con dos especies de abejas polinizadoras comercialmente

---

[1]Hymenoptera: Apidae

[2]Departamento de Investigación y Desarrollo (I+D), Koppert México SA de CV, Calle Circuito El Marqués Norte No. 82. Parque Ind. El Marqués, C.P. 76246, Querétaro, México.
[3]Universidad Autónoma de Querétaro, Licenciatura en Biología, Facultad de Ciencias Naturales, Laboratorio de Ecología y Diversidad Faunística. Avenida de las Ciencias s/n, Juriquilla, C.P. 76230 Querétaro, Querétaro, México.
[4]Estación de Biología Chamela, Instituto de Biología, Universidad Nacional Autónoma de México (UNAM). Apartado Postal 21, C.P. 48980, San Patricio, Jalisco, México.
[5]Corresponding author: atorres@koppert.com.mx

disponibles en México: la abeja melífera *Apis mellifera* L. y el abejorro *Bombus impatiens* Cresson. Otras especies de abejas nativas han sido utilizadas experimentalmente, pero sin que haya disponibilidad comercial hasta el momento. La elevada tasa de deforestación, aunado al uso intensivo de agroquímicos y pesticidas para el control de plagas en monocultivos extensivos, son las principales amenazas para la conservación de las abejas polinizadoras y silvestres. Es necesario que se continúe realizando investigaciones que permitan tener mayor número de especies de abejas que puedan ser usadas como polinizadores manejados en México, con el fin de cubrir las necesidades futuras de la gran diversidad de los cultivos mexicanos, con sus características agronómicas únicas.

Introduction

Pollination is a critical ecosystem service in agriculture. Many food crops in the world depend to some degree on visits by animal pollinators for production of seeds or fruit (Nabhan and Buchmann 1997). It has been estimated that 75% of human food crops require pollination by insects for adequate production (Klein et al. 2007). Of these pollinators, bees (Hymenoptera: Apoidea) are the most important and most used in managed pollination programs. In recent decades, a decline in natural populations of pollinators, principally Apoidea, has been documented throughout the world (National Research Council 2007, Potts et al. 2010, UNEP 2010). The causes of the decline are complex and multifaceted, but include habitat alteration and loss due, in part, to the expansion of areas dedicated to agriculture combined with the use of agrochemicals leading to reduction in diversity and abundance of native pollinators (Kremen et al. 2002, Freitas et al. 2009).

A further complication in crop pollination is the increase in cultivars grown in protected environments, such as greenhouses and shade houses, which restrict the access of pollinators to crops. Protected agriculture either reduces the role of insect pollinators in these crops or requires the use of managed pollinators to achieve acceptable amounts of production. According to the National Research Council (2007), managed pollinators are those that are semi-domesticated, produced in large quantities, and bought and sold commercially. The managed pollinator of greatest importance globally and used in the widest diversity of crops is the honey bee, *Apis mellifera* L. (Delaplane and Mayer 2000). In various countries, such as the United States and Canada, several other bee species, including both native and introduced, are used as managed pollinators in open fields and greenhouses. Commercially available species in the United States and Canada include: *Megachile rotundata* F., *Osmia lignaria* Say, *Osmia cornifrons* Radoszkowski, *Nomia melanderi* Cockerell, and *Bombus impatiens* Cresson (National Research Council 2007). Other managed pollinators of the Americas include several species of carpenter bees, *Xylocopa frontalis* Olivier, *Xylocopa suspecta* Moure and Camargo, and *Xylocopa grisescens* Lepeletier, used to pollinate distinct species of passion flowers in Brazil (Freitas and Filho 2001).

Mexico has the need and potential to develop management programs for underexploited pollinators considering the wide diversity of both pollinators and species of cultivated plants in the country. More than half of the cultivated plants of Mexico are cultivars with fruits or seeds consumed by humans, of which 85% depend to some degree on insect pollinators for efficient production (Ashworth et al. 2009). Mexico is a principal world supplier of fresh fruits and vegetables. For example, México is the major exporter of tomatoes, *Solanum lycopersicum* L., for

the world, with slightly more than a million tons of exports annually (FAO 2007). The country is also the principal exporter of avocadoes, *Persea americana* Mill, with annual exports exceeding 300,000 tons, and ranks third in exportation of green peppers, *Capsicum annuum* L. For these crops, visits by pollinators have a positive effect on production (Meisels and Chiason 1997, Morandin et al. 2001b, Gazit and Ish 2007), emphasizing the need for conservation of native pollinators, as well as the maintenance and development of new managed pollinator systems for the production of these and other fruits and vegetables in Mexico.

The current rate of loss of biodiversity in Mexico due to habitat destruction and degradation combined with accelerated climate change will almost certainly result in a decrease in pollination services by native bees and necessitates an increase in use of managed pollinators to ensure agricultural production. The objective of the present work was to review the species of bees presently commercially available in Mexico and analyze specifically: 1) their commercial availability, 2) crops where they are used as pollinators, and 3) perspectives on their sustainable use and conservation.

Availability of Managed Pollinators in Mexico

The honey bee is the most common managed pollinator in Mexico and the most valued for honey production, wax, and pollination services (Fig. 1B). *Apis mellifera* was probably introduced into Mexico from Cuba, through the states of Veracruz and Tabasco, in the late 1760's or early 1770's (Labougle and Zozaya 1986). Honey bees are found throughout Mexico. Approximately 1.8 million commercial honey bee hives were in Mexico in 2010 (SIAP 2010).

The technology of apiculture in Mexico is heterogeneous (Labougle 1990). Apiculture enterprises range from small-scale operations (10-60 hives) using traditional methods, to large-scale operations implementing advanced technology (Cajero-Avelar 1999). The practice of moving hives from one location to another for crop pollination is only reported for large-scale operations and from the northern states and state of Veracruz. An average of 131,000 hives was annually used for this purpose from 2000 to 2007, with a total of 135,586 hives in 2008 (SAGARPA 2010).

Before the introduction of honey bees, other bee species had been domesticated for many centuries in Mexico. The Maya of Mexico and Central America managed various bee species for hundreds of years, and many of the practices are used by the present-day Mayan people (Quezada-Euàn et al. 2001). The most important of the native domesticated species are stingless bees, managed principally for the harvest of honey (Slaa et al. 2006), cerumen ("cera de Campeche"), propolis, and pollen. Stingless bees have been reported to be effective pollinators of 16 crops (Slaa et al. 2006, Quezada-Euàn 2009), of which coffee, *Coffea arabica* L., may be most benefited. However, at present there are no species of stingless bees available on a commercial scale for use as managed pollinators in Mexico.

The common eastern bumble bee, *Bombus impatiens* Cresson (Fig. 1a), has been used since 1994 in México, principally for pollination of tomatoes in greenhouses (Winter et al. 2006). The natural distribution of this species is the eastern US and southeastern Canada (Velthuis and Van Doorn 2006, Williams 2009). This species is used as a managed pollinator in protected and open field crops in the US and Canada, within the natural distribution of the bumble bee in

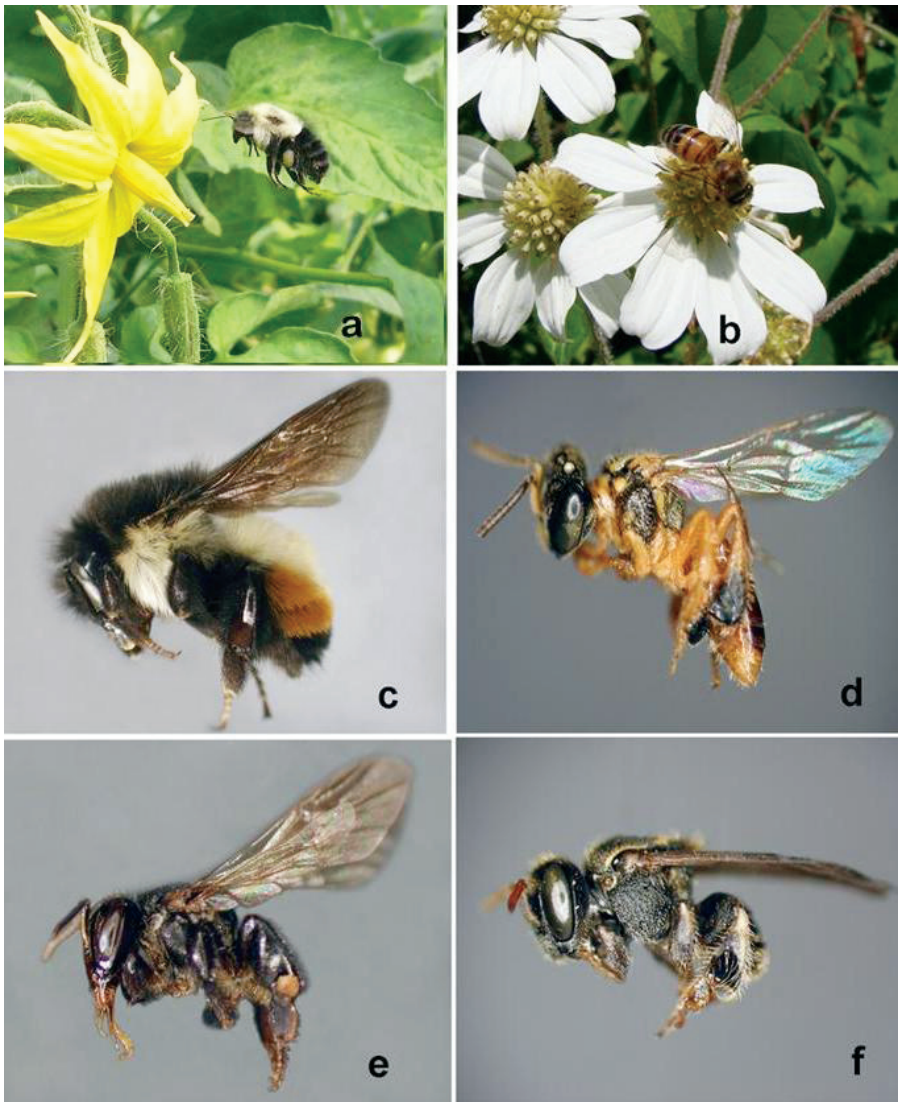

Fig.1. Bee fauna used as commercial and experimental pollinators in Mexico. a) *Bombus impatiens* Cresson b) *Apis mellifera* L., c) *Bombus ephippiatus* Say, d) *Tetragonisca agustula* Latreille, e) *Scaptotrigona mexicana* Guérin-Méneville, f) *Nannotrigona perilampoides* Cresson.

both countries. It is also used outside of its distribution in the western US but only within protected agriculture and with some restrictions (Winter et al. 2006). In Mexico, the Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA), through the National Center of Health, Safety and Agricultural Food Quality (SENASICA), regulates the importation of agricultural food products and is in charge of regulating the importation of species of bumble bees (*Bombus*) (SAGARPA 2010). Presently, two companies in Mexico produce and commercially market the common eastern bumble bee for use as a managed pollinator and have production plants with a complete production cycle: Koppert México in the state of Querétaro and Biobest in the state of Jalisco (Díaz 2011, Torres-Ruiz et al. 2011).

A native bumble bee, *Bombus ephippiatus* Say (Fig. 1c), has a widespread distribution throughout Mexico, with the exception of Baja California and the Yucatan Peninsula, and is found south through Central America to Panama (Labougle 1990, Ascher and Pickering 2012). This species is found in pine and oak forests above 1,500 m. *Bombus ephippiatus* has been considered a potential managed pollinator in previous studies (Fuentes and Madrid 2004, Hines et al. 2006) and used experimentally as a managed pollinator in tomatoes in greenhouses in the states of San Luis Potosí, Coahuila (Cuadrillero and Salinas-Navarrete 2006), Querétaro (Torres-Ruiz and Jones 2012), Jalisco (Cuadrillero 2011), and Chihuahua (Romo and Acosta 2010). Currently however, this species is not commercially available because it has not been successfully reared for mass production in a complete production cycle.

In conclusion, only two commercially produced species of Apoidea are available for use as managed pollinators in México: *Apis mellifera* and *Bombus impatiens.* This is few in comparison with the six species commercially available in the US and Canada (Table 1).

Table 1. Bee Species Commercially Available as Managed Pollinators in North America (National Research Council 2007)

Bee species	Countries of North America where commercially available		
Apis mellifera	Canada	United States	Mexico
Bombus impatiens	Canada	United States	Mexico
Nomia melanderi	Canada	United States	
Osmia cornifrons	Canada	United States	
Osmia lignaria	Canada	United States	

Crops for which Managed Bee Pollinators are Used

Honey Bees. The practice of renting honey bees for pollination is not as prevalent in Mexico as in other countries. A total of 135,000 hives was rented in Mexico for pollination in 2008 which represented only 7.5% of the honey bee hives present that year (SAGARPA 2010). Estimates from SAGARPA (2010) indicated that 70% of the rental of hives for pollination occurred within the northern states, of which the states of Sinaloa, Sonora, and Chihuahua account for 26, 18, and 15% of hive rentals, respectively. In contrast, the western zone annually rents approximately 22% of the hives. Hives are rented for a diverse number of crops in Mexico, principally for those destined for fruits and vegetables for exportation.

These crops include eggplant (*Solanum melongena* L.), squash (*Cucurbita* spp. L.), safflower (*Chartamus tinctorius* L.), strawberries (*Fragaria* spp. L.), apple (*Malus* spp. L.), melon (*Cucumis melo* L.), cucumbers (*Cucumis sativus* L.), watermelon (*Citrullus lanatus* [Thunb.] Matsum and Nakai), and tomatoes (*Solanum lycopersicum* Mill), primarily in open fields (Table 2).

Although the honey bee is a generalist pollinator and used in diverse crops, it is clearly not the most effective pollinator for all crops or the most practical. The honey bee is especially deficient as a pollinator for crops such as cranberries (*Vaccinium* sp.) and tomatoes that require pollination by vibration or "buzz pollination" (Stubbs and Drummond 2001, Javorek et al. 2002, Torres et al. 2007), because this kind of pollination is not characteristic of honey bees (Buchmann 1985). Another problem is the large size of honey bee hives that require special techniques and experience to manage. Africanization of honey bees also augments the possibility of massive attacks on workers within the vicinity of hives (Guzmán-Novoa et al. 2011). These problems limit the use of honey bees in restricted spaces such as greenhouses. For these reasons, the use of honey bees in greenhouses in Mexico is limited and only reported from greenhouses for pollination of cucurbit crops and strawberry in Baja California (Roberto Altamirano, Koppert México, personal communication).

Apple orchards of Mexico often require anti-hail nets because of frequent hail storms in the mountainous regions where apples are grown. In large orchards (>5 hectares) covered with anti-hail nets, honey bees often fail to pollinate the central portion of the orchard which results in reduced production (A. Torres and V. Gómez, unpublished data). In addition, honey bees are not active at temperatures colder than 15°C, which becomes a limiting factor where the flowering period is very short and environmental conditions are not optimal. Although the climate in regions where apples are grown in Mexico is considered to be temperate, with freezing temperatures in winter months, the annual oscillation in temperature is often less than 10^{o}C which contrasts to greater oscillations and warmer spring and summer temperatures in more northern regions (Hernández-Cerda and Carrasco-Anaya 2004). These relatively constant but cool temperatures can limit pollination and production in Mexican orchards of apples and peaches (Torres, unpublished data) and in blueberries (Torres et al. 2007).

Bumble Bees. All commercial bumble bee colonies presently in use in Mexico are *B. impatiens.* This *Bombus* species is primarily utilized for pollination of protected crops (greenhouses, shade houses, and macro tunnels). The estimated area of protected crop in Mexico is 12,000 hectares (INEGI 2007). Approximately 40% of this area is devoted to tomatoes, of which most are destined for exportation (SAGARPA 2010). Of the crops pollinated by *B. impatiens*, 90% are tomatoes. The remaining crops include other Solanaceae such as bell and chili peppers, as well as various cucurbits such as cucumbers and squash in greenhouses. Strawberries and raspberries (*Rubus* sp.) in shade tunnels are also pollinated by *B. impatiens*. It is estimated that 61% of the commercial colonies of bumble bees in Mexico are used in the northern states, of which three states are most important: Sinaloa (21% of the total colonies), Baja California (16%), and Sonora (9%) (Koppert México 2011, unpublished data). In contrast to *A. mellifera*, bumble bee colonies are not perennial, and no maintenance is required by the producer, which facilitates its implementation in the crop (Castañeda 2011).

Other Bee Species Used Experimentally as Managed Pollinators. Three Mexican species of stingless bees (meliponines) have been evaluated to date as

Table 2. Bee Species Used as Managed Commercially Available or Experimentally Managed Pollinators in Mexico

Bee species	Crop pollinated: Common name	Crop pollinated: Species name	Reference
Commercially available bee pollinators:			
Apis mellifera	Tomato	*Solanum lycopersicum*	
	Bell pepper	*Capsicum annuum*	
	Habanero pepper	*Capsicum chinense*	
	Squash	*Cucurbita* spp.	
	Strawberry	*Fragaria* spp.	
	Watermelon	*Citrullus lanatus*	
	Melon	*Cucumis melo*	Reyes and Cano (2006)
	Avocado	*Persea americana* Mill.	SAGARPA (2010)
	Apple	*Malus sylvestris*	
	Cucumber	*Cucumis sativus*	
	Safflower	*Chartamus tinctorius*	
	Mango	*Mangifera indica* L.	
	Citrus	*Citrus* spp. L.	
Bombus impatiens	Tomato	*Solanum lycopersicum*	Torres-Ruiz and Jones (2012)
	Bell pepper	*Capsicum annun*	Garcia and Gastelum (2012)
	Habanero pepper	*Capsicum chinense*	Palma et al. (2008a)
	Squash	*Cucurbita* spp.	Rogelio Castañeda Godoy personal communication
	Strawberry	*Fragaria* spp.	Rogelio Castañeda Godoy personal communication
Bee pollinators tested experimentally:			
Scaptotrigona mexicana	Rambutan	*Nephelium lappaceum*	Guzmán-Díaz et al. (2005), Esponda-Muñóz et al. (2005)
Tetragonisca angustula	Rambutan	*Nephelium lappaceum*	Slaa et al. (2006)
Nannotrigona perilampoides	Tomato	*Solanum lycopersicum*	Palma et al. (2008b), Cauich et al. (2004)
	Habanero pepper	*Capsicum chinense* Jacq.	Palma et al. (2008a), Cauich et al. (2006)
Bombus ephippiatus	Tomato	*Solanum lycopersicum*	Torres-Ruiz and Jones (2012), Romo Chacón and Acosta Muñiz (2010), Vergara and Fonseca-Buendia (2012)

managed pollinators: *Scaptotrigona mexicana* (Fig. 1e) (Arzaluz Gutiérrez et al. 2002, Esponda-Muñoz et al. 2005, Guzmán-Díaz et al. 2005), *Tetragonisca angustula* (Fig. 1d) (Slaa et al. 2006), and *Nannotrigona perilampoides* (Fig. 1f) (Cauich et al. 2004, 2006; Palma et al. 2008a,b; Quezada-Euán 2009). In Mexico, *S. mexicana* has been successfully used as a managed pollinator of rambutan, *Nephelium lappaceum* L. (Esponda-Munoz et al. 2005, Guzmán et al. 2005), and in small family-owned orchards in Chiapas (Remy Van Dame, personal communication). This species is also managed using traditional methods in coffee-growing and has been reported to significantly increase fruit production (Slaa et al. 2006).

The stingless bee *Nannotrigona perilampoides* has notable potential for commercial production in Mexico for several reasons. First, it is the stingless bee with the greatest distribution in Mexico. It is present the length of both coasts, from the Yucatán Peninsula to San Luis Potosí to the east and from Chiapas north to Sinaloa in the west, with populations found inland in the Rio Balsas depression (Ayala 1999). This distribution suggests that the species is most apt as a managed pollinator in tropical climates (Cauchi et al. 2004, 2006; Quezada-Euán 2009). Second, the species is relatively resistant to the warm temperatures common in greenhouses of Mexico (Cauich et al. 2004). Third, the species has been confirmed to be an effective pollinator of several crops. In habanero peppers (*Capsicum chinense* Jacq.) and tomato in greenhouses in the Yucatan Peninsula, the percentage of fruits and number of seeds produced, and fruit weight in treatments using *N. perilampoides* were similar in both crops to treatments pollinated by mechanical vibration (Cauchi et al. 2004, 2006; Palma et al. 2008a). However, *N. perilampoides* is not a buzz pollinator (Slaa et al. 2006), which is preferred for solanaceous crops such as tomato and peppers and for cranberry. Pollination by this species needs to be compared with that of bumble bees for solanaceous crops.

Perspectives on Sustainable Use and Conservation of Bees in Mexico

On a global perspective, the factors that impact the conservation of bees are habitat loss, invasive species, parasites, diseases, pesticides, overexploitation, extinction cascades, and climate change (Brown and Paxton 2009). For the neotropics, the conservation of native bees is threatened especially by human activities including deforestation, intensification of agriculture, and introduction of exotic species (Freitas et al. 2009). The deforestation rate for Mexico is approximately 347,000 hectares annually (FAO 2003), which is equivalent to 0.5% of the country's total forest surface area. This deforestation rate combined with the intensive use of agrochemicals, especially neocotinoid insecticides used in extensive monocultures, are the principal threats to bee pollinators in Mexico (Freitas et al. 2009, Brittain and Potts 2011, Whitehorn et al. 2012).

The presence of the widely reported Colony Collapse Disorder, a syndrome characterized by a marked decrease in managed honey bees reported in the United States and Europe (van Engelsdorp et al. 2008, Neumann and Carreck 2010, Potts et al. 2010) has not been detected in Mexico (Vandame and Palacios 2010). The number of honey bee hives reported for Mexico has decreased recently from 1.9 million in 1999 to 1.8 million in 2010 (SIAP 2010). Given the threat of Colony Collapse Disorder, various authors have advocated for improved apicultural practices in Mexico, with standardized methods for disease and pest prevention, in conjunction with improved training of apiculturists (Reyes and Cano 2006, SAGARPA 2010).

A total of 21 bumble bee species has been registered in Mexico (Labougle and Zozaya 1986). Three Mexican endemic species are considered most threatened: *Bombus haueri* Handlirsch, *Bombus macgregori* Labougle & Ayala, and *Bombus trinominatus* Dalla Torre (Williams and Osborne 2009). These three species have limited distributions and have been rarely collected in recent decades, a decline possibly caused by human activities. Given that *B. haueri*, *B. macgregori*, and *B. steindachneri* Handlirsch are Mexican endemics with reduced populations, we recommend that actions should be taken to categorize these species in the risk category of threatened (="amenazada") in accordance with Mexican law Nom-59-ECOL-2010 (SEMARNAT 2010).

Although these species are especially vulnerable, several biological characteristics of bumble bees in general make them susceptible to population declines including: climatic specialization, competition for food resources, and asynchrony of annual patterns of foraging activities with the presence of flowers (Williams et al. 2008). Climatic specialization limits bumble bees to temperate habitats generally higher than 1,500 m (Labougle 1990, Ascher and Pickering 2012). These temperate habitats, and especially cloud forests, have been greatly reduced in size in Mexico (Challenger 1998) and are one of the habitats most threatened by global warming (Ponce-Reyes et al. 2012).

The use of native bumble bee species as managed pollinators is recommended to reduce the risk associated with introduced species and possible displacement of native pollinators (Velthuis and Van Doorn 2006, Gouldson et al. 2008, Madjiiian et al. 2008). However, the development of the necessary technology for the production of multiple generations of bumble bee colonies under artificial conditions requires both basic and applied research during many years. In Mexico, two species of native bumble bees have been evaluated as managed pollinators: *Bombus ephippiatus* and *B. sonorus* Say (Vergara 2012). Most of these studies have evaluated efficiency of pollination in the field, but some studies have involved rearing methods. To date, all studies have used wild queens collected in the field without sustained reproduction, and no methods are yet available for rearing of these species. Such methods are necessary to ensure the quality of colonies for effective managed pollination. In addition, commercial rearing of native bumble bees would reduce the necessity for massive collection of bumble bee queens in natural habitats for single-generation colonies for pollination of crops in greenhouses, a practice presently utilized in the region of Autlan in Jalisco, Mexico (Cuadrillero 2011). More research is required to define the critical characteristics of successful managed pollinators. Recent information regarding the biological characteristics that favor the dispersion and successful establishment of the bumble bee, *Bombus terrestris* L. in non-native areas in Europe, offer guidelines for the selection of native species focusing on decreasing this environmental risk (Dafni et al. 2010). Finally, more effort is needed to develop rearing methods to ensure reliable procedures and rigorous hygienic standards.

Stingless bees have been considered to have potential for development as commercially managed pollinators based on the diversity of species and a long history of management (Slaa et al. 2006). Although some methods for maintenance of this species in hives with good development and colony viability have been developed (Arzaluz Gutiérrez et al. 2002), the limiting factor in the commercial use of this group of bees as managed pollinators is still the lack of technique for mass rearing. A total of 46 species of stingless bees (Meliponinae) is reported from Mexico (Ayala 1999). The conservation status of these bees has not been studied

in detail, but evidence from other regions suggests the bees are dependent on tropical forests and vice versa (Slaa et al. 2006). Bees use forest resources for food (floral resources) and nesting sites and may have specific requirements for each (Reyes-Novelo et al. 2009). Thus, the relatively high deforestation rates in Mexico threaten populations of stingless bees, although no species is presently classified with a threatened status under Mexican law Nom-59-ECOL-2010 (SEMARNAT 2010).

The promotion of traditional use of native stingless bees combined with development of new technologies for the use of these species as managed pollinators offer potential for their conservation in Mexico. In addition, because wild bees are good indicator groups of biodiversity and fragmentation (Reyes-Novelo et al. 2009), supporting conservation and use of stingless bees in general, would likewise encourage conservation of tropical habitats. Research to improve and support programs promoting stingless bee management would also offer sustainable alternatives for use of natural resources in rural communities, as well as provide insights into methods for commercial use of these pollinators.

Conclusions

Mexico has a rich diversity and heritage of cultivated plants, more than half of which produce seeds or fruits consumed by humans, and approximately 85% of which depend to some degree on pollinators for efficient production. Mexico also has a great diversity of species of bees, some of which have potential for use as managed pollinators. Managed pollinators are crucial for intensive agricultural practices, especially considering the accelerated loss of biodiversity and recent problems with honey bee decline. Despite the importance of managed pollinators, only two species are commercially available in Mexico: the honey bee, *Apis mellifera,* and common eastern bumble bee, *Bombus impatiens.* The honey bee is rented for pollination of fruit, horticultural, and industrial crops in open fields principally in the north of Mexico, whereas *B. impatiens* is used principally for pollination of tomatoes in protected cultivation. Deforestation combined with the intensive use of agrochemicals in extensive monocultures areas are the principal threats to conservation of wild and managed bees in Mexico. Improved monitoring and sanitary practices are necessary for honey bee hives in Mexico, and could prevent the marked decline in hives observed elsewhere. There has been concern about use of the common eastern bumble bee in Mexico given that the species in not native. Several other native bumble bees show potential as managed pollinators, and methods could be developed for their commercial production. Research is needed to provide a greater diversity of bee species that can be used for commercial, managed pollination services that could benefit the preservation of the grand diversity of crops and the habitats where they are grown in Mexico.

Acknowledgment

Thanks to Rogelio Castañeda, Rigoberto Bueno, Roberto Altamirano, and Saul García for sharing their experiences with commercial bumble bee pollination. Thanks also to Benjamin Breman for permission to use his photograph of *B. impatiens* (Fig. 1a). Thanks to Remy Vandame for sharing information regarding pollination by stingless bees.

References Cited

Arzaluz Gutiérrez, A., F. Obregón Hernández, and R. W. Jones. 2002. Optimum brood size for artificial propagation of the stingless bee, *Sacaptotrigona mexicana* Guérin (Hymenoptera: Apidae: Meliponinae). J. Apicult. Res. 41: 62-63.

Ascher, J. S., and J. Pickering. 2012. Discover life bee species guide and world checklist (Hymenoptera: Apoidea: Anthophila). http://www.discoverlife.org/mp/20q?guide=Apoidea_species

Ashworth, L., M. Quesada, A. Casas, R. Aguilar, and K. Oyama. 2009. Pollinator-dependent food production in Mexico. Biol. Cons. 142: 1050-1057.

Ayala, R. 1999. Revisión de las abejas sin aguijón de México (Hymenoptera: Apidae: Meliponini). Folia Entomol. Mex. 106: 1-123.

Brittain, C., and S. G. Potts. 2011. The potential impacts of insecticides on the life-history traits of bees and the consequences for pollination. Basic Appl. Ecol. 12: 321-331.

Brown, M. J. F., and R. J. Paxton. 2009. The conservation of bees: a global perspective. Apidologie 40: 1-7.

Buchmann, S. L. 1985. Bees use vibration to aid pollen collection from non-poricidal flowers. J. Kan. Entomol. Soc. 58: 517-525.

Cajero-Avelar, S. 1999. Situación de la apicultura en México, pp. 20-29. *En* C. M. Echazarreta y R. A. Arellano [eds.], Memorias del Primer foro de Proyectos Integrales SISIERRA, México.

Castañeda, G. R. 2011. Guía de manejo en campo de NATUPOL®. Koppert México SA de CV. Querétaro, México. http://www.koppert.com.mx/publicaciones/manejo-de-colmenas. Acceso Junio 2012.

Cauich, O., J. G. Quezada-Euán, J. O. Macias-Macias, V. Reyes-Oregel, S. Medina-Peralta, and V. Parra-Tabla. 2004. The behavior and pollination efficiency of *Nannotrigona perilampoides* (Hymenoptera: Meliponini) on greenhouse tomatoes (*Lycopersicon esculentum*) in subtropical México. J. Econ. Entomol. 97: 475-481.

Cauich, O., J. G. Quezada-Euán, V. Meléndez, G. R. Valdovinos-Núñez, and H. Moo-Valle. 2006. Pollination of habanero pepper (*Capsicum chínense*) and production in enclosures using the stingless bee *Nannotrigona perilampoides*. J. Apicult. Res. 45: 125-130.

Challenger, A. 1998. Utilización y conservación de los ecosistemas terrestres de México. Comisión Nacional para el Conocimiento y uso de la Biodiversidad, México, DF.

Cuadrillero, I. 2011. Ephippol, abejorros mexicanos para la polinización de tomates en invernaderos. Resumen. X International Symposium of Pollination. UDLAP Cholula, Puebla, México.

Cuadrillero, I., y J. C. Salinas-Navarrete. 2006. Los riesgos de importar polinizadores exóticos y la importancia de su legislación, p. 16. *En* Resúmenes. Primera reunión mexicana de la Campaña Norteamericana para la Protección de los Polinizadores (NAPPC). San Juan del Río, Querétaro. México.

Dafni, A., P. Kevan, C. L. Gross, and K. Goka. 2010. *Bombus terrestris*, pollinator, invasive and pest: An assessment of problems associated with its widespread introductions for commercial purposes. Appl. Entomol. Zool. 45: 101:113.

Delaplane, K. S., and D. F. Mayer. 2000. Crop Pollination by Bees. CABI Publishing. Wallingford, UK.
Diaz, L. J. 2011. Biobest in Mexico, History and Perspectives. X International Symposium of Pollination. UDLAP. Cholula, Puebla, México.
Esponda-Muñoz, J. A., R. M. Rincón, D. M. A. Guzmán, and R. Vandame. 2005. Efecto de la densidad de abejas *S. mexicana* en la producción de rambután (*Nephelium lappaceum* L.) en el Soconusco, Chiapas, pp. 1-5. *En* Memorias del IV Seminario Mesoamericano sobre Abejas sin Aguijón.
FAO. 2003. The State of the World´s Forest 2003. FAO, Rome.
FAO. 2007. Crop Economic Indicators by country. http://faostat.fao.org/site/291/default.aspx
Freitas, B. M., and J. Filho de Oliveira. 2001. Creaçao de Mamangavas para la polinizaçao em áreas agrícolas. Fortaleza: Banco do Nordeste.
Freitas, B. M., V. L. Imperatriz-Fonseca, L. Medina, A. M. Kleinert, L. Galetto, G. Nates-Parra, and J. G. Quezada-Euán. 2009. Diversity, threats and conservation of native bees in the Neotropics. Apidologie 40: 332-346.
Fuentes, M., y C. Madrid. 2004. Biología de *Bombus ephippiatus* Say (Himenoptera, Apidea). Tesis para obtener el título de biólogo. Universidad de las Américas Puebla.
García, M. S., y L. J. Gastelum. 2012. Control biológico de plagas e implementación de polinización natural con abejorros (NATUPOL®) sobre pimiento en el valle de Guaymas, Sonora, México. *En* A. Torres-Ruíz y E. Rodríguez-Leyva [eds.], Guía para el Manejo Integrado de Plagas del Pimiento bajo Invernadero, con énfasis en el Picudo del Chile. Koppert México S.A. de C.V. Querétaro, México.
Gazit, A., and G. A. Ish. 2007. Stingless bees can serve as efficient avocado pollinators. *In* C. A. C. Gardner, M. A. Harris, R. W. Hellmich, H. T. Horner, J. D. Nason, R. G. Palmer, J. J. Tabke, R. W. Thornburg, and M. P. Widrlechner [eds.], 9th International Pollination Symposium on Plant-Pollination Relationships-Diversity in Acton: Program and Abstracts. Iowa State University, Ames, IA.
Gouldson, D., G.C. Lye, and B. Darvill. 2008. Decline and conservation of bumble bees. Annu. Rev. Entomo. 5: 191-208.
Guzmán-Díaz, C., J. García, J. A. Esponda, R. Vandame, M. Padilla, M. Rincón, and D. Roubik. 2005. Influencia de la densidad y distribución de *Scaptotrigona mexicana* Guérin-Meneville (Apidae: Meliponini) en la producción de frutos de rambután (*Nephelium lappaceum* L.) en la región del Soconusco, Chiapas, México, pp. 1-7. *En* Memorias del IV Seminario Mesoamericano sobre Abejas sin Aguijón.
Guzmán-Novoa, E., B. A. Correa, M. L. Espinosa, y G. Guzmán-Novoa. 2011. Colonización, impacto y control de las abejas melíferas africanizadas en México. Vet. Mex. 42: 149-178.
Hernández-Cerda, M., y G. Carrasco-Anaya. 2004. Climatología. *En* I. Luna, J. J. Morrone, and D. Espinosa [eds.], Biodiversidad de la Sierra Madre Oriental, Comisión Nacional para el Conocimiento de la Biodiversidad, Xalapa, México.
Hines, H. M., S. A. Cameron, and P. H. Williams. 2006. Molecular Phylogeny of the bumblebee subgenus *Pyrobombus* (Hymenoptera: Apidae: *Bombus*) with insights into gene utility for lower-level analysis. Invert. Systematics 20: 289-303.

INEGI. 2007. Censo Agropecuario 2007. VIII Censo Agrícola Ganadero and Forestal.

Javorek, S. K., K. E. Macknzie, and S. P. Vander Kloet. 2002. Comparative pollination effectiveness among bees (Hymenoptera: Apoidea) on lowbush blueberry (Ericaceae: *Vaccinum angustifolium*). Ann. Entomol. Soc. Am. 95: 345-351.

Klein, A. M., B. Vaissière, J. H. Cane, I. Steffan-Dewenter, S. A. Cunningham, C. Kremer, and T. Tscharntke. 2007. Importance of pollinators in changing landscapes for world crops. Proc. R. Soc. B. 274: 303-313.

Kremen, C., N. M. Williams, and R. W. Thorp. 2002. Crop pollination from native bees at risk from agricultural intensification. Proc. Nat. Acad. Sci. 99: 16812-16816.

Labougle, J. M. 1990. *Bombus* of México and Central America (Hymenoptera: Apidae). Univ. Kans. Sci. Bull. 54: 35-73.

Labougle, J., y J. A. Zozaya. 1986. La apicultura en México. Ciencia y Desarrollo 12: 17-36.

Madjiiian, J. A., C. L. Morales, and H. G. Smith. 2008. Displacement of a native by an alien bumblebee: lower pollinator efficiency overcome by overwhelmingly higher visitation frequency. Oecologia 156: 835-845.

Meisels, S., and H. Chiasson. 1997. Effectiveness of *Bombus impatiens* Cresson as pollinators of greenhouse sweet peppers (*Capsicum annuum* L.). Acta Hortic. 437: 425-429.

Morandin, L. A., T. M. Laverty, and P. G. Kevan. 2001b. Bumble bee (Hymenoptera: Apidae) activity and pollination levels in commercial tomato greenhouses. J. Econ. Entomol. 94: 462-467.

Nabhan, P., and L. Buchmann. 1997. Services provided by pollinators, pp. 133-150. *In* G. C. Daily [ed.], Natural's Services: Societal Dependence on Natural Ecosystems. Island Press. Washington, DC.

National Research Council of the National Academies. 2007. Status of Pollinators in North America. National Academy of Science, Washington, DC.

Neumann, P., and N. Carreck. 2010. Honey bee colony losses. J. Apic Res. 49: 1-6.

Palma, G., J. G. Quezada-Euán, V. Meléndez-Ramírez, J. Irigoyen, G. R. Valdovinos-Nuñez, and M. Rejón. 2008a. Comparative efficiency of *Nannotrigona perilampoides*, *Bombus impatiens* (Hymenoptera: Apoidea), and mechanical vibration on fruit production of enclosed Habanero pepper. J. Econ. Entomol. 101: 132-138.

Palma, G., J. G. Quezada-Euán, V. Reyes-Oregel, V. Meléndez, and H. Moo-Valle. 2008b. Production of greenhouse tomatoes (*Lycopersicon esculentum*) using *Nannotrigona perilampoides*, *Bombus impatiens* and mechanical vibration (Hym.:Apoidea). J. Appl. Entomol. 132: 79-85.

Ponce-Reyes, R., V. H. Reynoso Rosales, J. E. M. Watson, J. VanDerWal, R. A. Fuller, R. L. Pressey, and H. P. Possingham. 2012. Vulnerability of cloud forest reserves in Mexico to climate change. Nature Climate Change 2: 448-452.

Potts, S., J. Biesmeijer, C. Kremen, P. Neumann, O. Schweiger, and W. Kunin. 2010. Global pollinator declines: trends, impacts and drivers. Trends Ecol. Evolut. 25: 345-353.

Quezada-Euán, J. 2009. Potencial de las abejas nativas en la polinización de cultivos. Acta Biológica Colombiana 14: 169-172.

Quezada-Euán, J., W. May-Itzá, and J. González-Acereto. 2001. Meliponiculture in Mexico: problems and perspective for development. Bee World 82: 160-167.
Reyes, C. L., y P. Cano. 2006. Manual de polinización apícola. Coordinación general de ganadería. SAGARPA.
Reyes-Novelo, E., V. M. Ramírez, H. D. González, and R. Ayala. 2009. Abejas silvestres (Hymenoptera:Apoidea) como bioindicadores en el neotrópico. Tropical and Subtropical Agroecosystems. 10: 1-13.
Romo, C. A., y C. H. Acosta. 2010. Validación de la eficiencia de los abejorros en la polinización del cultivar del jitomate en condiciones de invernadero en el noroeste de Chihuahua. Centro de Investigación en Alimentación y Desarrollo A.C. Cuauhtémoc, Chihuahua.
SAGARPA. 2010. Situación actual y perspectiva de la apicultura en México. Claridades Agropecuarias 199.
SEMARNAT (Secretaria de Medio Ambiente y Recursos Naturales). 2010. NOM-059-ECOL-2001. Protección ambiental-Especies nativas de México de flora y fauna silvestres-Categorías de riesgo y especificaciones para su inclusión, exclusión o cambio-Lista de especies en riesgo, pp. 1-77. Diario Oficial de la Federación, Segunda sección, 30 de Diciembre de 2010.
SIAP (Servicio de Información Agroalimentaria and Pesquera). 2010. http://www.siap.gob.mx/index.php/ganaderia/poblacion-ganadera.html. Acceso Junio 2012.
Slaa, J. E., A. L. Sánchez-Chaves, S. K. Malagodi-Braga, and E. F. Hofstede. 2006. Stingless bees in applied pollination: practice and perspectives. Apidologie 37: 293-315.
Stubbs, C. S., and F. A. Drummond. 2001. *Bombus impatiens* (Hymenoptera: Apidae): an alternative to *Apis mellifera* (Hymenoptera: Apidae) for lowbush blueberry pollination J. Econ. Entomol. 94: 609-616.
Torres-Ruiz, A., and R. W. Jones. 2012. Comparison of the efficiency of the bumblebees, *Bombus impatiens* and *Bombus ephippiatus* (Hymenoptera: Apidae), as pollinators of tomato in greenhouses. J. Econ. Entomol. 105:1871-1877.
Torres, A., R. Ruiter, and C. M. Mainland. 2007. High-bush blueberry pollination by the bumblebee *Bombus impatiens*. *In* C. A. C. Gardner, M. A. Harris, R. W. Hellmich, H. T. Horner, J. D. Nason, R. G. Palmer, J. J. Tabke, R. W. Thornburg, and M. P. Widrlechner [eds.], 9th International Pollination Symposium on Plant-Pollination Relationships-Diversity in Acton: Program and Abstracts. Iowa State University, Ames, IA.
Torres-Ruiz, A., P. Sima, and K. Bolckmans. 2011. Managing Pests and Diseases in Commercial Bumblebee Production. *In* Abstract of X International Symposium of Pollination. UDLAP Cholula, Puebla, México.
UNEP. 2010. UNEP Emerging Issues: Global Honey Bee Colony Disorder and Other Threats to Insect Pollinators.
Van Engelsdorp, D., J. Hayes, R. Underwood, and J. Pettis. 2008. A survey of honey bee colony losses in the US, Fall 2007 to Spring 2008. PLoS ONE 3: 1-6.
Vandame, R., and M. A. Palacios. 2010. Preserved honey bee health in Latin America: a fragile equilibrium due to low-intensity agriculture and beekeeping? Apidologie 41: 243-255.

Velthuis, C., and A. Van Doorn. 2006. A century of advances on bumblebee domestication and the economic and environmental aspect of its commercialization for pollination. Apidologie 37: 421-451.

Vergara, C. H. 2012. Laboratorio de Entomología. Universidad de las Américas Puebla: Proyectos de investigación con *Bombus* spp. 2002-2012. Taller/curso: Estatus de conservación and riesgos sanitarios de abejorros nativos del género *Bombus* en México. El Colegio de la Frontera Sur (ECOSUR), San Cristóbal de Las Casas, Chiapas.13 al 17 de Febrero de 2012.

Vergara, C. H., and P. Fonseca-Buendía. 2012. Pollination of greenhouse tomatoes by the Mexican bumblebee *Bombus ephippiatus* (Hymenoptera: Apidae). J. Pollination Ecol. 7: 27-30.

Whitehorn, R. P., S. O´Connor, L. F. Wackers, and D. Goulson. 2012. Neonicotinoid pesticide reduces bumble bee colony growth and queen production. Science 6079: 351-352.

Williams, P. H. 2009. Bumblebees of the World. www.nhm.ac.uk/research-curation/research/project./bombusregions.html/.

Williams, P. H., and J. L. Osborne. 2009. Bumblebee vulnerability and conservation world-wide. Apidologie 40: 367-387.

Williams, P. H., S. A. Cameron, H. M. Hines, B. Cederberg, and P. Rasmont. 2008. A simplified subgeneric classification of the bumblebees (genus *Bombus*). Apidologie 39: 46-74.

Winter, K., L. Adams, R. Thorp, D. Inouye, L. Day, J. Ascher, and S. Buchmann. 2006. Importation of Non-Native Bumblebees into North America: Potential Consequences of Using *Bombus terrestris* and other Nonnative Bumblebees for Greenhouse Crop Pollination in Canada, Mexico and the United States. North American Pollination Protection Campaign.