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Introduction

The natural environment and modern society are inextricably bound to pollinators; these pollinators maintain a healthy, genetically diverse ecosystem of wild plants and are essential in the pollination of many food crops and, thus, food security (Potts et al., 2006). Although some mammals, reptiles, and birds are pollinators, insects are by far the most common. Bees, including honey bees, bumble bees, and solitary bees, are the most prominent and economically important pollinators worldwide. Of all the bee species (>20,000 species in 9 families), the western honey bee (*Apis mellifera*) is by far the most commonly managed.

The economic value of pollination in 2009, based on the global crop market, was estimated in several ways. The minimum estimate was US$164 billion (Gallai, Salles, Settele, & Vaissière, 2009), while the estimate ranged from US$235 to US$577 billion annually if assessed based on an enhancement of crop yields (Potts et al., 2016). The value of the western honey bee's pollination in the USA alone has been estimated at some US$15 to US$20 billion annually (vanEngelsdorp, Hayes Jr, Underwood, & Pettis, 2010). In the USA, >90% of all almond, blueberry, and apple crops are reliant upon this one pollinator species (Calderone, 2012).

The vital role that pollinators play in enhancing the productivity of various crops, such as fruits and nuts, vegetables and pulses, oil and forage crops, have often been underestimated especially in developing countries, where pollinator services are considered to be more important because a greater proportion of the inhabitants is maintained by income from agriculture. Egypt is no exception. Crops that are fully dependent on pollinators, such as melons (including watermelons), citrus fruits, and *aubergine* (eggplant), are some of the biggest contributors to the Egyptian agricultural market. As populations of pollinators decline, these crops will suffer a dramatic drop in production, and this will impact not only individual producers but also Egypt's economy as a whole (Brading, El-Gabbas, Zalat, & Gilbert, 2009).

Therefore, the aim of this review is to compile what is known about beekeeping in Egypt, statistics on beehives in Egypt, non-*Apis* pollinators, crops in need of pollination, and the potential honey bee pollination gap in Egypt. This review was performed in an attempt to draw the attention of stakeholders and decision makers to the value of pollinators in terms of the sustainability of agricultural production in Egypt.

Beekeeping in Egypt

It could be argued that, of all the countries of the ancient world, Egypt has the longest documented history of honey bee use. The founder of the First Dynasty of Egyptian Kings, King Menes, was known as the "beekeeper" (~4445 BC), and future rulers were often referred to as the "Bee King" (Crane, 1999). The oldest drawings and paintings on tombs, sarcophagi, temples, and obelisks in Egypt clearly show how beekeeping was an intrinsic part of society (Figure 1). Beekeeping in ancient Egypt was characterized by the use of cylindrical hives and production of huge amounts of honey (Figure 2).

Modern beekeeping in Egypt began in 1918, when a group of amateurs began to use wooden Langstroth frames and formed the first association of beekeepers in 1920. Since then and continuing on up until today, this association has issued regular bulletins to improve upon methods and share ideas about beekeeping in Egypt (Maddi, 2016). After the introduction of Langstroth frames, a gradual shift from traditional beekeeping methods to modern methods has occurred, such that today 99% of beekeepers in Egypt use modern methodologies. As for pollination periods, Egypt offers three seasons for pollination, which are characterized as the citrus, clover, and cotton seasons.

The western honey bee, *Apis mellifera,* is found naturally across Europe, the Middle East, and Africa and has been partitioned into 20 subspecies. In 1906, Lamarck's honey bee (*A. m. lamarckii*) was categorized as originating from the Nile Valley and Sudan (Sheppard, Shoukry, & Kamel, 2001). It is assumed that this subspecies might be the same as the one that existed during the time of the Pharaohs. Lamarck's bee is described as a good housekeeper but a poor honey producer. This indigenous subspecies has been replaced by or hybridized with other imported varieties, mainly *A. m. carnica* (Kamel, Strange, & Sheppard, 2003; Sheppard et al., 2001). The isolated Siwa Oasis still hosts populations of the pure *A. m. lamarckii* species, which are reared in traditional hives.

Statistics on Beehives in Egypt

Egypt is considered as the most important country for beekeeping among Arab nations, as well as throughout Africa (Al-Ghamdi, Alsharhi, & Abou-Shaara, 2016). The food and agriculture organization (FAO) statistics on data collected for beehives in Egypt from 1960 to 2016 indicate that the numbers of beehives rose from 1961 to 1990, peaking at 1.7 million beehives, dropped thereafter and declined steeply between 2005 (~1.5 millions) and 2015 (~800 thousands) (Figure 3). The fluctuation in numbers of beehives in Egypt observed between 1960 and 2016

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Figure 1. Part of a beekeeping relief at Pabasa's tomb (Photo: Gene Kritsky and used with permission).

could be associated with several factors. The first might be related to the 10% increase in the total cropped area that occurred between 1970 and 1990, which reflects the development of new land plots and increasing cultivation, which provided more crops and cultivated areas where bees could forage and flourish. Moreover, the five most important crops in Egypt, in terms of area, occupied about 77% of the cropped area in 1970.

Figure 2. Mud hives used for beekeeping in Upper Egypt (https://pcela.rs/Egyptian_Beekeeping_2.htm).

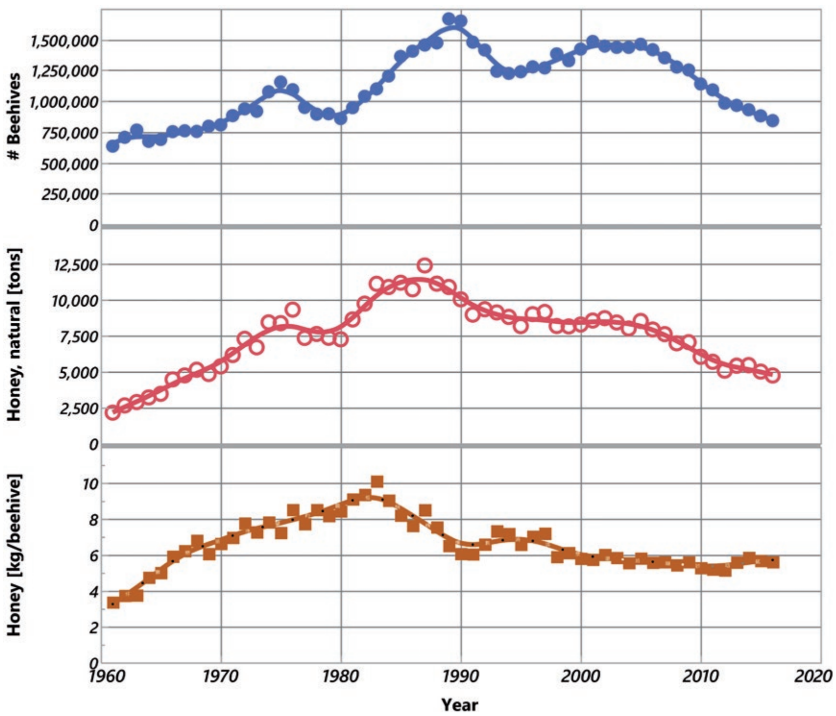

Figure 3. FAO statistics on numbers of beehives, honey production [tons], and honey yield per hive [kg] in Egypt from 1960 to 2016 (Data source: www.fao.org/faostat). Lines represent smoothed trend by the Loess method.

Some crops do not necessarily depend on animal pollination, but largely benefit from animal pollination. These crops include three major ones that are widespread in Egypt: *berseem* which is known as Egyptian clover (*Trifolium alexandrinum* L.), cotton, and maize (Dixit, Singh, & Gupta, 1989). Also, the area devoted to fruits increased by almost 165% in 1989, and the areas dedicated to winter and summer vegetables increased by about 94% and 32%, respectively (Goueli & El Miniawy, 1994). The increase in area allocated to fruits and vegetables and the minimal effect of honey bee parasites and pathogens observed during this period were significant in that these factors correlated with the increasing numbers of beehives.

The decline in numbers of beehives in Egypt observed between 1990 and 2016 could be attributed to several factors: (1) the destructive effects of the *Varroa* mite, which represents the major ectoparasite of honey bees in Egypt and worldwide and was first observed in Egypt in 1983 (Abou-Shaara & Tabikha, 2016); (2) the loss of agricultural land in Egypt due to urbanization (El-Hefnawi, 2005; El-Wakeil & Abdallah, 2012) that led to decreasing trends in cultivated crops that depend on honey bee pollination; (3) the extension and overuse of pesticides against different crop pests, which negatively affect bees (Al Naggar et al., 2015; Codling, Al Naggar, Giesy, & Robertson, 2018); (4) adverse effects of in-hive chemicals used to protect and treat honey bees against pathogens and parasites; and/or (5) the introduction of alien species (Shebl, Kamel, & Mahfouz, 2013).

Besides the number of beehives per year and country, the FAO database reports also included figures on honey (Figure 3) and beeswax production (not shown here). We also calculated the honey yield per beehive (lowest curve of Figure 3). Egyptian honey production was on the rise from 1961 up until the mid-1980s, with a parallel growth of productivity from an average of 3 kg/hive to 10 kg. From the mid-1980s to the 1990s, a pronounced decline to 6 kg/hive was observed and, later, a slow decline to 5–6 kg/hive stabilized productivity.

The Importance of Pollination in Egypt

Inadequate pollination not only reduces yields but may also delay the maturity and quality of fruits and impair the economic success of fruit production (Saltveit, 2005).

There are numerous ways a grower, with little or no intimate knowledge of the life and habits of pollinating animals, can assess the effectiveness of the pollination of his or her crop by observing the compact clusters of fruits or seeds, and uniform set. For example, adequate pollination is indicated by the presence of two or more muskmelons near the crown or base of the vine, or a majority of the apples developing from the king, or primary bud or bloom, at the tip of the cluster. In a watermelon field, adequate pollination would be indicated by a high percentage of melons in the number 1 class, that is, symmetrical, completely developed throughout, and of satisfactory weight (Abrol, 2012).

In Egypt, the effects of bee pollination that increase the yields, vitamin content, and quality of different crops have been extensively investigated (Blal, Kamel, Mahfouz, & El-Wahed, 2012; Bondok, El Nahrawy, & Esa, 2016; Taha & Bayoumi, 2009). For example, the foraging behavior of honey and wild bees and their effects as pollinators have been evaluated on summer seed watermelon flowers in Kafr El Sheikh Governorate, Egypt, in 2006 (Taha & Bayoumi, 2009). The authors of this study recorded 11 insect species as pollinators on summer seed watermelon plants, and *A. mellifera* was the predominant species seen. Their results also revealed that one hectare of summer seed watermelon could produce 10 kg of honey per season. Open pollination treatment produced the highest number of mature fruits and seed yield compared to caged plants lacking insect visitors, which did not produce any fruits.

Without services provided by pollinators, many plant species would be driven to extinction, and the cultivation of many modern crops would be impossible. Without bees providing these services, invisibly working in the background, many economies would collapse. For example, a study on the market value of Egyptian crops included an estimate based on 2004 data of the total loss that an absence of pollinators would cause. The annual cost to the Egyptian economy due to a catastrophic loss of pollinators would have amounted to approximately LE 13.5 billion (US$2.4 billion), 3.3% of the 2003 GDP (Brading et al., 2009).

Status of Pollination Services in Egypt

Based on FAO data on crop production and land use in Egypt, we statistically evaluated all 78 time series for groups of crops (some statistical analyses based on domestic data and some based on FAO data). From this list, we identified crops that need pollination (area [ha], production [tons]). The list is not complete, but no better data are publically available. Creating a list of the top 10 crops in terms of production, we created an estimate of ha and tons of crops that require pollination. These cover at least ~16% of the agricultural area and represent ~25% of the total agricultural production amount. Top products requiring pollination are tomatoes, oranges, watermelons, eggplants, melons, mangoes, clementines, apples, and chili peppers (**Table S1**).

Because several harvests are made each year, the harvested area exceeds the area of arable land by far, and crop productivity is high, which is also due to irrigation. An evaluation of the rate of production in terms of an absolute need for pollination yielded the total production 1961–2016 (lower part of Figure 4) and the production that depended on pollination. The upper part of Figure 4 shows the percentage of total production that strictly depends on pollination. That dependence on pollination increased from 22% to over 30% in 2009 and then diminished to 27% from 2009 up until 2016. Since around 2009, the absolute production [tons] is stagnant, while the total production grows constantly, which explains the falling rate. This might be an indicator that pollination services have become a limiting factor for production.

During the period from 1961 to 2016, the number of beehives in the pollinator-dependent area fell, calculated as beehives per pollination-dependent crop area [ha] (Figure 5). This rate (plotted at the lowest position) starts in 1961 at 3 hives/ha. Although the trend varied in the 1980s with rates above 2, a consistent, overall, downward trend was observed from 1990 up until 2016, the last year of data included in the FAO database. After 1990, as the number of beehives dwindled, the rate decreased constantly to less than 1 hive per ha. This is a clear evidence for the immediate current threat to pollination in Egypt (Figure 5) as this rate is expected to deteriorate in future if it is not counteracted. It is still unknown whether a relation between loss in number of beehives and the relative decline in areas of crops needing pollination in Egypt has existed during the past 10 years as the data are inconclusive. We can, however, devise a hypothesis that farmers will probably switch to crops that do not need pollination if the yields of pollination-dependent crops continue to deteriorate.

Non-*Apis* Pollinators in Egypt

The results of multiple studies have revealed that some plants need certain species of pollinators or bees other than honey bees. Certain wild bees are superior to honey bees for pollination (Kamel, Abu Hashesh, Osman, & Shebl, 2007; Shebl, Kamel, Abu Hashesh, & Osman, 2008a, 2008b). Alfalfa is one example; *Medicago sativa* is pollinated by leafcutter bees and commonly used as animal fodder in the USA, Canada, and other parts of the world (Richards, 1995).

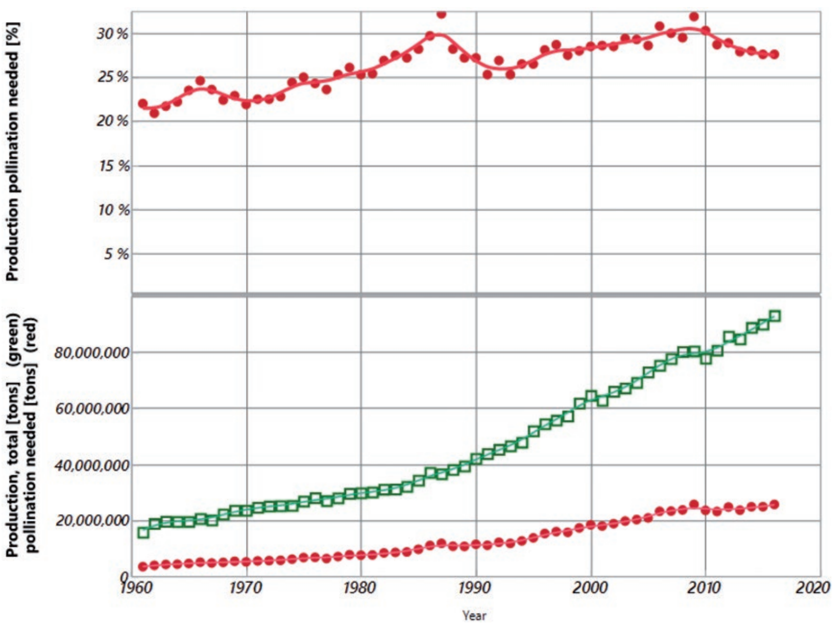

Figure 4. Agricultural production in Egypt and the need for pollination (1961–2016) (Data source: www.fao.org/faostat). Lines represent smoothed trend by the Loess method.

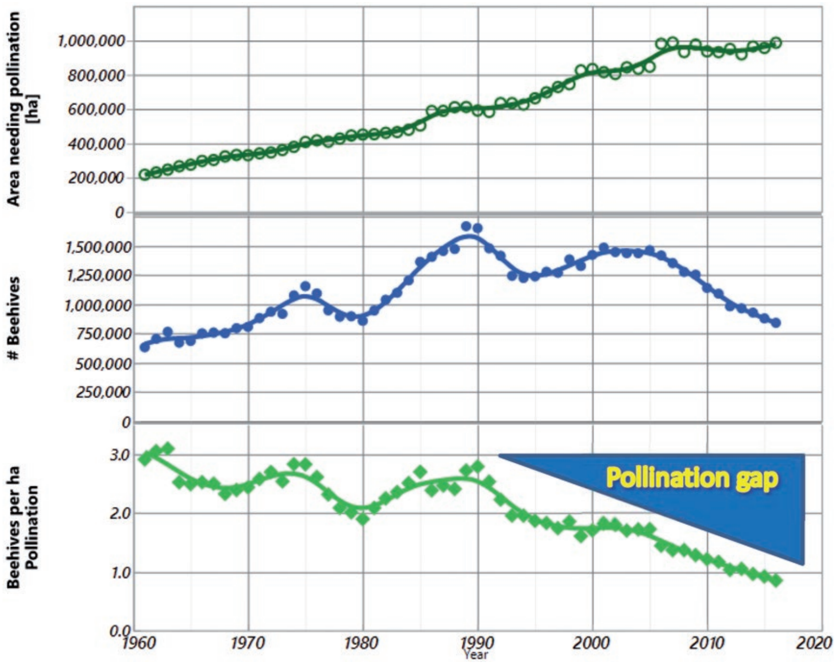

Figure 5. Honey bee pollination gap in Egypt (Data source: www.fao.org/faostat). Lines represent smoothed trend by the Loess method.

Artificial nest sites for the leafcutter bees (*Megachile minutissima*) increased production of alfalfa seed in Ismailia, Egypt more than did fertilization treatments (Shebl et al., 2008a). Alternatively, wild bees complement honey bees and increase efficiency of pollination in many cases (Winfree et al., 2018). An example is on hybrid sunflowers where wild bees effectively double honey bee pollination services under average field conditions (Greenleaf & Kremen 2006; Goras et al., 2016). These findings also demonstrate the economic importance of interspecific interactions and complementation for ecosystem services and suggest that protecting wild bee populations can help buffer the human food supply from instability due to honey bee shortages (Brittain, Williams, Kremen, & Klein, 2013; Winfree et al., 2018).

It is expected that diversity of bees present in Egypt is due to the diversity of the flora. However, the exact number of non-*Apis* species in Egypt is unknown due to the fact that few studies have been carried out. An unpublished collaborative study conducted in the 1960s and 1970s, involving researchers from USDA Bee Biology and Systematics Laboratory and researchers from Cairo University and the Egyptian Ministry of Agriculture, identified at least 36 species of bees that forage on alfalfa and clover, as well as numerous additional species on other important crops. Most notable was a community of megachilid bees that build their nests in tunnels in the walls of mud houses (Kamel & Shoukry, 2001).

From 1970 to 1980, studies were conducted that only covered parts of Northern and Upper Egypt around the Nile Valley, and about 44 species of bees and 16 species of other Hymenopteran wasps were found (Ibrahim, 1973, 1979; Rashad, 1979, 1980). Then, after a gap of more than 30 years, the biodiversity of native bee populations, their floral resources, and nesting habitats around the Canal region of Egypt were re-explored (Shebl et al., 2013). About 900–1,000 specimens of bees were collected from different locations of the Ismailia, Suez, and Sinai Governorates. The authors of this study identified 55 species of bees. The total number of species identified for each family was 7, 9, 11, 13, and 15 species for Andrenidae, Colletidae, Apidae, Halictidae, and Megachilidae, respectively.

Discussion

Our knowledge and response actions have not kept pace with threats to pollinators and pollination services. Although there has been increased interest from scientists (Lautenbach, Seppelt, Liebscher, & Dormann, 2012), policy-makers (Dicks et al., 2016), and the public, a mismatch remains between the collection of scientific evidence on the impacts and conservation efforts and/or management responses. Based on the results of analyses of FAO data on the current numbers of beehives in Egypt (~800 thousands) and a comparison with the numbers cited for 1990 (1.7 million), Egypt has lost about half of its honey bee colonies. Moreover, steep declines in the numbers of beehives were observed in recent years and particularly from 2005 to 2016. The loss observed during this period is largely matched by the loss of beehives seen in some countries in Europe and North America. This may correlate with the onset of colony collapse disorders (CCD) phenomena, which was first identified in 2005–2006 in North America and in other regions around the world (Johnson, 2010; Rucker, Thurman, Meiners, & Huggins, 2012). Egyptian beekeepers, based along the Nile River, have also reported increased colony loss rates over winter, with no clear cause for this phenomenon (Hassan, 2009).

Possible causes of CCD (habitat loss, pesticide use, bee parasites and pathogens, and global warming) are often discussed (Henry et al., 2012; Johnson, Evans, Robinson, & Berenbaum, 2009; Ratnieks & Carreck, 2010) and do not need to be described in detail here. Moreover, valuations of pollination services have frequently been cited. Although it is usually left to the reader to speculate on the relationship between colony losses and the supply of pollination services, the link is occasionally defined more explicitly. In this context, a potential pollination gap has been identified in Egypt based on the analysis of FAO data, and a current menace to pollination and the beekeeping industry in Egypt has been identified. Moreover, the effects of colony loss on pollination services would be tremendous, resulting in high annual costs to the Egyptian economy it is where to lose its pollinators, but no current figures exist; 15 years ago, these costs were an estimated 3.3% of the 2003 GDP (Brading et al., 2009). Therefore, some countries have begun to rely on non-*Apis* pollinators to overcome the beehive shortage (Rader et al., 2016). An estimated US$2–3 billion of the value of annual crop pollination can be attributed to the activities of native bees, other insects (Prescott-Allen & Prescott-Allen, 1990; Southwick & Southwick, 1992; Losey & Vaughan, 2006), and animals like bats.

Previous reports have indicated that bee diversity in Egypt is promising and linked to floral diversity. Additionally, some attempts to breed and propagate selected efficient insect pollinators in newly reclaimed land in Egypt from 1970 to 1980 have been reported by the Ministry of Agriculture (Ibrahim, 1973, 1979; Rashad, 1979, 1980). Unfortunately, these attempts were abandoned due to lack of funding, and no further reports were found.

It seems that there was national interest in beekeeping and pollination services in Egypt during the period of 1960–1990, which might have been due to the fact that national agricultural research projects were run in collaboration with USAID projects, and these contributed immensely to the productivity improvement of Egyptian agriculture (York, Pluchnett, & Yougbos, 1994). From the 1990s and on, this sector has been ignored. This led to massive losses in bee colony numbers and poses a real threat to pollination services and economy in Egypt. However, this menace should be remediated and overcome as soon as possible, particularly with the provision of 650,000 ha newly reclaimed land in Egypt for agricultural use (Tate, 2016). This has been confirmed by Hassan (2009), who reported that the new, reclaimed land vegetation seemed to defeat the symptoms of honey bee losses in Egypt.

Conclusions

Since these are vital for the agricultural productivity of Egypt, the benefits of and threats to populations of both managed honey bees and wild pollinators should be major considerations. Due to a pronounced loss in the number of beehives and a decline of productivity, Egypt produced only 40% of the honey production in 2016 (5,000 tons) that it produced at its peak period in 1987 (12,500 tons) (Figure 3). This justifies going on red alert, as declines in both hive numbers and productivity are markers of forced loss of pollinators.

There are three complementary approaches that can be taken to safeguard pollinators in agro-ecosystems (ecological intensification, strengthening diversified farming systems, and ecological infrastructure) (Potts et al., 2016), and these should be taken into consideration. Maintaining biodiversity is an important key to improve the resilience of pollinators and guarding against deficiencies in pollination. Relying not only on honey bees as the dominant pollinator species in Egypt, but also protecting the less abundant and rarer species, as "each farmer requires his or her crops to be adequately pollinated" (Winfree et al., 2018). Pesticide use can do more harm to this goal than has been perceived by farmers up until now. Moreover, a program for scientific investigation should be launched as soon as possible to fulfill the 2030 Sustainable Development Agenda.

Therefore, we suggest the

1. Systematic assessment of numbers of beekeepers and beehives as well as colony losses. Results should be presented in an annual statistical report that describes regional and overall trends and investigates associations with possible causes of bee decline in Egypt.
2. Establishment of a national plan to advance sustainable beekeeping methods in coalition with farmers by supporting local cooperation. Such might rely on a government-funded team of agro-experts to support sustainable farming and beekeeping practices. In this context, an improvement in education on pesticide use is a necessity.
3. Widely explore the native bee population in Egypt and develop programs for the breeding and propagation of some efficient insect pollinators, particularly in newly reclaimed farm land in Egypt.
4. Enhance attention on the diversity of plants (also wild plant species) and crops depending on pollination.
5. Attract the interest of government representatives, stakeholders, and members of the public by providing systematic media coverage, conferences, and forums and encouraging investment in the beekeeping sector and beekeeping industry.

Supplementary material

Supplementary material is included for this article at: http://dx.doi.org/10.1080/0005772X.2018.1484202.

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