2015

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Journal of Apicultural Research

ISSN: 0021-8839 (Print) 2078-6913 (Online) Journal homepage: http://www.tandfonline.com/loi/tjar20

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To cite this article: Nicola Seitz, Kirsten S. Traynor, Nathalie Steinhauer, Karen Rennich, Michael E. Wilson, James D. Ellis, Robyn Rose, David R. Tarpy, Ramesh R. Sagili, Dewey M. Caron, Keith S. Delaplane, Juliana Rangel, Kathleen Lee, Kathy Baylis, James T. Wilkes, John A. Skinner, Jeffery S. Pettis & Dennis vanEngelsdorp (2015) A national survey of managed honey bee 2014–2015 annual colony losses in the USA, Journal of Apicultural Research, 54:4, 292-304, DOI: 10.1080/00218839.2016.1153294

To link to this article: http://dx.doi.org/10.1080/00218839.2016.1153294

Journal of Apicultural Research, 2015
Vol. 54, No. 4, 292–304, http://dx.doi.org/10.1080/00218839.2016.1153294

ORIGINAL RESEARCH ARTICLE

A national survey of managed honey bee 2014–2015 annual colony losses in the USA

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(*Received 22 October 2015; accepted 8 February 2016*)

Declines of pollinators and high mortality rates of honey bee colonies are a major concern, both in the USA and globally. Long-term data on summer, winter, and annual colony losses improve our understanding of forces shaping the viability of the pollination industry. Since the mass die-offs of colonies in the USA during the winter of 2006–2007, generally termed "Colony Collapse Disorder" (CCD), annual colony loss surveys have been conducted. These surveys gage colony losses among beekeepers of all operation sizes, recruited to participate via regional beekeeping organizations, phone calls, and postal mail. In the last three years, these surveys include summer and annual losses in addition to winter losses. Winter losses in this most recent survey include 5,937 valid participants (5,690 backyard, 169 sideline, and 78 commercial beekeepers), collectively managing 414,267 colonies on 1 October 2014 and constituting 15.1% of the estimated 2.74 million managed colonies in the USA. Annual losses are typically higher than either winter or summer losses, as they calculate losses over the entire year. Total reported losses were 25.3% [95% CI 24.7–25.9%] over the summer, 22.3% [95% CI 21.9–22.8%] over the winter, and 40.6% [95% CI 40.0–41.2%] for the entire 2014–2015 beekeeping year. Average losses were 14.7% [95% CI 14.0–15.3%] over the summer, 43.7% [95% CI 42.8–44.6%] over the winter, and 49.0% [95% CI 48.1–50.0%] over the entire year. While total winter losses were lower in 2014–2015 than in previous years, summer losses remained high, resulting in total annual colony losses of more than 40% during the survey period. This was the first year that total losses were higher in the summer than in the winter, explained in large part by commercial beekeepers reporting losses of 26.2% of their managed colonies during summer, compared to 20.5% during winter. Self-identified causes of overwintering mortality differed by operation size, with smaller backyard beekeepers generally indicating colony management issues (e.g., starvation, weak colony in the fall), in contrast to commercial beekeepers who typically emphasize parasites or factors outside their control (e.g., varroa, nosema, queen failure). More than two-thirds of all beekeepers (67.3%) had higher colony losses than they deemed acceptable.

Encuesta nacional sobre la pérdida anual de colmenas de abejas manejadas durante 2014–2015 en los EEUU

El descenso de los polinizadores y las altas tasas de mortalidad de las colmenas de abejas melíferas son una de las preocupaciones más importantes, tanto en los EEUU como en todo el mundo. Los datos a largo plazo del verano, el invierno, y las pérdidas anuales de colmenas mejoran nuestra comprensión sobre las fuerzas que conforman la viabilidad de la industria de la polinización. Debido a las pérdidas masivas de colmenas durante el invierno de 2006 - 2007en los EEUU, fenómeno denominado generalmente como "Síndrome de Colapso de las Colmenas" (SCD), se han llevado a cabo encuestas anuales sobre pérdida de colmenas. Estas encuestas estiman las pérdidas de colmenas de los apicultores de cualquier tamaño de explotación, inscritos para participar a través de las organizaciones regionales apícolas, las llamadas telefónicas y el correo postal. En los últimos tres años, estas encuestas incluyen el verano y las pérdidas anuales además de las pérdidas del invierno. En la encuesta más reciente, las pérdidas incluyen 5.937 participantes válidos (5.690 aficionados, 169 como negocio suplementario y 78 apicultores profesionales), los cuales manejan colectivamente 414.267 colmenas a fecha del 1 de octubre de 2014 y que constituyen el 15,1% de los aproximadamente 2,74 millones de colmenas manejadas en los EEUU. Las pérdidas anuales suelen ser mayores que las pérdidas en invierno o verano, ya que incluyen las estimaciones de las pérdidas durante todo el año. Las pérdidas totales fueron del 25,3% [24,7 - 25,9%; IC del 95%] durante el verano, del 22,3% [21,9 - 22,8%; IC del 95%] durante el invierno, y del 40,6% [40,0 - 41,2%; IC del 95%] para todo el año apícola de 2014 - 2015. Las pérdidas medias fueron del 14,7% [14.0 - 15,3%; IC del 95%] durante el verano, del 43,7% [42,8 - 44,6%; IC del 95%] durante el invierno, y del 49,0% [48,1 - 50,0%; IC del 95%] durante todo el año. Mientras que las pérdidas totales del invierno fueron más bajas en 2014-2015 que en años anteriores, las pérdidas durante el verano se mantuvieron altas, lo que ocasionó en total una pérdida anual de colmenas superior al 40% durante el

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período muestreado. Este fue el primer año en el que las pérdidas totales fueron mayores en verano que en invierno, debido en gran parte a que los apicultores profesionales informaron de pérdidas en sus colmenas manejadas del 26,2% durante el verano, en comparación con el 20.5% del invierno. Las causas auto-identificadas de la mortalidad durante la temporada de hibernación diferían en función del tamaño de la explotación, así los apicultores aficionados más pequeños generalmente indicaron problemas de manejo de las colmenas (por ejemplo, la inanición, el debilitamiento de la colonia en otoño), en contraste con los apicultores profesionales que por lo general hicieron hincapié en los parásitos o factores fuera de su control (por ejemplo, varroa, nosema, fallos en la reina). Más de dos tercios de todos los apicultores (67,3%) consideraron que tuvieron elevadas pérdidas de colmenas, en función de lo que ellos denominan como aceptables.

Keywords: honey bee; overwinter; mortality; colony losses; 2014–2015

Introduction

Honey bee (*Apis mellifera*) colony losses remain at levels substantially higher than rates which beekeepers identify as acceptable, raising concerns about possible future crop pollination shortfalls (Calderone, 2012). In the USA and elsewhere, beekeepers are having difficulty keeping pace with the demand for managed colonies with increasing acreage of pollinator-dependent crops and demand for the insects that service them (Aizen & Harder, 2009). Multiple interacting factors drive honey bee colony mortality including parasitization and virus transmission by the ectoparasitic mite, *Varroa destructor*, other parasites and disease, poor nutrition due to changing land use patterns and decreased forage availability, large-scale replacement of nectar, and pollen-rich nitrogen fixing legumes with synthetic fertilizers, and sublethal impacts of pesticides (Alaux et al., 2010; Doublet, Labarussias, de Miranda, Moritz, & Paxton, 2015; Goulson, Nicholls, Botias, & Rotheray, 2015; Le Conte, Ellis, & Ritter, 2010). Managed honey bee colony numbers have declined steadily in the USA from a high of 5.1 million colonies in 1947 to a low of 2.39 million colonies in 2006 (vanEngelsdorp & Meixner, 2010). The large colony losses and the vast media attention given to "Colony Collapse Disorder" (CCD), a condition that emerged in 2006–2007 (Williams et al., 2010), has driven a surge in backyard beekeepers, while commercial beekeepers have built in buffers for higher losses, increasing their numbers of managed colonies to meet the requirements of their pollination contracts (vanEngelsdorp & Meixner, 2010). Despite widespread high winter losses, the number of managed colonies paradoxically rose 14.6%, from 2.39 million in 2006 (USDA-NASS, 2007) to 2.74 million in 2014 (USDA-NASS, 2015) reversing the long-term decline in the USA. Mitigating high annual colony losses through increased splitting of surviving stock or purchasing replacement colonies adds considerably to operation costs. Such costs are observed both in management time and lost revenue from decreased honey production, and because fewer full-strength pollination units may be available at times of high colony demand. Increased honey prices (USDA-NASS, 2015) and pollination rental fees (Burgett, Daberkow, Rucker, & Thurman, 2010; Traynor, 2013) have helped offset the expense of increasing colony numbers. Whether this constant rebuilding of lost colonies is sustainable over the long term remains to be seen, especially in light of ever increasing agricultural acreage dependent on pollination (Aizen & Harder, 2009).

Trends in available pollination units and seasonal colony losses have proven to be vital when appraising the long-term sustainability of agriculture in the USA. Comparable multi-year records enhance our understanding of the variability in colony losses and may help identify risk factors or risk combinations that otherwise escape casual observation. Surveys conducted in the USA since the winter of 2006–2007 allowed beekeepers to self-report numbers of living colonies at specific times of the year. The surveys tracked colony increases and decreases within an operation, the level of acceptable winter losses, whether colonies were moved across states lines, if the operation participated in almond pollination, and the beekeeper-perceived main cause of colony losses. Data from previous surveys have shown that total winter colony losses fluctuated between a high of 36% in 2007–2008 and a low of 22% in 2011–2012. Summer and annual losses were first added to the survey for the 2012–2013 beekeeping year, with total summer losses reported to be 25% in 2012–2013 and 20% in 2013–2014. Total annual losses were reported to be 45.0 and 34.1% in 2012–13 and 2013–14, respectively (Lee et al., 2015; Spleen et al., 2013; Steinhauer et al., 2014; vanEngelsdorp, Hayes, Underwood, Caron, & Pettis, 2011; vanEngelsdorp, Hayes, Underwood, & Pettis, 2008, 2010; vanEngelsdorp, Underwood, Caron, & Hayes, 2007; vanEngelsdorp et al., 2012). While winter colony losses have decreased in recent years, the self-described rate of acceptable losses has increased from a low of 13.2% in the 2010–2011 survey (vanEngelsdorp et al., 2012) to 19.1% last year (Lee et al., 2015), suggesting that beekeepers are adjusting their expectations to buffer against higher rates of colony losses. The present study reports the results from the latest colony mortality survey conducted by the Bee Informed Partnership (BIP, beeinformed.org) in the USA. It covers colony increases and mortality from 1 April 2014 to 1 April 2015, with subdivisions for summer and winter losses.

As in prior surveys, we divided survey respondents into the categories of backyard, sideline, and commercial beekeepers. Respondents typically vary widely in their management choices, including their use of synthetic varroa control. Commercial beekeepers tend to earn their primary income through pollination fees, often migrating colonies across large distances, participating in almond pollination, and maintaining colonies in dense conditions that facilitate disease and parasite transmission (Seeley & Smith, 2015). In contrast, backyard beekeepers are frequently stationary, managing fewer colonies and dedicating more time and financial input per unit, but managing hives less intensively. Sideliners fall in between these extremes, earning only part of their income from honey production, pollination, or both. Surveyed beekeepers were also categorized by state, as this can help account for climatic and regional differences in colony management practices and losses (see methods for details). Beekeepers were also asked to report the primary cause of colony losses, as this provides insight into regional management issues beekeepers face and what they perceive as the greatest threat to colony health.

Materials and methods

Survey

To estimate colony losses in the beekeeping industry from 2014 to 2015 in the USA, we utilized the Internet platform SelectSurvey.com. Beekeepers were invited to participate via email through distribution lists maintained by two national beekeeping organizations (American Beekeeping Federation and American Honey Producer's Association), a beekeeping supply company (Brushy Mountain Bee Farm), two honey bee brokers, two beekeeping journals (American Bee Journal and Bee Culture), and two subscription listservs (Catch the Buzz and ABFAlert). An email request to participate in the survey was also sent to approximately 12,500 beekeepers that signed up to participate via beeinformed.org, responded to a previous BIP survey and indicated their willingness to participate in future surveys, or participated in the USDA Animal Plant Health Inspection Service National Honey Bee Disease Survey and provided their email address. All survey requests asked beekeepers to forward the survey to other beekeepers, resulting in a snowballing distribution of the document. Additionally, requests to distribute the survey information were sent to the Apiary Inspectors of America, state extension apiculturists, industry leaders, and to a number of regional beekeeping clubs, including the Eastern Apicultural Society (eastern US), Heartland Apicultural Society (central US), and the Western Apicultural Society (western US).

Commercial beekeepers, while fewer in number than backyard beekeepers, manage the majority of colonies in the USA and have previously been the hardest subset to reach. Thus to increase participation of commercial beekeepers, we conducted surveys over the phone ($n = 20$) or mailed paper surveys ($n = 1{,}200$) either through BIP personnel or through state apiarists. As our methods for soliciting responses depended on other organizations and requests to pass on the invitation, we were unable to calculate the total number of beekeepers contacted and so cannot calculate the response rate. Due to solicitation methods, the survey was not randomly conducted, which could lead to biased results (van der Zee et al., 2013).

The survey was open online for responses from 1 April to 30 April 2015. Paper surveys were mailed in the third week of March 2015, and completed surveys returned by 29 May were included in our analysis.

The survey consisted of two parts: the "loss survey" and the optional "management survey." After completion of the loss survey, beekeepers were given the option to continue to the management survey. Only the responses to the loss survey are addressed in this study. The loss survey questions and the corresponding definition for valid responses to each question are given in the Supplementary material Table S1.

The 2014–2015 survey included the same core questions as the previous years' winter, summer, and annual loss surveys (Lee et al., 2015; Spleen et al., 2013; Steinhauer et al., 2014). As in the previous surveys in the USA, winter, summer, and annual periods are defined as fixed time periods: summer = 1 April 2014 to 1 October 2014, winter = 1 October 2014 to 1 April 2015, and annual = 1 April 2014 to 1 April 2015 (Lee et al., 2015; Spleen et al., 2013; Steinhauer et al., 2014; vanEngelsdorp et al., 2012; vanEngelsdorp et al., 2008; vanEngelsdorp et al., 2010, 2011, 2007). Since last year's survey (Lee et al., 2015), we also accounted for colony increases and decreases during the fixed time periods.

The loss data were edited to remove invalid responses. Duplicate entries were removed, as were entries from respondents outside the USA and those with insufficient answers to calculate a valid winter or summer loss, including illogical responses such as negative colony numbers. The questionnaire included multiple choice questions with an open entry "other" category, where responses were sorted to either keep the entry as "other" if the cause of death written was effectively different from the listed categories or revised to one of the preexisting categories where appropriate.

After the initial validation, three subsets of data based on the three time periods were created for analysis: valid for winter loss, valid for summer loss, and valid for annual loss. These subsets were necessary because not all respondents answered the entire set of loss questions. To be valid for a given time period, beekeepers needed to start that time period with at least one colony.

Each beekeeper's set of managed colonies will be referred to as that beekeeper's "operation." To compare different operation sizes, beekeepers were classified into three groups as in previous surveys based on the number of living colonies managed in their operations on 1 October 2014: "backyard beekeepers" managed 50 or fewer colonies, "sideline beekeepers" managed between 51 and 500 colonies, and "commercial beekeepers" managed more than 500 colonies.

Statistics

Total and average colony losses for summer, winter, and annually were calculated for all operations based on vanEngelsdorp et al. (2013) using R code developed and presented in Steinhauer et al. (2014). First, the percentage of operational losses for each respondent was calculated by dividing the number of colonies the beekeeper lost by the number of colonies at risk during that time period (Supplementary material, Table S1, questions 2–5, 5–8, and 2–8, respectively). Total loss results were then calculated by dividing the total number of colonies lost by the total number of colonies at risk in that respective time period, and multiplying that value by 100. Average losses were calculated by summing all the operational losses for that time period, then dividing that by the number of respondents for that same time period. The 95% confidence intervals (95% CIs) for the total losses were calculated using a generalized linear model (quasibinomial distribution) (R Development Core Team, 2015). The 95% CI for average losses were calculated using the Wald formula (see vanEngelsdorp et al., 2013 for details).

Total loss, or weighted loss, calculations counted each individual colony equally, without regard to operation size. This means that beekeepers managing more colonies exerted a greater influence on the total loss results than those managing fewer colonies. Additionally, we computed average loss (or unweighted loss) calculations, where each beekeeper's operational loss was used to calculate the average loss across all operations. Total loss calculations thus reflected commercial operations as they manage significantly more colonies compared to backyard and sideliner operations, while average loss calculations were more representative of backyard beekeepers. Total loss allowed more informative comparisons of loss across seasons and among states, while average loss was more informative for comparing categories of respondents.

We used the Kruskal–Wallis rank sum test to check operational colony losses for significant differences between several factors including operation types (backyard, sideline, commercial), migrating vs. stationary beekeeping, almond pollinating vs. non-almond pollinating, acceptable vs. higher than acceptable losses, and between the various causes of death. In case of significance, the Kruskal–Wallis test was followed by the Mann–Whitney *U* test (also known as Wilcoxon Rank Sum test) for a pairwise check of significance using a Bonferroni correction when multiple comparisons were conducted. Operation type-based differences regarding the likelihood for higher than acceptable losses and for the causes of colony death were detected using the Chi-squared test. All statistical tests were two tailed with a level of significance of $\alpha = 0.05$. All statistical analyses were performed in *R* (R Development Core Team, 2015).

When reporting colony losses by state, we followed the USDA-NASS method of counting colonies of multistate beekeepers repetitively in each state in which the beekeeper reported having colonies (USDA-NASS, 2015). Multistate beekeepers can be migratory or stationary. For states with five or fewer respondents, we do not report the losses, in order to guarantee the anonymity of the participants.

Results

Average and total losses

The survey resulted in 7,570 responses. We removed duplicate (*n* = 456) and non-US beekeepers (*n* = 356), and an additional 625 responses because they had invalid data entries. Thus, the final analytical data-set comprised 6133 beekeepers. The valid subsets for summer contained 4,971 responses, for winter 5,937, and 4,775 for annual.

The total loss of colonies for 2014 to 2015 over the summer was 25.3% [95% CI 24.7–25.9%], over winter 22.3% [95% CI 21.9–22.8%], and annually 40.6% [95% CI 40.0–41.2%], see Figure S1 for a breakdown by operation type. The average losses per operation in summer amounted to 14.7% [95% CI 14.0–15.3%], in winter 43.7% [95% CI 42.8–44.6%], and annually to 49.0% [95% CI 48.1–50.0%] (Table 1).

Table 1. Total and average colony losses per season.

Season	*n*	No. of colonies					Total loss (%) [95% CI]	Average loss (%) [95% CI]
		1 April 14	Interim changes	1 October 14	Interim changes	1 April 15		
Summer	4,971	370,063	+204,535 −26,143	409,700	-	-	25.3 [24.7–25.9]	14.7 [14.0–15.3]
Winter	5,937	-	-	414,267	+ 65,880 −9,191	365,770	22.3 [21.9–22.8]	43.7 [42.8–44.6]
Annual	4,775	337,633	+ 196,741 −23,517	380,616	+ 64,525 −9,064	336,386	40.6 [40.0–41.2]	49.0 [48.1–50.0]

Notes: Sample size (*n*) is the number of beekeepers having provided valid responses. Interim changes include the numbers of increases (+) by splits or purchases and decreases (–) through selling or giving away during a time period. Increases and decreases are taken into account in the calculation of colonies at risk.

Table 2. Total and average colony losses by operation type.

Season	Operation type	n	No. of colonies (start)	% of colonies (start)	Total loss (%) [95% CI]	Average loss (%) [95% CI]
Summer	Backyard	4,751	22,096	6	15.9 [15.3–16.5]	14.6 [13.9–15.2]
	Sideline	140	16,043	4.3	21.3 [17.8–25.1]	14.7 [11.5–17.9]
	Commercial	80	331,924	89.7	26.2 [21.6–31.1]	21.6 [17.3–25.9]
Winter	Backyard	5,690	34,569	8.3	41.2 [40.4–42.0]	44.3 [43.4–45.3]
	Sideline	169	23,024	5.6	30.9 [27.2–34.7]	31.8 [28.0–35.5]
	Commercial	78	35,6674	86.1	20.1 [16.9–22.9]	22.9 [18.8–27.0]
Annual	Backyard	4,566	21,106	6.3	48.5 [47.6–49.3]	49.5 [48.5–50.5]
	Sideline	136	15,643	4.6	43.3 [38.8–47.8]	39.1 [34.8–43.4]
	Commercial	73	300,884	89.1	39.9 [35.0–44.9]	37.3 [32.4–42.1]

Note: Sample size (*n*) is the number of beekeepers having provided valid responses.

Table 3. Colony numbers (mean, median, and mode) by operation type for the winter season.

Operation type	n	mean	s.err.	median	mode
Backyard	5,690	6.1	0.1	3	2
Sideline	169	136.2	7.8	99	52
Commercial	78	4,572.7	867.1	2,800	2,000

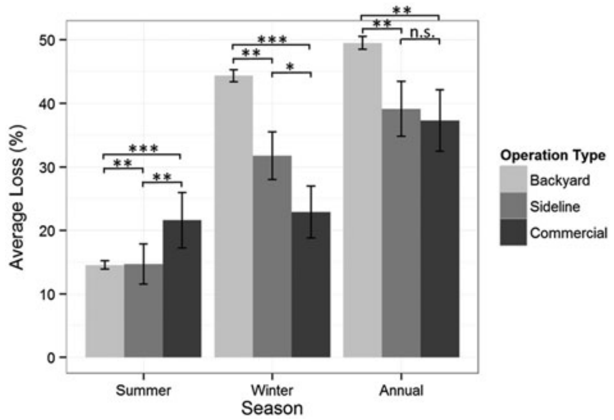

Figure 1. Operational differences in average colony loss by season.
Notes: Bars represent 95% CI. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, n.s.: not significant.

The valid respondents for winter losses managed 414,267 colonies on 1 October 2014, representing approximately 15.1% of the 2.74 million honey producing colonies nationwide (USDA-NASS, 2015). Backyard beekeepers predominated (*n* = 5,690), but managed only 8.3% of colonies reported. The 169 sideliners managed 5.6% of colonies, while 78 commercial beekeepers managed the remaining 86.1% of the colonies (Table 2). Over the winter, 25.7% of all respondents (*n* = 1,525) reported they lost zero colonies. When asked to compare their winter losses to the previous year, 34.7% of beekeepers (*n* = 2,059) indicated they suffered higher winter losses this year, 26.3% (*n* = 1,559) experienced fewer losses, and 22.2% (*n* = 1,317) reported similar losses. The remainder either did not respond to the question, or did not know if their losses differed between years, or did not keep bees in the previous year.

Losses by operation type

The majority of beekeeping operations in the USA are small-scale backyard beekeepers and accordingly they make up the majority of valid respondents to our survey for all three seasons. Due to the relatively small operation size of these backyard beekeepers, they proportionally accounted for the fewest number of managed colonies (Table 2), while the majority of colonies were maintained by commercial beekeepers. During the winter, backyard beekeepers maintained on average 6.1 ± 0.1 colonies, sideliners maintained 136.2 ± 7.8, and commercial beekeepers 4,572.7 ± 867.1 (Table 3) with similar means for summer and annual time periods.

Colony losses during both summer and winter were significantly different depending on operation type

Table 4. Average colony loss of almond pollinating vs. non-almond pollinating operations.

Operation type	Pollinated almonds	n	Average winter loss (%) [95% CI]	Kruskal–Wallis rank sum test χ^2	df	p-value
Commercial	No	13	32.0 [18.4–45.6]	1.9177	1	0.1661
	Yes	60	21.6 [17.3–26.0]			
Sideline	No	136	33.0 [28.7–37.3]	0.2885	1	0.5912
	Yes	18	26.9 [18.9–34.9]			

Note: Sample size (*n*) is the number of beekeepers having provided valid responses.

Table 5. Average colony loss of migratory vs. stationary operations.

Operation type	Migrated hives	n	Average winter loss (%) [95% CI]	Kruskal–Wallis rank sum test		
				χ^2	df	p-value
Commercial	No	15	21.2 [11.6–30.8]	0.3778	1	0.5388
	Yes	58	24.1 [19.2–29.0]			
Sideline	No	120	32.1 [27.8–36.4]	<0.001	1	0.9930
	Yes	34	33.1 [24.0–42.3]			

Note: Sample size (n) is the number of beekeepers having provided valid responses.

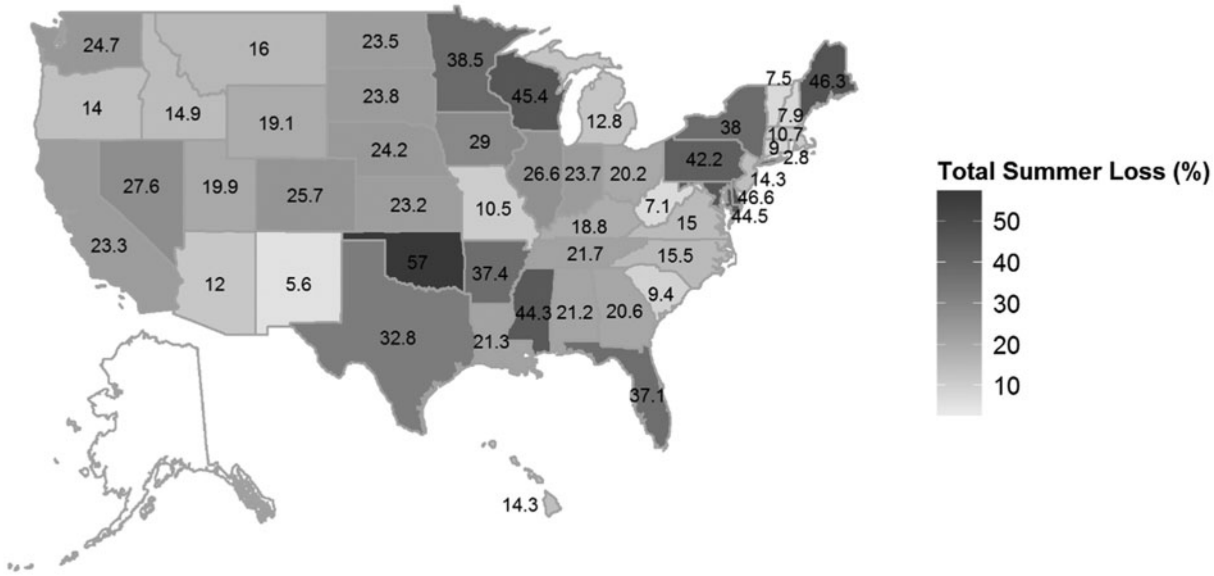

Figure 2. Total colony loss in summer by state.

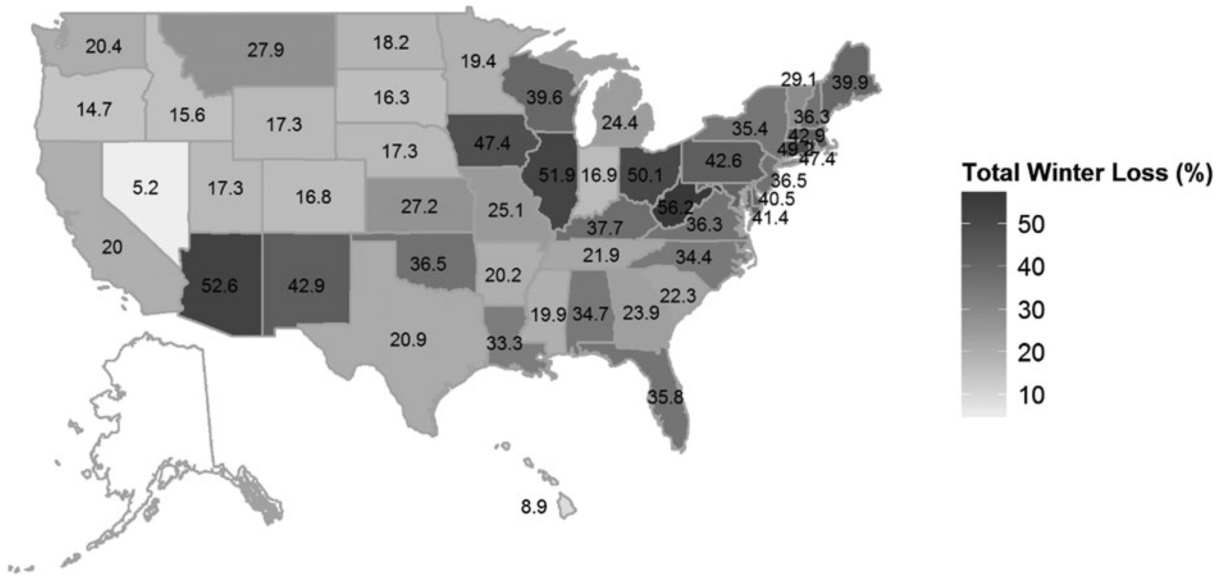

Figure 3. Total colony loss in winter by state.

(summer: Kruskal–Wallis $\chi^2 = 51.879$, Mann–Whitney p-values < 0.01; winter: Kruskal–Wallis $\chi^2 = 29.979$, Mann–Whitney p-values < 0.05). During the summer, commercial beekeepers suffered the highest colony losses, approximately 50% higher average losses than backyard beekeepers (Figure 1). This trend was reversed in the winter, when operational colony losses were twice as high in backyard beekeepers compared to commercial beekeepers. Sideliner losses fell in-between the two other groups during both seasons.

Average colony losses did not differ significantly for commercial or sideline beekeepers who pollinated almonds in California compared to beekeepers who did not (Table 4). Migratory and stationary beekeepers also experienced similar colony losses compared to each other (Table 5). Most commercial beekeepers moved their colonies into almond orchards and migrated between states, while the majority of sideliners were stationary beekeepers.

State losses

Valid responses for each state ranged between a low of 2 (Alaska) and a high of 860 (Pennsylvania) (Supplementary material, Table S2). Pennsylvania and Virginia had the highest number of respondents, two states with very active honey bee inspection programs, state beekeeping programs, and grant initiatives to support new beekeepers. A map that gives an overview of respondents by state in winter is included in the Supplementary material (Figure S2).

Total losses varied greatly by state throughout all seasons. In summer, total losses ranged from 2.8% (Rhode Island) to 57.0% (Oklahoma). In addition to Oklahoma, Pennsylvania, New York, Maine, Wisconsin, and Florida experienced comparably high losses during the summer (Figure 2). In winter, total losses ranged from 5.2% (Nevada) to 56.2% (West Virginia). States from the Northeast, Maryland, West Virginia, Arizona, and New Mexico had the highest total losses in winter (Figure 3). Annually, the total losses ranged from 13.9% (Hawaii) to 63.4% (Oklahoma) (Supplementary material, Figure S3).

The average losses per operation also varied greatly by state and ranged from 7.0% (Arizona) to 29.2% (Wyoming) in summer, 8.8% (Hawaii) to 59.5% (Minnesota) in winter, and 21.2% (Hawaii) to 64.8% (Nevada) annually (Supplementary material, Figures S4–S6).

Acceptable winter losses

Participants of the survey indicated a loss up to 18.7% on average as acceptable over winter (n = 5,937). Using this value as our threshold, 67.3% of beekeepers had higher than acceptable losses. The average loss of beekeepers with acceptable loss levels was 2.6% [95% CI: 2.4 – 2.8%], significantly lower than the average losses of 63.7% [95% CI: 62.8–64.5%] experienced by beekeepers above acceptable loss levels (Kruskal–Wallis χ^2 = 4023.2, p-value < 0.001). Furthermore, the likelihood of having acceptable or higher losses differed significantly by operation type (Chi-squared test: χ^2 = 10.225, p-value = 0.0060). Backyard beekeepers were 30% more likely than commercial beekeepers to have higher than acceptable losses.

Commercial beekeepers reported a lower percentage as an acceptable loss than backyard or sideline beekeepers. On average, they indicated 14.0% [95% CI: 12.4–15.6%] as acceptable, compared to 18.7% [95% CI: 18.3–19.2%] of backyard and 19.1% [95% CI: 17.1–21.2%] of sideline beekeepers.

Regardless of operation size, beekeepers who experienced high losses also indicated a higher rate of colony losses as acceptable compared to beekeepers with lower losses. Beekeepers who lost less than the 18.7% loss rate also reported a lower value for acceptable losses, reporting on average acceptable loss rates of only 15.0%. In contrast beekeepers who lost more colonies than the acceptable rate, typically reported an average of 20.5% colony losses as acceptable.

Self-reported causes of winter loss

Of the 5937 beekeepers in our winter subset, 4,224 suffered losses and indicated at least one cause for colony death. The three most frequently named reasons were starvation (n = 1,552), poor winter conditions (n = 1,514), and weak colonies in the fall (n = 1,451).

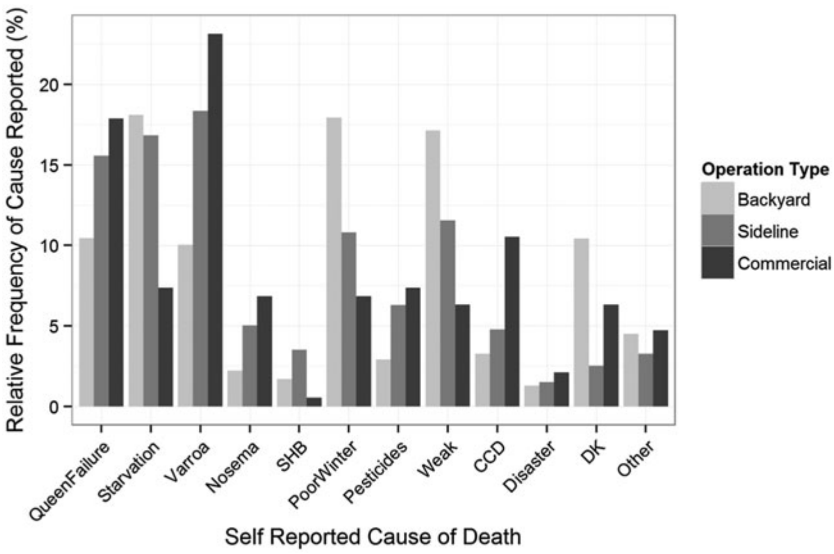

Figure 4. Self-reported causes of winter loss by operation type in relative frequency.
Notes: SHB: small hive beetle; CCD: colony collapse disorder; DK: do not know.

Table 6. Causes of death with associated total and average winter losses and operation type differences.

Cause of death	*n*	*n* (backyard)	*n* (sideline)	*n* (commercial)	Average loss [95% CI]	Chi-squared test for operation type differences χ^2	df	*p*-value	Risk ratio commercial vs. backyard
Queen failure	945	849	62	34	50.2 [48.3–52.1]	72.489	2	<0.001	2.5
Starvation	1,552	1,471	67	14	57.7 [56.2–59.2]	12.416	2	0.0020	0.6
Varroa	933	816	73	44	56.1 [54.2–58.0]	154.290	2	<0.001	3.3
Nosema	214	181	20	13	53.9 [50.0–57.8]	56.046	2	<0.001	4.4
SHB	153	138	14	1	61.0 [56.3–65.7]	16.551	2	0.0003	0.4
Poor winter	1514	1458	43	13	66.3 [64.9–67.8]	9.723	2	0.0077	0.6
Pesticides	274	235	25	14	63.9 [60.4–67.4]	55.006	2	<0.001	3.7
Weak	1451	1393	46	12	57.3 [55.7–58.8]	7.858	2	0.0197	0.5
CCD	305	266	19	20	67.5 [64.3–70.6]	63.600	2	<0.001	4.6
Disaster	115	105	6	4	63.7 [57.9–69.4]	4.198	2	0.1226	–
DK	868	846	10	12	66.8 [64.8–68.8]	17.168	2	<0.001	0.9
Other	387	365	13	9	60.0 [57.0–63.0]	1.741	2	0.4187	–

Notes: SHB: small hive beetle; CCD: colony collapse disorder; DK: do not know. Sample size (*n*) is the number of beekeepers having provided valid responses. Risk ratios indicate the likelihood of commercial beekeepers to report a cause compared to backyard beekeepers. Risk ratios are only indicated when operation-type differences are significant, *p*-value < 0.05.

Due to the large proportion of backyard beekeepers participating in the survey, these responses strongly reflect the perceived causes of winter loss for backyard beekeepers. When segregated by operation type, the most commonly reported causes of winter loss differed (Figure 4). Commercial beekeepers reported varroa mites and queen failure as the most common reasons for colony death. Ten of twelve listed possible causes differed significantly by operation type (Table 6). CCD, nosema, varroa mites, and queen failure were more likely to be reported by commercial beekeepers than by backyard beekeepers (causes indicated from highest to lowest risk ratio). Backyard beekeepers reported small hive beetles, poor winter, starvation, and "do not know" with a greater likelihood than commercial beekeepers (causes indicated from highest to lowest risk ratio). Only the responses in the categories "disaster" and "other" did not differ significantly by operation type. Beekeepers of any operation type that reported losing colonies to poor winter conditions, pesticides, CCD, or "do not know" reported losing more bees than those who did not report those causes (Kruskal–Wallis $\chi^2 = 143.660$, 6.995, 25.996, 72.018, respectively, *p*-values < 0.01). Beekeepers who reported losing colonies to queen failure, varroa, nosema, or weak conditions in fall had fewer losses compared to beekeepers who did not report those causes (Kruskal–Wallis $\chi^2 = 101.330$, 10.037, 5.554, 5.977, respectively, *p*-values < 0.05).

One common symptom of CCD is that no dead bees are found in dead colonies. An additional question in the survey asks respondents if their colonies experienced the symptom of no dead bees found in dead colonies. Of the 4,224 valid respondents for this question, 1,336 beekeepers (31.6%) reported this symptom. They indicated having lost a total of 38,115 colonies with this symptom, which would represent 36.2% of the 105,186 colonies lost over the winter last year by all respondents. Operations with this symptom did not have higher losses than operations without the occurrence of the symptom (Kruskal–Wallis $\chi^2 = 0.564$, *p*-value = 0.4527). Commercial beekeepers were 160% more likely than backyard beekeepers to report the symptom of no dead bees in the hive (Chi-squared test: $\chi^2 = 111.18$, *p*-value < 0.001).

Discussion

In this ninth annual survey of winter colony losses in the US (Lee et al., 2015; Spleen et al., 2013; Steinhauer et al., 2014; vanEngelsdorp et al., 2012; vanEngelsdorp et al., 2008; vanEngelsdorp et al., 2010, 2011, 2007), and third reported survey of summer and annual losses, we report similar total and average winter losses as experienced last year (Lee et al., 2015). However, total summer losses were almost 30% higher than last year, and so for the first time total summer losses exceeded total winter losses. The acceptable loss rate of 18.7% remained high compared to earlier survey years, suggesting that beekeepers are adjusting their expectations downward when it comes to acceptable colony survival rates. Unfortunately, total summer losses alone exceeded the rate of acceptable loss reported by beekeepers.

At 22.3%, this year's total winter loss is the second lowest rate experienced during the last nine years. In stark contrast, the average winter loss at 43.7% is among the highest winter mortalities beekeepers have sustained since the survey began. A similar pattern occurred last year, suggesting that commercial beekeepers who manage the majority of colonies in the USA have reined in their winter mortality, thus causing a dip in total winter losses. Backyard beekeepers continue to lose a large proportion of their hives during the winter, elevating the average winter losses, given that this measurement ranks all beekeeping operation types equally.

The winter and annual loss rates experienced by beekeepers in the USA fall toward the upper spectrum of worldwide colony loss rates. Other studies investigating colony losses between 2009 and 2013 in Europe, Canada, China, Turkey, and South Africa reported winter losses between a low of 9.3% among small-scale beekeepers (Slovakia 2012/2013) and a high of 46.2% (South Africa 2010/2011) (Clermont et al., 2014; Pirk, Human, Crewe, & vanEngelsdorp, 2014; van der Zee et al., 2014). The average winter losses reported by several European countries for 2012 to 2014 ranged between a low of 3.5% (Lithuania 2013/2014) and a high of 33.6% (Belgium 2012/2013) (Laurant, Hendrikx, Ribiere-Chabert, & Chauzat, 2015). The pan-European epidemiological study on honey bee colony losses (EPILOBEE) looked at colony losses in 16 EU countries from 2012 to 2014, finding that winter mortality decreased in the majority of countries in 2013–2014 compared to the previous year. Annual colony mortality decreased in 8 of the 16 countries and remained unchanged in the remainder (Laurant et al., 2015); however the EPILOBEE study extrapolated results from limited surveying and are not beekeeper self-reported colony losses as reported here. Caution should be used in comparing across studies, due to differences in methodology, sample sizes, and proportions of operation types within the evaluated sample. Colony losses for the winter of 2014–2015 have so far only been published for the USA and so it is currently unknown how they compare to loss rates experienced elsewhere.

We added summer losses into the loss reports three years ago after two years of piloting it in the survey. Beekeepers lost a quarter of all managed hives during the summer season, a total summer loss rate 30% higher than last year, yet similar to the rate reported two years ago. This is the first year where total summer losses exceed total winter losses, an unexpected finding that highlights the importance of monitoring colony losses throughout the year. Traditionally, winter losses were believed to be higher than summer losses, as weak colonies have trouble surviving the winter nectar dearth and long-term confinement. Summer, in contrast, is the time of year when colonies typically thrive, expanding on abundant nectar and pollen sources. Our results highlight how colony losses have shifted, especially among commercial beekeepers, who lost 30% more hives during the summer season compared to winter (26.2% vs. 20.1%). In contrast, the average summer loss rate of 14.7% highlights that backyard beekeepers typically fare much better during the summer than the winter. The difference in summer losses may be due to increased pesticide exposure risk during pollination events for commercial beekeepers or increased disease and viral transmission when commercial colonies are transported or placed in large holding yards, but causes for increased summer losses need further investigation.

The EPILOBEE study conducted during 2013 and 2014 is the only other study that included summer losses (Laurant et al., 2015). Reported summer loss rates were low, ranging from 0.1% in Lithuania to 11.1% in France. However, this study only calculated average losses and not total losses. Average loss calculations in our survey reflect the situation of backyard beekeepers, who continue to lose the majority of their colonies during winter and suffer moderate losses during summer. Even so, average summer losses at 14.7% in the USA are substantially higher than European summer losses, which were below 6% for all EU countries except Belgium (9.1%) and France (11.1%).

Due to the increase in total summer losses, the annual total losses rose to 40.6% from last year's low of 34.1%, but were still lower than the 45.2% experienced in 2012–2013 (Lee et al., 2015; Steinhauer et al., 2014). In contrast, average annual losses at 49.0% were almost identical to the last two years (49.4% and 51.5%, respectively), indicating that on average beekeepers lose almost 50% of their managed hives during the year. Since the majority of respondents are backyard beekeepers, these small-scale hobby farmers lose half of their livestock annually. With replacement colonies costing $90–$175, it is not surprising that many drop out of beekeeping after 1–2 years.

Survey respondents vary from year to year, although many participate annually. We ask beekeepers how their winter losses compare to the previous year. Although the average winter losses that we calculated were very similar between the two years, the most common response was that beekeepers experienced higher losses this year (34.7%), while about one quarter (26.3%) reported lower losses and just over one fifth (22.2%) indicated similar losses.

Commercial and backyard beekeepers differ drastically in scale and in their management practices. The majority of commercial beekeepers migrate their colonies multiple times each year, transporting colonies large distances. Pollination environments potentially expose bees to increased pesticide pressure (Krupke, Hunt, Eitzer, Andino, & Given, 2012; Pettis et al., 2013) and vast nutritional monocultures that may impact stress resistance (Huang, 2012). Despite rigorous pollination schedules, winter mortality for commercial beekeepers is half the rate of backyard beekeepers. This lower rate of winter losses may be due to the southern migration of commercial beekeepers who avoid the northern temperate climate so they can prepare colonies for California almond pollination in February. The lower rate may also be influenced by different management practices.

Summer losses in contrast were 50% higher this year for commercial compared to backyard beekeepers, similar to what beekeepers experienced in the 2012–2013 survey. Despite the elevated summer losses, commercial beekeepers suffered significantly lower annual losses compared to backyard beekeepers. European studies have shown similar trends, with lower losses in larger beekeeping operations (van der Zee et al., 2012, 2014). Additionally, the international results segregated beekeepers into classes similar to our backyard beekeeper and sideliner categories. Commercial operations managing several thousand colonies (see Table 3 for average commercial operation size) are relatively uncommon outside the USA.

These stark differences in colony losses between commercial and backyard beekeepers highlight the bifurcation of the beekeeping industry in the USA and may illustrate that the two populations face different honey bee health issues and follow different management practices. Backyard beekeepers, for example, seem to treat less for varroa mites. In the current survey, backyard beekeepers indicated that winter colony losses were predominantly due to "weak in fall," "poor winter conditions," and "starvation." A symptom of heavy varroa parasitization is a dwindling colony that has difficulty surviving the winter (Genersch et al., 2010; Le Conte et al., 2010; Yang & Cox-Foster, 2007), suggesting that backyard beekeepers could reduce their winter losses through better varroa management and improved winter preparation. Losses of over 20% during both the summer and winter period indicate that commercial beekeepers face challenges to honey bee health throughout the year and would benefit from identifying and mitigating the causes of summer losses. The causes of the summer losses are beyond the scope of this survey, but require further investigation. Potential factors underlying higher losses include pesticide exposure, disease and viral transmission, and poor queen quality. Extension and research efforts to reduce colony losses should address these two beekeeping populations separately, finding solutions tailored to the unique needs of each. Even though backyard beekeepers have lower summer losses than commercial beekeepers, their average rate of loss in the summer alone is still higher than the 10% rate of acceptable colony loss described in EPILOBEE (Laurant et al., 2015) and in Germany (Genersch et al., 2010).

Participating in almond pollination or migrating colonies did not impact colony loss rates. It is often postulated that transporting hives negatively impacts colony health through increased stress, but so far only one study in South Africa has shown a negative effect on honey bee colony survival (Pirk et al., 2014). Previous surveys in the USA have shown no impact or reduced colony mortality in migratory compared to stationary beekeeping operations. The lower colony mortality might be explained by decreased varroa infestation rates, as the number of varroa mites per 100 bees is reduced in migratory hives (Traynor et al., 2016).

High winter losses were concentrated in the Northeast and mid-Atlantic region which experienced a mild fall followed by an exceptionally long and cold winter (National Centers for Environmental Information [NOAA], 2014, 2015)). Such weather patterns often result in colonies entering winter with depleted honey stores, as the bees keep flying during the warm yet nectar barren fall. Bees typically start rearing brood in late winter, using up the majority of their honey stores to raise the broodnest temperature. The long, cold, wet spring delayed spring nectar sources, which may explain why the most commonly self-reported cause of death was starvation. Beekeepers in Arizona and New Mexico also reported high winter losses. Both states experienced low rainfall with record warmth, suggesting that bees may have experienced no break in the brood cycle, resulting in elevated varroa mite levels coupled with reduced nectar availability. Summer losses were highest in Oklahoma, a state that experienced a severe drought in May 2014, which may have negatively impacted spring nectar flows, preventing colonies from building-up after the winter.

Regional variations in colony losses are very common worldwide (Laurant et al., 2015; McMenamin & Genersch, 2015). EPILOBEE (Laurant et al., 2015) found a tendency toward higher average losses in colder northern countries in Europe, but other studies, like Genersch et al. (2010) or van der Zee et al. (2014) have not displayed clear regional clustering. Caution should be used when interpreting the data from the latter, as beekeepers self-defined the length of their winter, making it difficult to compare loss rates over the same time frame.

Self-reported acceptable loss rates over the past 9 years have varied from a low of 13.2% to a high of 19% last year (Lee et al., 2015; Spleen et al., 2013; Steinhauer et al., 2014; vanEngelsdorp et al., 2012; vanEngelsdorp et al., 2008; vanEngelsdorp et al., 2010, 2011, 2007). Despite this year's relatively high acceptable loss rate of 18.7%, two-thirds (67.3%) of beekeepers exceeded this colony mortality rate. The one-third that stayed below the threshold lost on average only 2.6% of their hives, while the other two-thirds lost 63.7% of their colonies on average. This wide divergence highlights that colony losses are not equitably distributed across the industry. Beekeepers who experience lower rates of losses also report lower acceptable loss rates, suggesting that prior personal experience of loss rates influences perception of acceptable colony loss rates. This may help explain why commercial beekeepers report a lower tolerance for colony losses, as they typically experience lower rates of colony loss. Beekeepers in the USA report higher rates of colony loss as acceptable compared to their European counterparts, where a maximum loss of 10–12% is considered acceptable (Charrière & Neumann, 2010; Genersch et al., 2010; Vejsnæs, Nielsen, & Kryger, 2010).

Beekeepers reported which factors had the greatest impact on colony losses over the winter. The most common causes of colony death selected by beekeepers were starvation, poor winter, weak colonies, queen failure, varroa mites, and "do not know." These were commonly selected choices in previous surveys. In contrast to last year's results, pesticides and CCD were reported with less frequency. Commercial beekeepers reported varroa as the most common cause of colony losses, displacing queen failure as the top reason (Lee et al., 2015; Steinhauer et al., 2014). CCD was the third most commonly selected cause among commercial beekeepers, though they reported varroa more than twice as frequently. Pesticides dropped in the ranking, falling along with starvation to fourth place and followed closely by nosema. Commercial beekeepers have shifted their focus to varroa mites as the leading reason for colony losses, which matches the increased attention this parasite has received in scientific publications and the media as one of the major threats to honey bee survival (e.g., Genersch et al., 2010; van der Zee et al., 2015).

It is somewhat surprising that backyard beekeepers have not listed varroa as a leading cause of colony loss, perhaps because their colonies perish predominantly in the winter and they do not associate the dwindling colony strength as a latent response to this parasite. Hidden predominantly inside the brood cells, varroa is not a directly visible lethal factor and backyard beekeepers may have trouble recognizing its impact on colony health. The diverse factors selected by beekeepers for colony mortality align well with the current perspective that colony losses are driven by multifactorial, interacting factors (McMenamin & Genersch, 2015).

This study highlights the benefits of surveying colony losses throughout the year, as this year commercial beekeepers lost more colonies during summer than winter. It demonstrates the importance of considering individual operation types separately, underscoring that the two distinct branches of the beekeeping industry face different hurdles. Backyard beekeepers lost almost 50% of their colonies over the year, and their average winter losses exceeded the annual average losses of commercial beekeepers. As management surveys have revealed, more than half of all US backyard beekeepers do not manage for varroa (Bee Informed Partnership, 2015). Ongoing education efforts have emphasized the negative impact of this parasite, but adoption of best management practices remains low. Several key extension efforts, such as regional Sentinel Hive projects that monitor varroa mite infestation levels in beekeeping club apiaries throughout the active beekeeping season, are working to improve backyard beekeeper understanding of varroa impacts on colony health.

Commercial beekeepers meanwhile lost 40% of their managed hives, equally split between the winter and summer months. When monitored throughout the year, it is evident that beekeepers in the USA are still experiencing unacceptably high losses. Other survey efforts may be underestimating their annual colony loss rates when they neglect summer losses, especially in commercial operations that experience summer stress factors such as pesticide exposure and nutritional monocultures. Additional surveys of summer losses in other countries would help place the losses in the USA into a global context and indicate whether high summer losses are unique to the migratory pollination environment of commercial beekeepers in the USA.

Acknowledgments

We thank all respondents for their participation. We thank Anthony Nearman, Heather Eversole, Rachel Fahey, and Shayne Madella for entering the answers from paper surveys. Our gratitude goes out to the many beekeeping organizations, industry leaders, and beekeeping clubs that forwarded our appeal for participation emails. A special thank you is owed to USDA APHIS, the Apiary Inspectors of America, the American Honey Producers Association, Brushy Mountain Bee Farm, Bee Culture magazine, and American Bee Journal for sending out participation requests to their online audiences.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This project was financially supported by the Coordinated Agricultural Project (CAP) grant from US Department of Agriculture-National Institute of Food and Agriculture (USDA-NIFA): the Bee Informed Partnership and includes, in addition to several of the authors, Joseph H. Connell, Susan Donohue, Jonathan Engelsma, Wayne Esaias, Eugene J. Lengerich, Steve Pernal, Marla Spivak, and the USDA-ARS Area wide Program on Bee Health.

Supplementary material

The supplementary material for this article is available online at http://dx.doi.10.1080/00218839.2016.1153294.

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