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Comparison of apiculture and winter mortality of honey bee colonies (*Apis mellifera*) in Austria and Czechia

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ABSTRACT

Honey bees are the most important managed pollinators and provide income because of bee products. In Austria and Czechia, we monitored winter losses of honey bee colonies and also collected information on the apicultural sector, hive management, population dynamics and treatment against the mite *Varroa destructor* from 2013–14 to 2016–17. Numbers of beekeepers and colonies, colony density and percentage of beekeepers in human population are higher in Czechia than in Austria. Winter loss rates of honey bee colonies ranged from 8.1% to 28.4% in Austria and 6.4% to 19.4% in Czechia, with significantly higher loss rates in all 4 investigated winters in Austria. The portion of colonies lost because of living colonies with unsolvable queen problems ranged from 3.6 to 4.4% in Austria and from 2.2 to 3.0% in Czechia. Despite of colony losses during winter, colony production in summer allows for compensation or even expansion of colony populations in both countries. We identified differences between the two countries in the treatments applied by beekeepers against the parasitic varroa mite. In Austria, organic acids are most commonly used, whereas the application of synthetic acaricides is widely spread in Czechia. Our study points at the better understanding of apiculture and the importance of international comparisons to facilitate our knowledge on honey bee colony losses.

1. Introduction

Honey bees are the most important managed pollinators of wild plants and agricultural crops. The total economic value of pollinators was estimated to represent 9.5% of the value of the world agricultural production used for human food (Gallai et al., 2009). Despite wild insect pollinators have higher pollination impact on crops (Garibaldi et al., 2013), honey bees are still the most important managed pollinators of wild plants and agricultural crops. Given the importance of managed honey bee colonies for economy and ecology, colony losses have been in the focus of research in the last years. Honey bee colony failure may occur at any time of the year, but in temperate climate, winter is a drastic challenge for colonies. Forage is not available, brood production is ceased and workers need to survive several months instead of a few weeks in summer. One of the main information sources on winter colony losses is voluntary crowd sourcing data from internationally standardized questionnaire studies. In many countries, data collection is coordinated by the international association COLOSS (Prevention of honey bee COlony LOSSes, Neumann and Carreck, 2010; van der Zee et al., 2013). Loss rates presented by COLOSS fluctuated from very high winter losses to winters with moderate or low mortality rates (Brodschneider et al., 2016, 2018; van der Zee et al., 2012, 2014). A similar trend was reported from United States beekeepers (van Engelsdorp et al., 2010; Lee et al., 2015a; Kulhanek et al., 2017).

Austria and Czechia have historically shared beekeeping thanks to geographical as well as cultural proximity. Some historically important persons related to beekeeping, e.g. Franz Hruschka, the inventor of the honey extractor or Gregor Johann Mendel, beekeeper and father of genetics, have their cultural background in the common history of both countries. Empress Maria Theresia founded the first beekeeping school in Vienna in 1769 and induced other activities for prosperity of apiculture (Pechhacker and Moosbeckhofer, 2003). She influenced the beekeeping of Austria and Czechia until today by her 1775 document on the freedom and prosperity of apiculture (Schulz, 1991). Both countries breed mainly *Apis mellifera carnica* bees in last decades (Brascamp et al., 2016). Today, a vast majority of beekeepers in the two countries are hobby, or backyard, beekeepers with a small number of hives. Beekeeping practice of backyard beekeepers might be different compared to large beekeeping operations, which could affect honey bee colony winter loss rate. This effect was demonstrated in multi-country comparisons of winter colony losses (Brodschneider et al., 2016, 2018). In both countries, beekeepers

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are organized in local and national beekeeping clubs. Official information about number of beekeepers and their colonies are collected by beekeeping organizations or administrative authorities, e.g. ministeries. Registration as a beekeeper, including the number of maintained colonies and apiary location, is mandatory in Czechia for many years, but has only started recently in Austria.

The aim of this publication is to compare apiculture in Austria and Czechia. We therefore collected key numbers that describe beekeeping in both countries. We analysed data which were collected by citizen scientist beekeepers between 2014 and 2017 using the COLOSS questionnaire. Such data has previously been used to identify regions with high loss rates and to identify risk factors, for example due to parasites, diseases or environmental factors (van der Zee et al., 2012, 2014, 2015; Simon-Delso et al., 2014; Switanek et al., 2017; Kuchling et al., 2018). Although winter loss rates of honey bee colonies in the two countries of single years have been published previously (Brodschneider et al., 2010, 2016, 2018) we here present a comprehensive summary of winter losses since 2013-14 to 2016-17 and accompanying information. In this study, we emphasize honey bee winter losses due to queen problems. Genetics, health and fitness of honey bee queens have been identified as important factors for overall colony health and winter colony losses, nevertheless the occurrence of this problem has rarely been investigated on a large scale (Genersch et al., 2010; van Engelsdorp et al., 2013; Smart et al., 2016). Our aim is therefore to clarify, if queen problems remain at a constant level or increase when high colony loss rates are recorded. We were also interested if there is a difference in the frequency of queen related problems between the two different countries. Based on winter loss rates and net changes of colony numbers during summer, we have modelled the changes of honey bee population in Austria and Czechia. Finally, we investigated different treatment strategies of beekeepers against the ectoparasitic mite *Varroa destructor* (Rosenkranz et al., 2010) in Austria and Czechia.

2. Material and methods

2.1. Comparison of apiculture in Austria and Czechia

To compare the apicultural sector between Austria and Czechia, official information from beekeeping organizations (Biene Österreich in Austria) or ministeries (Ministry of Agriculture of the Czech Republic) on numbers of beekeepers and honey bee colonies was used. From these data, calculations of average operation size, colony density, colonies per capita, percentage of beekeepers in population, change in number of beekeepers and colonies between 2013 and 2016 and response rate in winter loss survey were made. Calculations based on country area or population were made using the EUROSTAT dataset (EUROSTAT, 2018).

2.2. Honey bee colony winter loss rate

The winter loss rate was surveyed using the standardized COLOSS questionnaire in Austria and Czechia each spring between 2014 and 2017 (van der Zee et al., 2013). Participation was based on voluntary basis and anonymous responses were possible. In both countries, the survey was promoted by beekeeping journals, internet and during beekeepers meetings. Data were collected mostly online but also in paper form to reach all interested beekeepers from all regions. Multiple entries, incomplete or illogic datasets were removed prior the data analysis. The winter loss rate and 95% confidence intervals were calculated according to van der Zee et al. (2013). Since 2014/15, beekeepers were asked also to differentiate their losses between colonies that were dead or reduced to a few hundred workers (empty hives) and colonies that were alive but had unsolvable queen problems (like a missing queen, laying workers, or a drone-egg laying queen). Both categories were used for separate loss rate calculation, but summed up for overall loss rate. In 2017, beekeepers additionally could submit counting of colonies lost by natural disaster during winter 2016/17. These colonies were not included in overall loss rate calculation as they are the result of occasional events, rather than disease or other epidemiologic relevant causes of colony losses.

We calculated the relative frequencies of operational loss (i.e. the loss rate experienced by individual beekeeping operations) divided into 5 categories. These categories were no operational losses (0%), losses between > 0 and 10%, > 10 and 30%, > 30 and 50% and more than 50% of the wintered honey bee colonies (Brodschneider et al., 2010).

2.3. Biannual honey bee colony population dynamic

From 2014 to 2017 we asked beekeepers in Austria and Czechia on the number of colonies in previous spring and previous autumn using standard mandatory questions from the COLOSS questionnaire. The number of colonies in spring of the actual survey year was derived by subtracting the number of colonies lost during winter from the number of colonies managed in autumn. From this we calculated the total colony stock numbers of all participants providing all necessary numbers. Then we calculated ‚summer change rate‘, ‚winter loss rate‘, ‚spring-spring change ‘and ‚spring autumn estimation ‘of this subsample of beekeeping operations according to Fig. 1. Here we defined ‚winter loss rate ‘as the sum of dead colonies and the colonies with queen problems for the first three years. For 2016-17, the wording of the questionnaire was slightly changed, hence also the colonies lost due to natural disaster were included in this analysis (Brodschneider et al., 2018). ‚Summer change ‘is the net change in number of colonies from spring to autumn, mostly comprised of own breeding or purchase of colonies. Summer change could also include colonies lost, merged or sold colonies. ‚Spring-spring change ‘compares the colony numbers in spring of two consecutive years. ‚Spring-autumn estimation ‘calculates the rate of colony production needed to re-establish the number of colonies before winter (previous autumn). The latter is therefore only affected by the winter loss rate and not by any other measured parameter. After calculating all these change rates for each country, we applied these change rates to 100 fictitious honey bee colonies for Austria and Czechia, respectively, to model the theoretical development of honey bee populations based exclusively on these change rates.

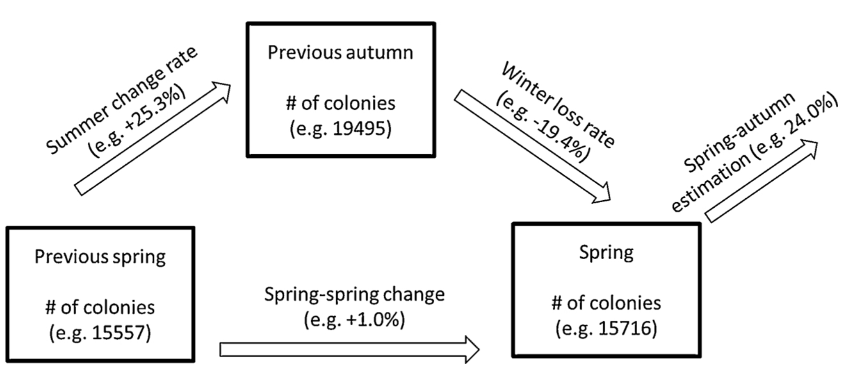

Fig. 1. Scheme of terminology and dates of colony numbers as collected using the COLOSS questionnaire in Austria and Czechia 2014–2017 (in boxes) and terminology and parameters calculated from the colony numbers in ‚previous spring‘, ‚previous autumn ‘and ‚spring‘. Calculated parameters of colony population change are shown as arrows (‚summer change rate‘, ‚spring-spring change‘, ‚winter loss rate ‘and ‚spring autumn estimation‘). Spring autumn estimation is the increase needed to re-establish the previous autumn population based on the number of surviving colonies in spring. To further illustrate calculations, examplary data of 2014-15 from 959 Czech beekeeping operations is shown.

Table 1
Comparison of the apicultural sector in Austria and Czechia.

	Austria[a]	Czechia[b]
Number of beekeepers (2016)	26609	58581
Number of honey bee colonies (2016)	354080	693069
Average operation size (number of colonies)	13.3	11.5
Honey bee colony density per square km	4.2	8.8
Honey bee colonies per capita	0.04	0.06
Change in number of beekeepers between 2013 and 2016	+4%	+13%
Change in number of colonies between 2013 and 2016	−8%	+40%
Percentage of beekeepers in population	0.3%	0.6%
Response rate in winter loss survey (percentage of beekeeping operations, 2014-2017)	4.0%, 5.0%, 4.9%, 6.2%	1.1%, 1.7%, 1.7%, 2.0%

[a] Data and calculations based on annual reports from Biene Österreich.
[b] Ministry of Agriculture of the Czech Republic.

2.4. *Treatment against Varroa destructor*

In all four years the questionnaire contained the same question on the months when beekeepers started a treatment or management plan against *V. destructor* during the period April of the previous year to April of the respective year. The table in the questionnaire contained a number of different treatments, irrespectively the treatment is recommended or authorised in the two countries.

3. Results

3.1. *Structure of apiculture in Austria and Czechia*

The comparison of some key characteristics of Austrian and Czech apiculture is summarized in Table 1. Number of beekeepers, honey bee colonies, colony density and percentage of beekeepers in human population are higher in Czechia than in Austria. Average operation size is comparable between the two countries. Based on the official datasets, we calculated the change in number of beekeepers and colonies for the study period. We found that number of beekeepers increased in both countries (Table 1). Colony numbers increased in Czechia, whereas there was a slight decrease in Austria.

3.2. *Winter losses of honey bee colonies*

In both countries, participation in the surveys increased during the four years of investigation presented here. Altogether we collected 5227 answers from beekeepers wintering 108,946 colonies in Austria, and from 3688 beekeepers collectively managing 72,225 colonies in Czechia. Sample sizes (number of participating beekeeping operations) for individual years and winter honey bee colony loss rates are shown in Fig. 2. For comparability, Fig. 2 includes older data from the Austrian study on winter loss rates that have partially been published before (Brodschneider et al., 2010; van der Zee et al., 2012, 2014; Brodschneider and Crailsheim, 2013). Our study represents between 4.0 and 6.2% of Austrian beekeeping operations and 1.1 and 2.0% in Czechia (Table 1). Beekeepers from all regions of Austria and Czechia participated in our study, as shown in Fig. 3. There were no significant differences in response rates among different districts in Czechia (data not shown).

We found that in both countries the winter loss rate was fluctuating from year to year, whereas beekeepers in Czechia always experienced significantly lower losses compared to Austria (which can be seen by non-overlapping 95% confidence intervals in Fig. 2). The highest loss rates were recorded for the winter of 2014-15, where 28.4% of honey bee colonies in Austria and 19.4% of colonies in Czechia did not survive winter. The lowest loss rates were found for the following winter 2015-16, where in Austria 8.1% and in Czechia 6.4% of colonies did not survive winter. Winter losses in Austria and Czechia also varied among regions of the two countries, Fig. 4 depicts

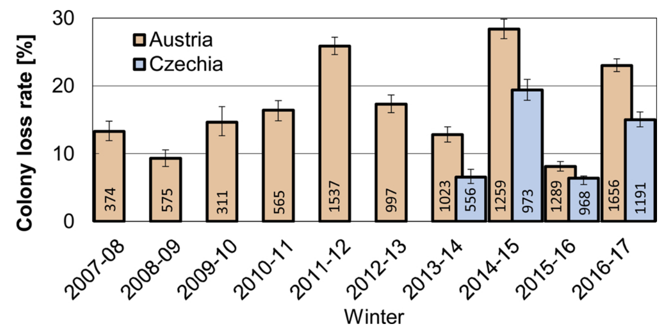

Fig. 2. Winter loss rate (and 95% confidence interval) of honey bee colonies in Austria (red) and Czechia (blue) for the last ten and four years, respectively. Sample size = number of beekeeping operations.

regional loss rates of the four investigated years. We found that the majority of beekeeping operations in both countries experienced no or low losses (Table 2). Substantial losses of more than 50% of the colonies were experienced by less than a quarter of all beekeeping operations, and particularly happened in the two winters with higher loss rates (2014–15 and 2016–17).

Queen problems marginally contributed to winter colony losses in both countries. The extent varied between 3.6 and 4.4% in Austria and from 2.2 to 3.0% in Czechia (Fig. 5). Losses caused by queen problems are relatively stable in both countries among surveyed years, whereas the losses due to dead colonies or empty hives fluctuated greatly in both countries.

3.3. *Biannual honey bee colony population dynamics*

The loss rates presented in Table 3 slightly differ from the loss rates in Fig. 2, because only the subsample of beekeepers that completely submitted all relevant information for calculation of population dynamics (Fig. 1) were used (compare sample sizes in Table 3 and Fig. 2). Colony population numbers for the dates, previous spring‘, ‚previous autumn ‘and ‚spring ‘of years 2014 to 2017 are presented in Table 3. Summer change rate was between +24.4 and +44.9% in Austria and +15.2 and +27.2% in Czechia. These exceed our calculated ‚spring-autumn estimation ‘which is needed to re-establish the previous autumns colony population (see Table 3, compare ‚spring autumn estimation ‘with ‚summer change rate ‘of next year). ‚Spring-spring change ‘of colony numbers has been negative in only one year in Austria (2014–15) and Czechia (2016–17), respectively. This underlines that the number of colonies maintained the previous spring was reached or even overrun in most of the years.

Based on the change rates shown in Table 3, we modelled the development of 100 fictitious honey bee colonies each in Austria and Czechia, respectively. Fig. 6 shows the decrease of colony numbers during winter, which is always followed by an increase during summer. After four years, the models suggests a possible net increase of 52 colonies in Austria and of 36 colonies in Czechia based on ‚winter loss ‘and ‚summer change ‘rates.

3.4. *Varroa fighting strategies in Austria and Czechia*

Approximately three quarters of Austrian and Czech beekeepers monitor the mite infestation level of their colonies (Fig. 7). The exact monitoring methods were not recorded in the questionnaire. The biotechnological treatment method ‘drone brood removal’ was performed by 63% of Austrian beekeepers, but only by 36% of Czech beekeepers, respectively. Among the medicaments to fight Varroa, treatments based on organic compounds are preferred by beekeepers in Austria. Czech beekeepers rather apply synthetic treatment strategies. Short term formic acid (52%) and long term formic acid (46%) evaporation, followed by oxalic acid sublimation (42%) and oxalic acid trickling (28%) are the most commonly applied treatments in Austria. On the other hand, Czech beekeepers mainly fumigate colonies with amitraz (84%) or apply short term evaporation of formic acid (60%). Gabon strips are inserted into colonies by 33% of Czech beekeepers and 20% apply long term evaporation of

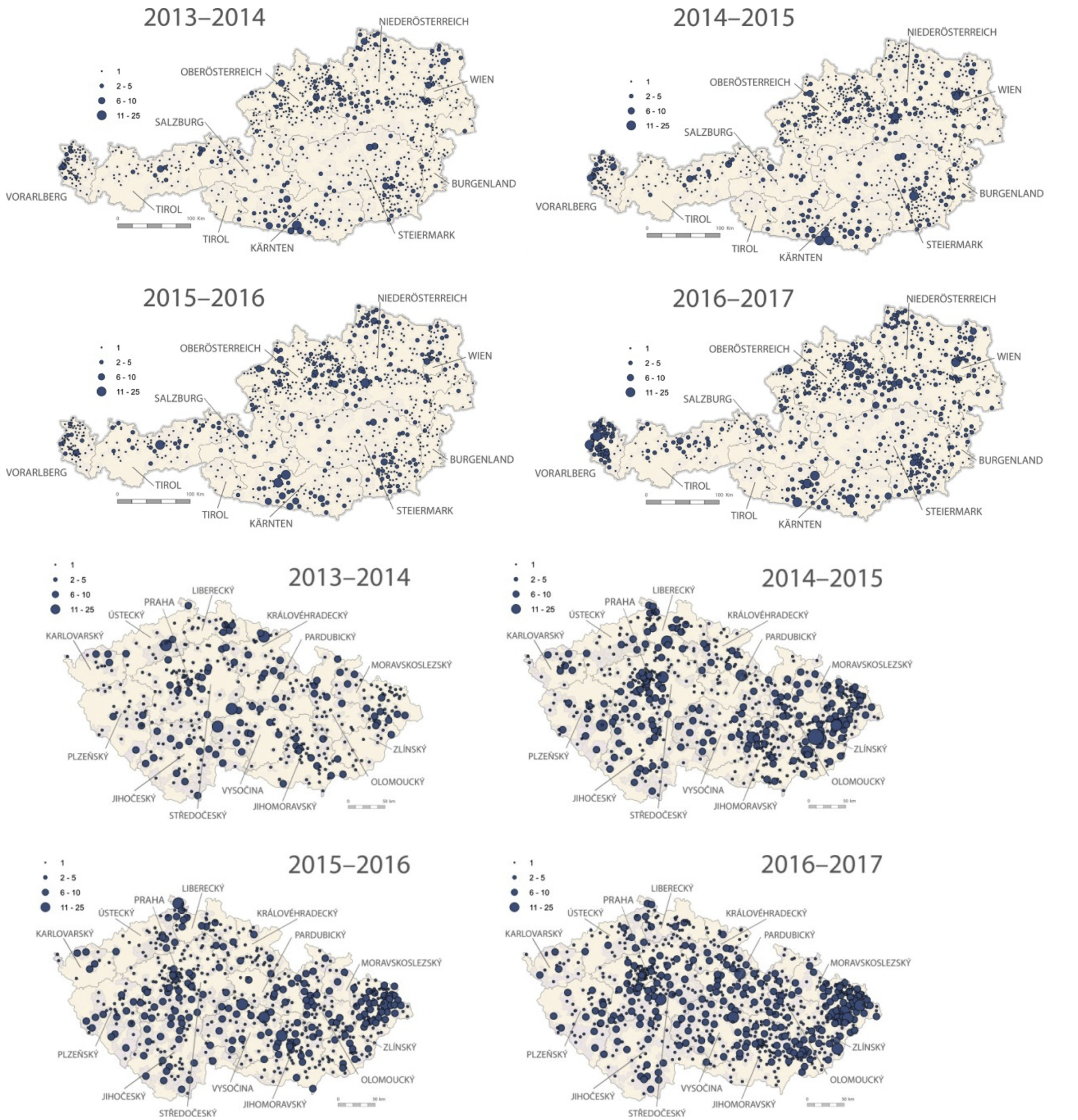

Fig. 3. Geographic origin and number of beekeeping operations participating in Austria and Czechia during the four studied years. Respondents from Vienna are excluded.

formic acid. Only a limited number of Czech beekeepers use hyperthermia compared to Austria (1 and 5%, respectively). Products like Bienenwohl/ Beevital-Hiveclean were used only in Austria because they were not registered in Czechia at the time of the study. The opposite situation is for tau-fluvanilate and amitraz, which are not applied in Austria. Beevital-Hiveclean has been renamed to VarroMed in all EU countries since 2017.

4. Discussion

4.1. The structure of apiculture in Austria and Czechia

Apiculture in agricultural context is often characterized by key numbers that allow international comparisons (Daberkow et al., 2009; De la Rúa et al., 2009; Chauzat et al., 2013). In this study we present the probably most detailed comparison of the apiculture of two countries. Austria and Czechia are two neighboring European countries of similar size and common history, but have different development of beekeeping in the last 100 years. Our study, for example, underlines that there is more than the double number of honey bee colonies managed in Czechia, compared to Austria. In both countries, operation size is rather small (Table 1) compared to other countries (Chauzat et al., 2013; Lee et al., 2015a), with the majority of beekeeping operations being hobbyist or sideline beekeepers (Brodschneider et al., 2010). One could base this difference in colony numbers and colony density between the two countries to different landscape composition in the two countries, but except for the larger areas of mountainous regions in

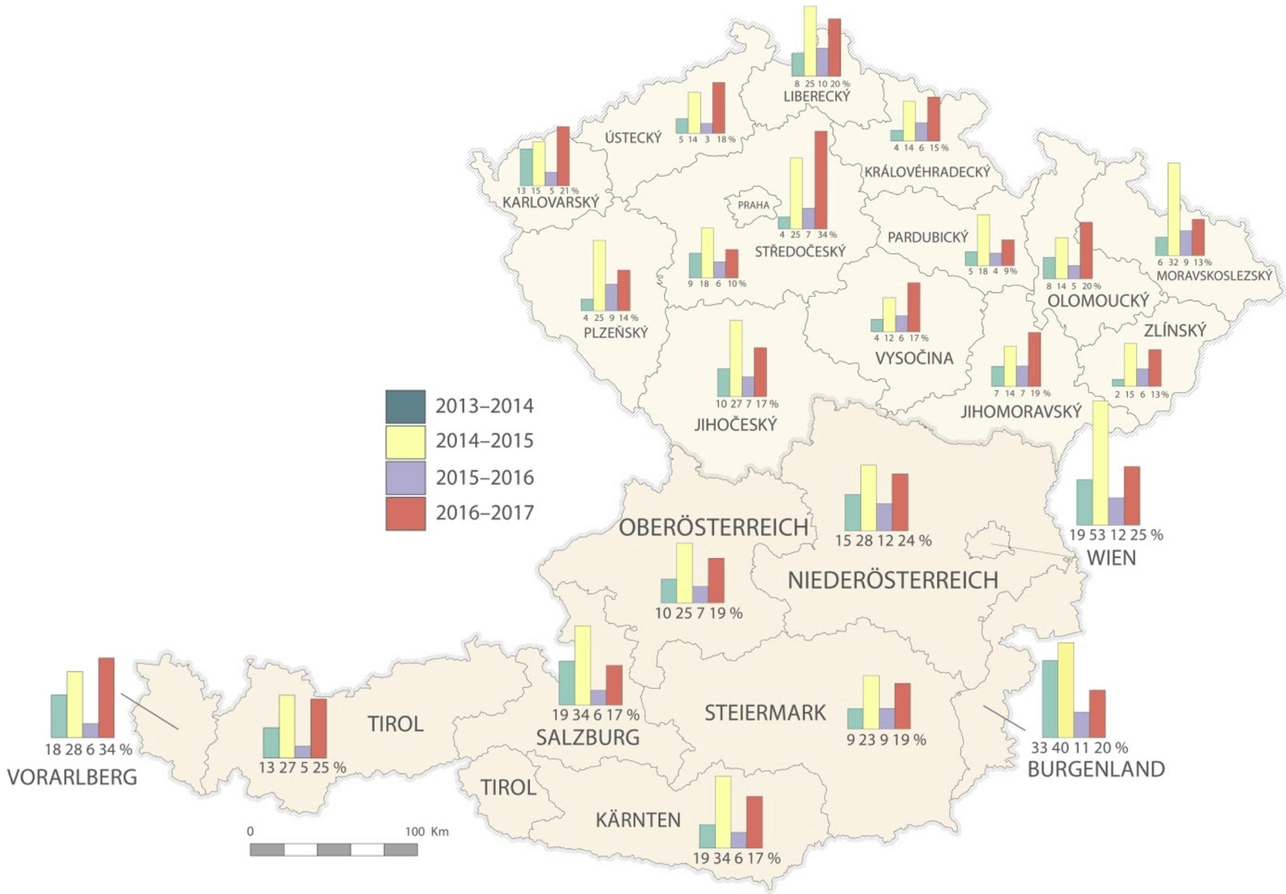

Fig. 4. Honey bee colony losses (sum of dead colonies and colonies lost due to queen problems) for the winters 2013–14 to 2016–17 in Austrian and Czech regions. Total sample size per year is the same as in Fig. 2.

Austria, the landscape structure, in particular the cultivation of agricultural crops (data not shown), is quite similar. Our analysis rather suggests that this gap in number of bee colonies and colony density can be attributed to the higher interest in beekeeping in Czechia. We illustrate this higher interest in beekeeping by the higher number of beekeepers related to the total population and the higher number of hives per capita in Czechia, compared to Austria (Table 1). For Czechia, a comparison with older literature suggests that the proportion of beekeepers in the population has not much changed, as Pokorný (1928) similarly to our findings reported about six beekeepers per 1000 capita. The strong connection between human management for hobby or income underlines the importance to enthuse and reward people for beekeeping to maintain stable honey bee populations (Vural and Karaman, 2009; vanEngelsdorp and Meixner, 2010; Simpach, 2012; Brodschneider and Crailsheim, 2013). Therefore, the socio-economics of beekeeping as a source for income need to be strongly considered for sustainable honey bee populations (Sumner and Boriss, 2006). A survey performed in UK found that a household would pay around 43 £ yearly for protection policy (Mwebaze et al., 2018).

4.2. *Losses of honey bee colonies*

The major problem in beekeeping seems to be colony losses (van Engelsdorp et al., 2010; Brodschneider et al., 2016; Kulhanek et al., 2017). In this study we summarize the existing winter mortality data of Austria and Czechia (Fig. 2). In the four years we present comparable data from both countries, Czechia always experienced lower losses than Austria, although the trends for high or low losses are the same in both countries. We need to point out that these results are based on subsamples of beekeepers, and hence honey bee populations. The response rate of our survey was higher in Austria (between 4.0 and 6.2% of beekeeping operations) than in Czechia (1.1 to 2.0%, Table 1). The difference in loss rates between the countries could therefore also be affected by slight differences in the beekeeper population surveyed (van

Table 2
Percentage of beekeeping operations with no operational losses (0%) or that experienced winter losses between > 0 and 10%, > 10 and 30%, > 30 and 50% and more than 50% of their wintered honey bee colonies. Data is from four winters in Austria and Czechia, sample size is the same as in Fig. 2.

Operational loss	Austria				Czechia			
	2013-14	2014-15	2015-16	2016-17	2013-14	2014-15	2015-16	2016-17
0%	40.0%	19.9%	49.0%	26.3%	58.6%	38.7%	62.4%	41.9%
> 0% - 10%	19.3%	10.7%	19.9%	12.3%	20.7%	16.4%	17.8%	18.6%
> 10% - 30%	24.6%	26.2%	20.4%	28.5%	15.3%	20.2%	15.3%	24.0%
> 30% - 50%	8.8%	19.8%	6.1%	15.0%	3.2%	10.9%	3.1%	9.0%
> 50% - 100%	7.3%	23.4%	4.7%	17.8%	2.2%	13.7%	1.4%	6.5%

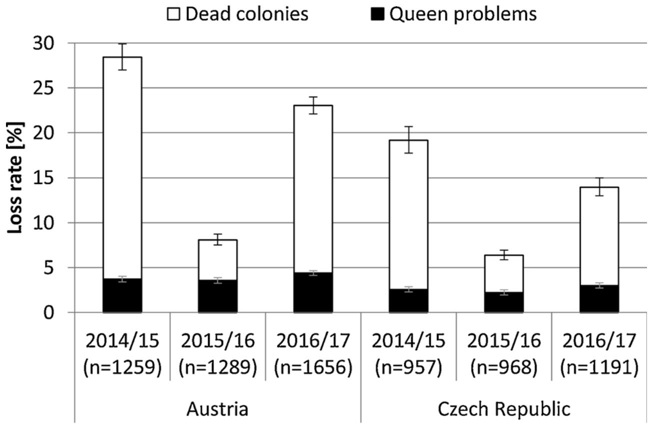

Fig. 5. Percentage of colonies lost during winter in Austria and Czechia due to dead colonies (many dead bees or empty hives) and due to queen problems (a missing queen, laying workers, or a drone egg laying queen). The 95% confidence intervals for both, queen problems and dead colonies are shown (n = sample size of number of beekeeping operations).

der Zee et al., 2013). Our results show large variations in winter colony loss rates between regions in both countries (Fig. 4) and also among the beekeeper community. Table 2 shows the latter bias of losses, which severely affect only a small portion of beekeeping operations. This distribution of operational losses seems to be a general pattern and has been demonstrated before for Austria (Brodschneider et al., 2010) and Germany (Genersch et al., 2010).

Previous studies identified different factors of hive management to contribute to honey bee colony winter losses. For example, operation size, age of queens, disease control (treatment against mites), landscape composition and beekeeper education are believed to influence colony mortality (van der Zee et al., 2012, 2014; Brodschneider et al., 2016; Jacques et al., 2017; Kulhanek et al., 2017; Kuchling et al., 2018). The fluctuations we report here among years and regions are next to these factors probably depending on factors other than hive management. Albeit the general lower losses in Czechia, both countries experienced similar trends in high or low winter loss rates. Next to variations in amount and quality of forage available or disease and parasite pressures, weather could be a factor partially explaining such year to year variations (Simon-Delso et al., 2014; Switanek et al., 2017).

One special case of winter losses is caused by queen problems. Queen vitality is crucial for colony health and survival (Genersch et al., 2010; van Engelsdorp and Meixner, 2010; van der Zee et al., 2012, 2014; vanEngelsdorp et al., 2013v; Smart et al., 2016; Amiri et al., 2017). Honey bee colonies rely on a healthy and mated queen, which lives several years, greatly exceeding lifespan of workers (Corona et al., 2005; Brodschneider et al., 2012; Pettis et al., 2016). Colonies with eggs or young brood are able to rear emergency queens, in case of a queen running out of sperm stores, decreasing pheromone production, queen death or accident (Châline et al., 2003; Moritz et al., 2005; Sagili et al., 2018). However, in countries with a temperate or cold climate, no queen rearing is possible during winter and no drones will be available for mating with queens after winter. Beekeepers therefore may add surviving workers to other colonies, but colonies with queen problems after winter are regarded as lost colonies (van der Zee et al., 2013).

We found that queen problems account for a rather low and remarkably constant amount of winter losses, suggesting a baseline mortality of honey bee colonies during winter based on queen problems. The rate of queen problems during winter found in this study is lower than reports from the United States (Smart et al., 2016). Pettis et al. (2016) attribute colony failure to low sperm viability due to poor shipping conditions of queens, whereas in the by far smaller countries of our investigation, the majority of queens is typically bred and traded locally. It is important to point out that no trends in rise or decline of queen problems were found during the three years we studied this topic in Austria and Czechia. One limitation in the assessment of overwinter success and the assignment to simple symptoms of colony failure is caused by an often considerable time gap between the occurrence of an event, and the assessment by the (citizen science) beekeeper or apiary inspector. Also, our analysis on national level, without exceptional high queen problem rates, does not exclude local areas where elevated queen problems may exist, or certain factors, as shipping or pesticide exposure, harm queen quality (Williams et al., 2015; Pettis et al., 2016). The isolated view on queen problems during overwintering as described in this study can be approximately equalized to a natural winter loss rate in an almost ideal environment for the honey bee, without any external stressors. The established drivers that influence winter survival of the superorganism include exposure to pests and pathogens, pesticides or danger of starvation (Döke et al., 2015; Goulson et al., 2015). Even without these biotic or abiotic factors, queen problems will remain a biological relevant factor for colony survival, as there is a biological limit for honey bee queens' survival and functionality. Still, the queen loss rates presented here must be interpreted with caution as they are influenced by supersedure and beekeeping management, in particular *Varroa* fighting strategies with varroacides (Pettis et al., 1991; Rosenkranz et al., 2010; Giacobino et al., 2015).

4.3. Biannual honey bee population dynamics

Our model of honey bee populations displays regular fluctuations in colony numbers. Winter is characterized by losses, whereas in summer colony numbers increase. This model focuses on biannual changes that include winter losses, but also for the first time summer change rate, a hitherto understudied subject (van Engelsdorp and Meixner, 2010; Brodschneider and Crailsheim, 2011; Moritz and Erler, 2016). The 'summer change' rate is mostly characterized by the net increase of honey bee colonies through making splits or buying new colonies, but could exceptionally include decreases for single operations. Reduction in colony number during the summer season could derive from colony

Table 3
Number of beekeeping operations from Austria and Czechia providing complete data, winter loss rate of this subpopulation, colony numbers for the dates ‚previous spring‘, ‚previous autumn ‘and ‚spring ‘of years 2014 to 2017 are shown. ‚Summer change rate‘, ;spring-spring change ‘and ‚spring-autumn estimation ‘were calculated according to Fig. 1.

	Austria				Czechia			
Year	2014	2015	2016	2017	2014	2015	2016	2017
n	973	1188	1195	1537	556	959	951	1166
Winter loss of subpopulation (%)	12.9	28.6	7.9	22.5	6.6	19.4	6.3	14.9
Previous spring	14319	17355	15102	27695	8497	15557	13408	20940
Previous autumn	17816	21616	21800	40141	10458	19495	17050	24127
Spring	15518	15437	20070	31108	9772	15716	15969	20529
Summer change rate (%)	24.4	24.6	44.4	44.9	23.1	25.3	27.2	15.2
Spring-spring change (%)	8.4	−11.1	32.9	12.3	15.0	1.0	19.1	−2.0
Spring-autumn estimation (%)	14.8	40.0	8.6	29.0	7.0	24.0	6.8	17.5

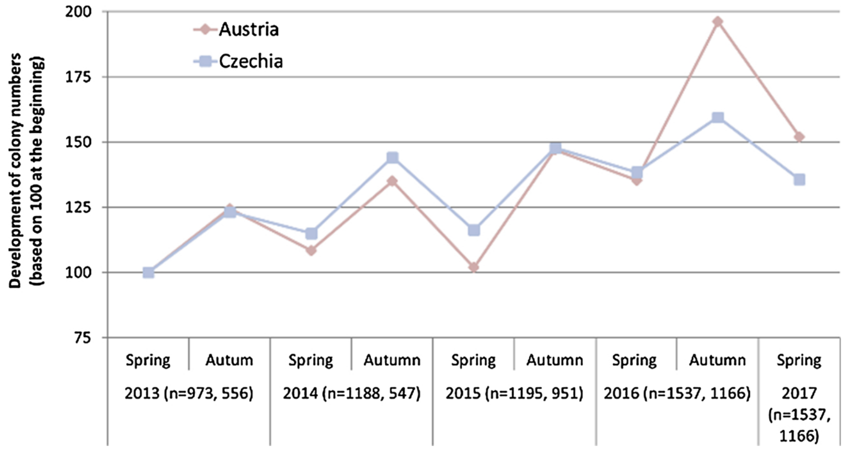

Fig. 6. Model development of temporal changes in honey bee colony numbers based on winter loss rates and summer change in Austria and Czechia 2014–2017. Change rates (see Table 3) were applied to 100 fictitious colonies in spring 2013 (n = number of operations in Austria and Czechia, respectively).

losses because of diseases, merging of colonies or selling of colonies, which could have different reasons. Next to biological reasons it could also be due the personal motivation of a beekeeper to reduce operation size. However, we applied the obtained 'winter loss' rates and 'summer change' rates on a fictitious population of 100 honey bee colonies. The result depicts the regular but fluctuating decreases during winter and (net) increases during summer (Fig. 6). 'Summer change rate' was between 15.2% and 44.9% and underlines the strong potential in apiculture to produce new livestock during summer.

Our findings clearly demonstrate that, although in some years many colonies are lost during winter, it is theoretically possible to increase the fictitious 100 colonies at the start to up to around 150 after 4 years, even considering losses during winter. Based only on losses during winter, followed by increase of honey bee colonies in summer, our model predicts a growing or at least stable number of honey bee colonies. We therefore suggest, that mechanisms other than colony losses and colony production by beekeepers additionally influence honey bee colony populations, that have in some countries or regions been reported to be declining (van Engelsdorp and Meixner, 2010; Brodschneider and Crailsheim, 2011; Moritz and Erler, 2016). For example, the socio-economic mechanisms related to the proportion of people in a country engaged in beekeeping deserve further research. This could, next to colony losses and increases, further elucidate our understanding of honey bee colony numbers in a country. Interestingly, the annual net increase in honey bee colonies is higher in Austria, compared to Czechia. In all four years of this investigation, Austria has suffered higher colony losses than Czechia. This finding therefore could be an adaption of Austrian beekeepers, who got used to higher losses and therefore make higher efforts during summer to maintain or even exceed colony numbers as reserve colonies or for sale. Notably, both countries exhibit the pattern, that low losses result in peak numbers of honey bee colonies, further supporting the hypothesis that reserve-colonies are being wintered. The fact that changes in colony stock numbers are rather moderate, as shown by the ‚spring-spring ‘comparison in Table 3, underlines the importance of monitoring honey bee colonies losses to better understand dynamics of apiculture (Lee et al., 2015b; Kulhanek et al., 2017).

One limitation of our modelling approach is, that our methodology may include new beginners that contribute data, but people that quit beekeeping for whatever motivation, are not representated at all in our dataset. We therefore believe we slightly overestimate the upwards development of honey bee colonies as shown in this model. On the other hand, the number of officially registered colonies in Czechia increased by 40% between 2013–2016 (Table 1). This is consistent with our model, which suggests a 36% increase in number of colonies during the same time period (Fig. 6). Still, our analysis demonstrates the importance of understanding also the production of colonies during the active bee season to better react on threats to honey bee colony population. The parameter used in our model is a very rough approximation to the changes that honey bee colony stock numbers undergo, and we therefore deliberately do not speak about reproduction rates. The ‚summer change rate ‘as defined in this study, only reflects net changes in colony numbers, no matter where the colonies come from or where they go to. It is therefore not clear, whether single operations

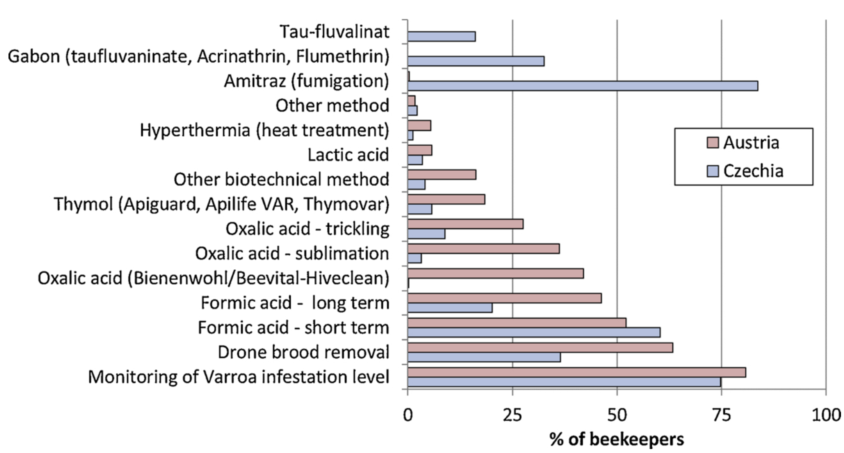

Fig. 7. Comparison of treatments against *Varroa destructor* used by Austrian (n = 4986) and Czech (n = 3688) beekeepers in the four investigated years. Percentage of beekeepers that applied the specified method in at least one month during the period April to April is shown.

sold or obtained any colonies to reach the number of colonies in autumn or produced them theirselves. As this renewal of honey bee livestock is at the work and financial expense of beekeepers, it is important to reduce colony losses for an economically sustainable apicultural sector. As suggested by our model, the situation in beekeeping may also be influenced by politics which financially support the beekeeping sector. Districts in Czechia stimulate citizens to start beekeeping with subsidies and flat-rate payments. The Czech national government updated § 10 from the Act No. 586/1992 Coll. in January 2014, which allows to keep up to 60 colonies without paying taxes. Similar efforts are undertaken in Austria. We believe that the biannual changes in honey bee colony livestock, we report here for Austria and Czechia, can be generalized for other countries with similar structural and climatic conditions.

Both study countries have different ways of registration of number of beekeepers and colonies. Whereas this is long established in Czechia, in Austria such a system has just been introduced recently. As we can only speculate about the coverage of the national registration systems, and the way of data collection differs from our voluntary study, comparison of the development of the officially registered honey bee colony populations and our results based on biannual changes must be made with caution. Further longitudal analysis of a subsample of (identifiable) beekeeping operations are recommendable. Our results on the high renewal of colonies during summer could provoke speculations about higher production rates of honey bee colonies as a result from winters with high losses. We therefore suggest further research aiming on the reasons for renewal on honey bee livestock and the exact way this is accomplished by beekeepers (Büchler et al., 2013).

4.4. *Varroa* fighting strategies in Austria and Czechia

Infestation of colonies with varroa mites and the methods to fight mites have strong effects on winter survival of honey bee colonies (Genersch et al., 2010; Rosenkranz et al., 2010; van der Zee et al., 2012, 2014; Giacobino et al., 2015). We present the first comprehensive survey data on strategies applied by beekeepers to fight *V. destructor*, which differ significantly between the two countries. In both countries, the majority of beekeepers do regularly monitor the infestation levels of their colonies (Fig. 7). To treat colonies, in Austria the majority of beekeepers follows the recommendation to evaporate formic acid after honey harvest and trickle or sublimate oxalic acid products in winter (Moosbeckhofer et al., 2015). In contrast to this recommendation of organic acids or essential oil treatments in Austria, the official authority State Veterinary Administration in Czechia recommends other obligatory treatments. Briefly, Czech beekeepers collect winter hive debris for examination of varroa mites before each spring, which is performed by offical laboratories. The debris from 10 colonies is pooled and mixed. If the debris sample contains more than 3 mites per colony, then spring *Varroa* treatment (with a product containing amitraz) is commanded. Summer treatment can also be commanded by authorities with Gabon strips (contains either tau-fluvanilate or flumethrin and till 2016 also acrinathrin). If there is no commanded treatment, there is still a recommendation for a summer treatment with any other registered product (based on formic acid or thymol; eAGRI, 2016). Autumn treatment is also commanded by veterinary authorities, the treatment is performed with Varidol 125 mg/ml (amitraz) or by other registered products (e.g. Formidol, Thymovar, Apiguard; ÚSKVBL, 2018). It was mandatory to treat the colonies 3x with fumigation of Varidol 125 mg/ml or MP10 (tau-fluvanilate) until 2013. Since 2013 Czech beekeepers have free choice in which product they will use, but the treatment in autumn remained obligatory. In contrast to this, use of synthetic acaricides is rather restricted in Austria.

As treatment strategy against the varroa mite is the most obvious difference in bee management, one is tempted to attribute the lower losses experienced in Czechia to the commanded treatments and use of synthetic acaricides. However, one needs to be careful with such declarations and final conclusions can only be made from controlled field trials. The two different strategies of *Varroa* control both have their advantages and disadvantages. These drawbacks include for example the risk of poor efficacy or undesired side effects on honey bees (Rosenkranz et al., 2010). Residues in the wax or honey, or growing resistance in mites, are drawbacks that concern mainly synthetic acaricides and their use should therefore be critcially evaluated. One such resistance, regarding the pyrethroid tau-fluvalinate, was recently investigated in Czechia (Stara et al., 2019), whereas it is longer known for Austria (Trouiller, 1998).

4.5. Conclusions

Honey bee health and colony losses are an international problem. We therefore underline the importance of internationally standardized data collection for to facilitate our understanding of the problem. In this article, we compare the apicultural sectors of Austria and Czechia, that have some similarities, but strongly differ for example in strategies to fight the varroa mite. In both countries, colony losses during winter were fluctuating from year to year, with strong regional differences. Winter losses related to queen problems occurr at rather stable and low levels. In both countries, we could in the last years successfully involve beekeepers as citizen scientists to collect quantitative data on a large scale. With this method, valuable long term data can be obtained, that allows further investigations of honey bee colony losses.

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References

Amiri, E., Strand, M.K., Rueppell, O., Tarpy, D.R., 2017. Queen quality and the impact of honey bee diseases on queen health: potential for interactions between two major threats to colony health. Insects 8, 48.

Brascamp, E.W., Willam, A., Boigenzahn, C., Bijma, P., Veerkamp, R.F., 2016. Heritabilities and genetic correlations for honey yield, gentleness, calmness and swarming behaviour in Austrian honey bees. Apidologie 47, 739–748.

Brodschneider, R., Crailsheim, K., 2011. Völkerverluste der Honigbiene: Risikofaktoren für die Bestäubungssicherheit in Österreich. Entomologica Austriaca 18, 73–86.

Brodschneider, R., Crailsheim, K., 2013. Fünf Jahre Untersuchung des Bienensterbens in Österreich. Entomologica Austriaca 20, 195–205.

Brodschneider, R., Moosbeckhofer, R., Crailsheim, K., 2010. Surveys as a tool to record winter losses of honey bee colonies: a two year case study in Austria and South Tyrol. J. Apic. Res. 49, 23–30.

Brodschneider, R., Arnold, G., Hrassnigg, N., Crailsheim, K., 2012. Does Patriline Composition Change over a Honey Bee Queen’s Lifetime? Insects 3, 857–869.

Brodschneider, R., Gray, A., van der Zee, R., Adjlane, N., Brusbardis, V., Charrière, J.-D., Chlebo, R., Coffey, M.F., Crailsheim, K., Dahle, B., Danihlík, J., Danneels, E., de Graaf, D.C., Dražić, M.M., Fedoriak, M., Forsythe, I., Golubovski, M., Gregorc, A., Grzęda, U., Hubbuck, I., İvgin Tunca, R., Kauko, L., Kilpinen, O., Kretavicius, J., Kristiansen, P., Martikkala, M., Martín-Hernández, R., Mutinelli, F., Peterson, M., Otten, C., Ozkirim, A., Raudmets, A., Simon-Delso, N., Soroker, V., Topolska, G., Vallon, J., Vejsnæs, F., Woehl, S., 2016. Preliminary analysis of loss rates of honey bee colonies during winter 2015/16 from the COLOSS survey. J. Apic. Res. 55, 375–378.

Brodschneider, R., Gray, A., Adjlane, N., Ballis, A., Brusbardis, V., Charrière, J.-D., Chlebo, R., Coffey, M.F., Dahle, B., Graaf, D.C., Dražić, M.M., Evans, G., Fedoriak, M., Forsythe, I., Gregorc, A., Grzęda, U., Hetzroni, A., Kauko, L., Kristiansen, P., Martikkala, M., Martín-Hernández, R., Medina-Flores, C.A., Mutinelli, F., Raudmets, A., Ryzhikov, V.A., Simon-Delso, N., Stevanovic, J., Uzunov, A., Vejsnæs, F., Wöhl, S., Zammit-Mangion, M., Danihlík, J., 2018. Multi-country loss rates of honey bee colonies during winter 2016/2017 from the COLOSS survey. J. Apic. Res. 57, 452–457.

Büchler, R., Andonov, S., Bienefeld, K., Costa, C., Hatjina, F., Kezic, N., Kryger, P., Spivak, M., Uzunov, A., Wilde, J., 2013. Standard methods for rearing and selection of *Apis mellifera* queens. J. Apic. Res. 52, 1–30.

Châline, N., Ratnieks, F.L.W., Arnold, G., Papin, C., 2003. Patriline differences in emergency queen rearing in the honey bee, *Apis mellifera*. Insectes Soc. 50, 234–236.

Chauzat, M.-P., Cauquil, L., Roy, L., Franco, S., Hendrikx, P., Ribière-Chabert, M., 2013. Demographics of the European apicultural industry. PLoS One 8, e79018.
Corona, M., Hughes, K.A., Weaver, D.B., Robinson, G.E., 2005. Gene expression patterns associated with queen honey bee longevity. Mech. Ageing Dev. 126, 1230–1238.
Daberkow, S., Korb, P., Hoff, F., 2009. Structure of the U.S. Beekeeping Industry: 1982–2002. J. Econ. Entomol. 102, 868–886.
De la Rúa, P., Jaffé, R., Dall'Olio, R., Muñoz, I., Serrano, J., 2009. Biodiversity, conservation and current threats to European honeybees. Apidologie 40, 263–284.
Döke, M.A., Frazier, M., Grozinger, C.M., 2015. Overwintering honey bees: biology and management. Curr. Opin. Insect Sci. 10, 185–193.
eAGRI, 2016. Methodology for Animal Health Control and Vaccination for 2017, č.j. 58015/2016-MZe-17210. Ministery of Agriculture of the Czech Republic, available only in Czech language (Accessed 21 June 2018). http://www.svscr.cz/wp-content/files/dokumenty-a-publikace/Metodika-kontroly-zdravi-zvirat-a-narizene-vakcinace-na-rok-2017.pdf.
EUROSTAT, 2018. EUROSTAT Database Collection. Statistical Office of the European Communities, Luxembourg (Accessed 21 June 2018). http://ec.europa.eu/eurostat.
Gallai, N., Salles, J.-M., Settele, J., Vaissière, B.E., 2009. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. Ecol. Econ. 68, 810–821.
Garibaldi, L.A., Steffan-Dewenter, I., Winfree, R., Aizen, M.A., Bommarco, R., Cunningham, S.A., Kremen, C., Carvalheiro, L.G., Harder, L.D., Afik, O., Bartomeus, I., Benjamin, F., Boreux, V., Cariveau, D., Chacoff, N.P., Dudenhöffer, J.H., Freitas, B.M., Ghazoul, J., Greenleaf, S., Hipólito, J., Holzschuh, A., Howlett, B., Isaacs, R., Javorek, S.K., Kennedy, C.M., Krewenka, K.M., Krishnan, S., Mandelik, Y., Mayfield, M.M., Motzke, I., Munyuli, T., Nault, B.A., Otieno, M., Petersen, J., Pisanty, G., Potts, S.G., Rader, R., Ricketts, T.H., Rundlöf, M., Seymour, C.L., Schüepp, C., Szentgyörgyi, H., Taki, H., Tscharntke, T., Vergara, C.H., Viana, B.F., Wanger, T.C., Westphal, C., Williams, N., Klein, A.M., 2013. Wild pollinators enhance fruit set of crops regardless of honey bee abundance. Science 339, 1608–1611.
Genersch, E., von der Ohe, W., Kaatz, H., Schroeder, A., Otten, C., Büchler, R., Berg, S., Ritter, W., Mühlen, W., Gisder, S., Meixner, M., Liebig, G., Rosenkranz, P., 2010. The German bee monitoring project: a long term study to understand periodically high winter losses of honey bee colonies. Apidologie 41, 332–352.
Giacobino, A., Molineri, A., Cagnolo, N.B., Merke, J., Orellano, E., Bertozzi, E., Masciángelo, G., Pietronave, H., Pacini, A., Salto, C., Signorini, M., 2015. Risk factors associated with failures of *Varroa* treatments in honey bee colonies without broodless period. Apidologie 46, 573–582.
Goulson, D., Nicholls, E., Botías, C., Rotheray, E.L., 2015. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. Science 347 (6229), 1255957.
Jacques, A., Laurent, M., E.P.I.L.O.B.E.E. Consortium, Ribière-Chabert, M., Saussac, M., Bougeard, S., Budge, G.E., Hendrikx, P., Chauzat, M.-P., 2017. A pan-European epidemiological study reveals honey bee colony survival depends on beekeeper education and disease control. PLoS One 12 (3), e0172591.
Kuchling, S., Kopacka, I., Kalcher-Sommersguter, E., Schwarz, M., Crailsheim, K., Brodschneider, R., 2018. Investigating the role of landscape composition on honey bee colony winter mortality: a long-term analysis. Sci. Rep. 8, 12263.
Kulhanek, K., Steinhauer, N., Rennich, K., Caron, D.M., Sagili, R.R., Pettis, J.S., Ellis, J.D., Wilson, M.E., Wilkes, J.T., Tarpy, D.R., Rose, R., Lee, K., Rangel, J., van Engelsdorp, D., 2017. A national survey of managed honey bee 2015–2016 annual colony losses in the USA. J. Apic. Res. 56, 328–340.
Lee, K.V., Steinhauer, N., Rennich, K., Wilson, M.E., Tarpy, D.R., Caron, D.M., Rose, R., Delaplane, K.S., Baylis, K., Lengerich, E.J., Pettis, J., Skinner, J.A., Wilkes, J.T., Sagili, R., vanEngelsdorp, D., 2015a. A national survey of managed honey bee 2013-2014 annual colony losses in the USA. Apidologie 46, 292–305.
Lee, K., Steinhauer, N., Travis, D.A., Meixner, M.D., Deen, J., vanEngelsdorp, D., 2015b. Honey bee surveillance: a tool for understanding and improving honey bee health. Curr. Opin. Insect Sci. 10, 37–44.
Moosbeckhofer, R., Köglberger, H., Derakhshifar, I., Morawetz, L., Boigenzahn, C., Oberrisser, W., 2015. *Varroa*-Bekämpfung einfach-sicher-erfolgreich. 2. Völlig Neu Bearbeitete Auflage. Herausgeber: Biene Österreich.
Moritz, R.F.A., Erler, S., 2016. Lost colonies found in a data mine: global honey trade but not pests or pesticides as a major cause of regional honeybee colony declines. Agric. Ecosyst. Environ. 216, 44–50.
Moritz, R.F.A., Lattorff, H.M.G., Neumann, P., Kraus, F.B., Radloff, S.E., Hepburn, H.R., 2005. Rare royal families in honeybees, Apis mellifera. Naturwissenschaften 92, 488–491.
Mwebaze, P., Marris, G.C., Brown, M., MacLeod, A., Jones, G., Budge, G.E., 2018. Measuring public perception and preferences for ecosystem services: a case study of bee pollination in the UK. Land use policy 71, 355–362.
Neumann, P., Carreck, N.L., 2010. Honey bee colony losses. J. Apic. Res. 49, 1–6.
Pechhacker, H., Moosbeckhofer, R., 2003. Die bienenkunde in Österreich. Denisia 8, 15–45.
Pettis, J.S., Wilson, W.T., Shimanuki, H., Teel, P.D., 1991. Fluvalinate treatment of queen and worker honey bees (*Apis mellifera* L) and effects on subsequent mortality, queen acceptance and supersedure. Apidologie 22, 1–7.
Pettis, J.S., Rice, N., Joselow, K., vanEngelsdorp, D., Chaimanee, V., 2016. Colony failure linked to low sperm viability in honey bee (*Apis mellifera*) queens and an exploration of potential causative factors. PLoS One 11, e0147220. https://doi.org/10.1371/journal.pone.0147220.
Pokorný, V., 1928. Význam včelařství vůbec a pro zemědělství zvlášť. Ministery of Agriculture of the Republic Czechoslovakia, Prague.
Rosenkranz, P., Aumeier, P., Ziegelmann, B., 2010. Biology and control of Varroa destructor. J. Invertebr. Pathol. 103, 96–119.
Sagili, R.R., Metz, B.N., Lucas, H.M., Chakrabarti, P., Breece, C.R., 2018. Honey bees consider larval nutritional status rather than genetic relatedness when selecting larvae for emergency queen rearing. Sci. Rep. 8, 7679.
Schulz, S., 1991. Die historische Entwicklung des Rechts an Bienen, §§ 961-964 BGB. Zeitschrift der Savigny-Stiftung für Rechtsgeschichte Germanistische Abteilung 518.
Simon-Delso, N., San Martin, G., Bruneau, E., Minsart, L.-A., Mouret, C., Hautier, L., 2014. Honeybee colony disorder in crop areas: the role of pesticides and viruses. PLoS One 9, e103073.
Simpach, O., 2012. Statistical view of the curent situation of beekeeping in the Czech Republic. In: Tomas, Löster, Tomas, Pavelka (Eds.), 6th International Days of Statistics and Economics, pp. 1054–1062.
Smart, M., Pettis, J., Rice, N., Browning, Z., Spivak, M., 2016. Linking measures of colony and individual honey bee health to survival among apiaries exposed to varying agricultural land use. PLoS One 11, e0152685.
Stara, J., Pekar, S., Nesvorna, M., Kamler, M., Doskocil, I., Hubert, J., 2019. Spatio-temporal dynamics of *Varroa destructor* resistance to tau-fluvalinate in Czechia, associated with L925V sodium channel point mutation. Pest Manag. Sci. https://doi.org/10.1002/ps.5242.
Sumner, D.A., Boriss, H., 2006. Bee-economics and the leap in pollination fees. ARE update. Giannini Found. Agric. Econ. 9, 9–12.
Switanek, M., Crailsheim, K., Truhetz, H., Brodschneider, R., 2017. Modelling seasonal effects of temperature and precipitation on honey bee winter mortality in a temperate climate. Sci. Total Environ. 579, 1581–1587.
Trouiller, J., 1998. Monitoring *Varroa jacobsoni* resistance to pyrethroids in western Europe. Apidologie 29, 537–546.
ÚSKVBL, 2018. Database of Veterinary Medical Devices. Institute for State Control of Veterinary Biologicals and Medicines, Brno-Medlánky, Czech Republic (Accessed 21 June 2018). http://www.uskvbl.cz.
van der Zee, R., Pisa, L., Andonov, S., Brodschneider, R., Charrière, J.-D., Chlebo, R., Coffey, M.F., Crailsheim, K., Dahle, B., Gajda, A., Gray, A., Drazic, M.M., Higes, M., Kauko, L., Kence, A., Kence, M., Kezic, N., Kiprijanovska, H., Kralj, J., Kristiansen, P., Hernandez, R.M., Mutinelli, F., Nguyen, B.K., Otten, C., Özkırım, A., Pernal, S.F., Peterson, M., Ramsay, G., Santrac, V., Soroker, V., Topolska, G., Uzunov, A., Vejsnæs, F., Wei, S., Wilkins, S., 2012. Managed honey bee colony losses in Canada, China, Europe, Israel and Turkey, for the winters of 2008–9 and 2009–10. J. Apic. Res. 51, 100–114.
van der Zee, R., Gray, A., Holzmann, C., Pisa, L., Brodschneider, R., Chlebo, R., Coffey, M.F., Kence, A., Kristiansen, P., Mutinelli, F., Nguyen, B.K., Noureddine, A., Peterson, M., Soroker, V., Topolska, G., Vejsnæs, F., Wilkins, S., 2013. Standard survey methods for estimating colony losses and explanatory risk factors in Apis mellifera. J. Apic. Res. 52, 1–36.
van der Zee, R., Brodschneider, R., Brusbardis, V., Charrière, J.-D., Chlebo, R., Coffey, M.F., Dahle, B., Drazic, M.M., Kauko, L., Kretavicius, J., Kristiansen, P., Mutinelli, F., Otten, C., Peterson, M., Raudmets, A., Santrac, V., Seppälä, A., Soroker, V., Topolska, G., Vejsnæs, F., Gray, A., 2014. Results of international standardised beekeeper surveys of colony losses for winter 2012-2013: analysis of winter loss rates and mixed effects modelling of risk factors for winter loss. J. Apic. Res. 53, 19–34.
van der Zee, R., Gray, A., Pisa, L., de Rijk, T., 2015. An observational study of honey bee colony winter losses and their association with *Varroa destructor*, neonicotinoids and other risk factors. PLoS One 10, e0131611.
van Engelsdorp, D., Meixner, M.D., 2010. A historical review of managed honey bee populations in Europe and the United States and the factors that may affect them. J. Invertebr. Pathol. 103, 80–95.
van Engelsdorp, D., Hayes, J., Underwood, R.M., Pettis, J.S., 2010. A survey of honey bee colony losses in the United States, fall 2008 to spring 2009. J. Apic. Res. 49, 7–14.
vanEngelsdorp, D., Tarpy, D.R., Lengerich, E.J., Pettis, J.S., 2013v. Idiopathic brood disease syndrome and queen events as precursors of colony mortality in migratory beekeeping operations in the eastern United States. Prev. Vet. Med. 108, 225–233.
Vural, H., Karaman, S., 2009. Socio-Economic analysis of beekeeping and the effects of beehive types on honey production. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 37, 223.
Williams, G.R., Troxler, A., Retschnig, G., Roth, K., Yañez, O., Shutler, D., Neumann, P., Gauthier, L., 2015. Neonicotinoid pesticides severely affect honey bee queens. Sci. Rep. 5, 1–8.