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Lost colonies found in a data mine: Global honey trade but not pests or pesticides as a major cause of regional honeybee colony declines

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ABSTRACT

Recent losses of honeybee (*Apis mellifera*) colonies have been linked to several non-exclusive factors; such as pests, parasites, pesticides (e.g., neonicotinoids) and other toxins. Whereas these losses pose a threat to apiculture, the number of globally managed colonies appeared to be less affected because beekeepers replace lost colonies. From a socioeconomic and ecological perspective the number of managed colonies is arguably more relevant when addressing the issue of apiculture and pollination services provided by honeybees. We here use the FAO data base to dissect the interactions between the global honey market and the number of colonies. Global scale analyses do not show a general colony decline. Whereas Western Europe and the US show suffer colony declines, other regions show considerable increase. We could not find any link between the colony dynamics and the occurrence of specific pathogens or the use of pesticides. In contrast, changes in the political and socioeconomic system show strong effects on apiculture. In addition, many countries show a tight negative correlation between honey import and the number of managed colonies. For some countries, the amount of honey produced per colony is highly positively correlated with the amount of honey imports, and we cannot exclude large scale relabeling of imported to nationally produced honey. It is very clear that honey trade is a dominating factor for the number of managed colonies since countries with a strong import and export ratio are those suffering most strongly from colony declines.

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1. Introduction

The past decade has seen a multitude of dramatic reports on honeybee (*Apis mellifera*) declines that raised great public and societal concern. Indeed the value of honeybees for human society has been estimated to exceed 153 billion (Gallai et al., 2008) primarily as key pollinators of many crops. The function as generalist pollinators also puts them into a key position for any ecosystem functioning that arguably exceeds any conceivable pecuniary value. A global decline of honeybee colonies would be of particular concern, because of large scale declines of wild pollinators (Biesmeijer et al., 2006) and a global loss of pollinators would clearly have profound and devastating impact on life on earth, a sinister scenario that sparked a huge debate in the public media. Pathogens, pesticides, and their interactions, but also climate change, landscape alteration, agricultural intensification and non-native species (González-Varo et al., 2013) have been attributed to have substantially contributed to the losses of honeybee colonies (Kluser et al., 2010; Le Conte et al., 2012; Martin et al., 2012; Potts et al., 2010a). However, historically reports about regional large scale losses of honeybee colonies are both recurrent and frequent, with dramatic events dating back to medieval times (Fleming, 1871). Today mass losses can be typically linked to diseases or regional poisoning (Pistorius et al., 2009). A prominent exception has been the so called colony collapse disorder (CCD) which killed millions of colonies in the US (vanEngelsdorp et al., 2009). In spite of considerable research efforts (Cox-Foster et al., 2007; Stokstad 2007) CCD could not be clearly associated with a specific pathogen (Anderson and East 2008) or poisoning. As a consequence interactions among pests, pathogens and pesticides were suspected to have caused these massive colony deaths (vanEngelsdorp and Meixner, 2010; Nguyen et al., 2010; Potts et al., 2010a). Recently, neonicotinoid pesticides have been suggested to play a potential role in these colony losses (Johnson et al., 2010; Johnson, 2015) which led to a ban of these compounds by the European Commission (2013). However, several recent reviews

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show that the documentation of colony losses can be regional extremely variable. Potts et al. (2010b) showed in their pan-European study, including data between 1965 and 2005, the losses rarely exceeded 30% at the national scale. Although this may be high from an apicultural perspective, one should keep in mind that this may well be in the range of sustainable mortality rates expected in the wild if a queen lives for three years and issues a reproductive swarm every year.

In general however, although the loss of colonies can be disastrous for the individual apicultural operation, the number of lost colonies is much less relevant than the number of existing colonies from a societal or ecological perspective. For Europe the densities of managed honeybee colonies have recently been reported to have fallen below one colony per square kilometre (Chauzat et al., 2013) which is more than an order of magnitude less that the density of wild honeybees in the African Kalahari desert in regions without any beekeeping and rather unfavourable environmental conditions for honeybees (Jaffé et al., 2010). For pollination services the number of bees, both wild and managed, available in the blooming season are essential, not those that died after or before the season. The number of honeybee colonies lost are of course most important for apiculture because the beekeepers need to take measures to compensate for the losses. Honeybee colonies are typically lost over winter (Genersch et al., 2010), and this places the beekeeper into a pivotal position for honeybee conservation. It is apicultural routine to replace lost colonies by splitting one colony into two for swarm prevention and to compensate for the winter losses (Ambrose, 1992). This also allows for a vivid market for honeybee colonies in many countries that is contributing towards the compensation of regional and local colony losses. Yet whereas the number of colony losses are often poorly documented and require the combination of diverse sources of different quality (e.g., Potts et al., 2010b), the numbers of managed colonies have been officially documented for ~100 countries since 1961 in the global database managed by the FAO (Food and Agriculture Organization of the United Nations). Whereas, the absolute data may be difficult to compare among countries due to differences in national statistical procedures, and some obvious inconsistencies are rather apparent as we will show later, the relative changes of the long term trends may be nevertheless be informative. This data has been used before to document the decline of honeybee colonies in Europe and the US over the past between 1961 and 2009 in spite of a global increase of colony numbers (Aizen and Harder, 2009a; vanEngelsdorp and Meixner, 2010; Moritz et al., 2010). However, the data also showed that the global increase of colonies is insufficient to compensate for the even higher demand for pollination which by far exceeded the availability of honeybee colonies (Aizen and Harder 2009a; Breeze et al., 2014). In addition to colony numbers, the data gathered by the FAO also includes the national production, import, and export of marketed honey of the various nations. The combination of these various sources of information related to honeybees and their products might not only reveal imprecisions in the data sets but also allow for the detection of the major patterns and eventually allow for interpretations in search of the causal reasons of a potential colony decline.

2. Material and methods

We used the data sets for colony numbers (1961–2013), national honey production (tonnes, 1961–2013), import and export of marketed honey (tonnes, 1961–2011) from the FAO database (FAOSTAT (http://faostat.fao.org). For some countries data sets were fused to have a complete data set thru 2013: (1) former Soviet Union (URS = Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Republic of Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan), (2) former Yugoslavia (YUG = Bosnia and Herzegovina, Croatia, Montenegro, Serbia, Serbia and Montenegro, Slovenia, the former Yugoslav Republic of Macedonia), (3) former Czechoslovakia (TCH = Czech Republic and Slovakia), and (4) Belgium-Luxembourg (BEL). Data analysis and statistics (comprising correlation and GLM) were done using simple spreadsheet software and STATISTICA 8.0 (StatSoft, Tulsa, OK). Values are given as means and standard errors. We use the data set to test if colony numbers change in response the arrival of the major honeybee pest, the parasitic mite *Varroa destructor*, and the introduction of neonicotinoid pesticides. We compare those changes with the effects of socioeconomic transformations known to have had major impact on national economies. We test if the amount of honey produced per colony is plausible, given the climatic conditions of the various countries in question. We finally test if honey trade may have any impact on the number of managed colonies in those countries for which all four metrics are available: colony number, national honey production, honey import and honey export.

3. Results and discussion

3.1. The FAO database—colony numbers

More than 100 countries provided data to the FAO-database and globally there is a significant trend of colony increase of more than 60% over the past 50 years from 1961–2013 (Fig. 1). Clearly, the globally collected data does not support the notion of a global colony decline. However, the variability among the reporting countries is huge, ranging from declines down to one forth to more than the four fold increase of the colony number as of 1961. At a continental scale the most dramatic decline occurred in Europe between 1989 and 1995 where almost seven million colonies disappeared within only five years (Fig. 1). This loss in managed colony numbers coincided with the collapse of the socialistic regimes in the Eastern European countries after 1989 (Aizen and Harder 2009a; Moritz et al., 2010; Smith et al., 2013). The association of the colony decline with the political changes in East and Central Europe is very robust since the change in the number of colonies among the various countries shows a highly significant correlation (mean $r = -0.79 \pm 0.04$, $n = 7$; TCH and HUN excluded, as no significant colony decline was observed during this period) in the five years before and after the societal transitions in Eastern Europe and the Balkan (Fig. 2). Comparing the impact of each country and the years of colony decline in a general linear model in the Eastern European and Balkan data set, the factor 'year' was much more important than 'country', with both significantly influencing colony declines (GLM for normalized data (as of 1984 for each country), with country as random and year as fixed factors; country: $F = 8.96$, dF = 6, $P = 0.000001$; year: $F = 14.68$, dF = 10, $P < 0.000001$). Thus although there was considerable national variability among the different Eastern European and Balkan countries, the temporal dynamics over time were highly similar. This also shows that the FAO data base is in principle suitable to detect major impacts on the number of colonies. In contrast, the arrival of the parasitic mite *V. destructor* in the early eighties (Potts et al., 2010b; Rosenkranz et al., 2010) had no detectable effect on the number of managed colonies in the full European data set. On the contrary, the number of colonies in Europe increased from 21.4 Mio to 22.4 Mio between 1980 and 1990 (Fig. 1). So, although *V. destructor* has been clearly identified as the major pest and foremost factor in colony losses (Genersch et al., 2010; Potts et al., 2010a), it did not affect the number of managed colonies reported to the FAO at all. Thus to be explicit: this does not show that *Varroa* does not kill honeybee colonies, it

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