A National Survey Of Managed Honey Bee 2012-2013 Annual Colony Losses In The USA: Results From The Bee Informed Partnership

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Abstract

For the past six years in which overwintering mortality of honey bee colonies has been surveyed in the USA, estimates of colony loss have fluctuated around one-third of the national population. Here we report on the losses for the 2012-2013 seasons. We collected data from 6,482 US beekeepers (6,114 backyard, 233 sideline, and 135 commercial beekeepers) to document overwintering mortality rates of honey bee colonies for the USA. Responding beekeepers reported a total 30.6% (95% CI: 30.16-31.13%) loss of US colonies over the winter, with each beekeeper losing on average 44.8% (95% CI: 43.88-45.66%) of their colonies. Total winter losses varied across states (range: 11.0% to 54.7%). The self-reported level of acceptable winter loss was 14.6%, and 73.2% of the respondents had mortality rates greater than this level. The leading self-identified causes of overwintering mortality were different according to the operation type; backyard beekeepers generally self-identified "manageable" factors (e.g., starvation, weak colony in the fall), while commercial beekeepers generally identified non-manageable factors (e.g., queen failure, pesticides) as the main cause of losses. For the first time in this series of surveys, we estimated mortality during the summer (total loss = 25.3% (95% CI: 24.80-25.74%), average loss = 12.5% (95% CI: 11.92-13.06%)). The entire 12-months period between April 2012 and April 2013 yielded a total loss of 45.2% (95% CI: 44.58-45.75%), and an average loss of 49.4% (95% CI: 48.46-50.43%). While we found that commercial beekeepers lost fewer colonies than backyard beekeepers in the winter (30.2% (95% CI: 26.54-33.93% vs 45.4% (44.46-46.32%) respectively), the situation was reversed in the summer where commercial beekeepers reported higher average losses than backyard beekeepers (21.6% (95% CI: 18.4-24.79%) vs 12.1% (11.46-12.65%)). These findings demonstrate the ongoing difficulties of US beekeepers in maintaining overall colony heath and survival.

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A National Survey Of Managed Honey Bee 2012-2013 Annual Colony Losses In The USA: Results From The Bee Informed Partnership

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Summary

For the past six years in which overwintering mortality of honey bee colonies has been surveyed in the USA, estimates of colony loss have fluctuated around one-third of the national population. Here we report on the losses for the 2012-2013 seasons. We collected data from 6,482 US beekeepers (6,114 backyard, 233 sideline, and 135 commercial beekeepers) to document overwintering mortality rates of honey bee colonies for the USA. Responding beekeepers reported a total 30.6% (95% CI: 30.16-31.13%) loss of US colonies over the winter, with each beekeeper losing on average 44.8% (95% CI: 43.88-45.66%) of their colonies. Total winter losses varied across states (range: 11.0% to 54.7%). The self-reported level of acceptable winter loss was 14.6%, and 73.2% of the respondents had mortality rates greater than this level. The leading self-identified causes of overwintering mortality were different according to the operation type; backyard beekeepers generally self-identified "manageable" factors (e.g., starvation, weak colony in the fall), while commercial beekeepers generally identified non-manageable factors (e.g., queen failure, pesticides) as the main cause of losses. For the first time in this series of surveys, we estimated mortality during the summer (total loss = 25.3% (95% CI: 24.80-25.74%), average loss = 12.5% (95% CI: 11.92-13.06%)). The entire 12-months period between April 2012 and April 2013 yielded a total loss of 45.2% (95% CI: 44.58-45.75%), and an average loss of 49.4% (95% CI: 48.46-50.43%). While we found that commercial beekeepers lost fewer colonies than backyard beekeepers in the winter (30.2% (95% CI: 26.54-33.93% vs 45.4% (44.46-46.32%) respectively), the situation was reversed in the summer where commercial beekeepers reported higher average losses than backyard beekeepers (21.6% (95% CI: 18.4-24.79%) vs 12.1% (11.46-12.65%)). These findings demonstrate the ongoing difficulties of US beekeepers in maintaining overall colony heath and survival.

Encuesta nacional anual sobre pérdidas de colonias manejadas de la abeja de la miel 2012-2013 en EE.UU.: resultados de la Asociación Abeja Informada

Resumen

Durante los últimos 6 años en los que la mortalidad invernal de colonias de abejas de la miel ha sido monitoreada en los EE.UU., las estimaciones de pérdida de colonias han fluctuado en torno a un tercio de la población nacional. Aquí informamos sobre las pérdidas para las temporadas 2012-2013. Se recogieron datos de 6,482 apicultores de Estados Unidos (6,114 tradicionales, 233 como negocio complementario, y 135 apicultores comerciales) para documentar las tasas de mortalidad invernal de colonias de abejas de la miel en los Estados Unidos . Los apicultores que respondieron reportaron una pérdida del 30.6% (IC del 95%: 30.16-31.13%) de colonias de EE.UU. durante el invierno, con un promedio de pérdidas del 44.8% de colonias por apicultor (IC del 95%: 43.88-45.66%). Las pérdidas totales de invierno varían entre estados (rango: 11.0% al 54.7%). El nivel de pérdidas invernales reportado por los propios apicultores como aceptable fue de 14.6%, y 73.2% de los encuestados tenían tasas de mortalidad superiores a este nivel. Las causas principales identificados por los propios apicultores de mortalidad de hibernación fueron diferentes según el tipo de apicultura; apicultores tradicionales generalmente identificaron factores " manejables " (por ejemplo, el hambre, debilidad de las colonias en otoño), mientras que los apicultores comerciales generalmente identificaron factores no controlables (por ejemplo, problemas con la reina, pesticidas) como la causa principal de las pérdidas. Por primera vez en esta serie de encuestas, se estima la mortalidad durante el verano (pérdida total= 25.3% (IC del 95%: 24.80 a 25.74%), pérdida media = 12.5% (IC del 95%: 11.92 a 13.06%)). Todo el período de 12 meses entre abril de 2012 y abril de 2013 arrojó una pérdida total del 45.2% (IC del 9 %: 44.58 a 45.75%), y una pérdida promedio de 49.4% (IC del 95%: 48.46 a 50.43%). Si bien hemos encontrado que los apicultores comerciales perdieron menos colonias que los apicultores tradicionales durante el invierno (30.2% (IC del 95%: 26.54 a 33.93% frente a 45.4% (44.46-46.32%), respectivamente), la situación se invirtió en el verano donde los apicultores comerciales reportaron pérdidas promedio más altas que los apicultores tradicionales (21.6% (IC 95%: 18.4 a 24.79%) frente a 12.1% (11.46-12.65%)). Estos hallazgos demuestran las dificultades actuales de los apicultores de Estados Unidos en el mantenimiento de la salud general de las colonias y su supervivencia.

Introduction

The global population of honey bee (*Apis mellifera*) colonies has shown a 64% increase between 1961 and 2007 (Aizen *et al.*, 2009), but not all regions have shown this expansion. For example, during the same period, both Europe (-26.5%) and North America (-49.5%) experienced severe reductions in their total number of managed colonies (Aizen *et al.*, 2009). In the USA, managed colony numbers have declined by 61% from 1947 to 2008 (vanEngelsdorp & Meixner, 2010). A reduction in colonies is of concern because honey bees provide vital pollination services to agricultural crops. In the US, the value attributed to honey bees from crops directly dependent upon pollination has been was estimated at $11.68 billion by 2009 (Calderone, 2012). Although global crop yields have not yet been affected by pollinator decline (Aizen *et al.*, 2008), the last 50 years of agriculture have been marked by a shift toward more pollinator-dependent crops (Aizen *et al.*, 2008) that could soon exceed the pollination services provided by declining pollinator stocks (Aizen & Harder, 2009; Calderone, 2012). Efficient pollination has already been documented as a limiting factor for some crops at regional or local levels (Klein *et al.,* 2007; Garibaldi *et al.*, 2009).

The suspected factors behind this population decline are both biologic (Potts *et al.*, 2010b; vanEngelsdorp & Meixner, 2010) and socio-economic (Potts *et al.*, 2010a; vanEngelsdorp & Meixner, 2010). While longitudinal estimates of honey bee colony populations can help predict shortages or surpluses of pollination service, they do not fully capture the year-to-year mortality rates. Beekeepers can replace lost colonies by either dividing surviving colonies ('splitting') or creating new colonies (installing 'packages' of bees or nucs (nucleus colonies)) purchased from other beekeepers (vanEngelsdorp *et al.*, 2007). Over-wintering losses have been proposed as a more direct indicator of honey bee health (vanEngelsdorp *et al.*, 2007; van der Zee *et al.*, 2012).

For the past six years, overwintering mortality of honey bee colonies have been surveyed in the US, estimating total overwintering losses as 32%, 36%, 29%, 34%, 30% and 22% for the winters of 2006-7, 2007-8, 2008-9, 2009-10, 2010-11 and 2011-12, respectively (vanEngelsdorp *et al.*, 2007, 2008, 2010, 2011a, 2012; Spleen *et al.*, 2013). High overwintering mortality rates of honey bee colonies have also been reported in many other countries, mostly in Europe, but also in the Middle East, Africa, and Asia (Neumann & Carreck, 2010; Nguyen *et al.*, 2010; van der Zee *et al.*, 2012, Pirk *et al.*, 2014). The underlying factors responsible for this mortality are unclear. There is, however, a general consensus that the causes of colony mortality are multi-factorial and interacting (Potts *et al.*, 2010b; USDA, 2002). When asking bee-keepers to self-identify the reasons their colonies died, the most commonly reported factors have been queen failure, starvation, parasitic varroa mites (*Varroa destructor*), and weak colonies in the fall (vanEngelsdorp *et al.*, 2007, 2008, 2010, 2011a, 2012; Spleen *et al.*, 2013). This is suggestive of the wide range of causes that can contribute to colony death, some of them resulting directly from bee-keeping management strategies (vanEngelsdorp *et al.*, 2012).

Continuing the series of winter loss papers produced by the Bee Informed Partnership (www.beeinformed.org), this study documents the 2012-2013 mortality rate of honey bee colonies for the US at national and state levels. We also compare rate of loss between varying sized operations, beekeeping activity, and by the symptom of having "no dead bees found in the hive." This study further quantifies the prevalence of self-reported suspected causes of death from the bee-keepers. For the first time, we additionally present estimates of summer, and annual (year-long) losses.

Material and methods

A combined 2012-2013 winter loss and management survey was posted on an internet platform (SelectSurvey.com) and an invitation to participate in the survey was sent by email to national (n = 2), state (n = 47), and local (n = 466) beekeeping organizations. Invitations were also distributed through a beekeeping supply company's email list (Brushy Mountain Bee Farm) and through honey bee brokers (n = 20; for almond pollination in California). Advertisements were published in two beekeeping journals; *American Bee Journal* and *Bee Culture*, who forwarded the invitation to their subscription listservs (Catch the Buzz and ABF Alert). Previous years' participants that had requested to be included in future surveys and individuals who indicated their wish to be contacted (by signing up on the beeinformed.org web site or at talks and meetings) received the invitation by email (n = 5,662). To increase recruitment, announcements were posted on web-forums and on social media websites (e.g., Facebook). All solicitations encouraged the recipient to forward the request to other beekeepers. Personal letters were also sent to the Apiary Inspectors of America (AIA), a majority of state extension apiculturists, club newsletters, and industry leaders.

Because our previous surveys showed a shortfall in the representation of commercial beekeepers, a more targeted strategy was used to increase large-scale beekeeper's participation. Paper versions of the survey (n = 1,300) were mailed to large commercial beekeepers directly or through their state apiarists. At their request, we also extended the survey time by two weeks compared to previous years. Our recruitment method prevents us from calculating a response rate, as the total number of beekeepers contacted is unknown.

All the data analysed in this study were gathered through 18 questions (Box 1). To ensure consistency with other international estimates, core survey questions (1 to 13) were derived from the efforts of Working Group 1 of the international honey bee research network COLOSS (prevention of honey bee COlony LOSSes) (van der Zee, 2013). After answering this traditional "winter loss survey", participants were offered an optional survey ("management survey") from which this study estimates summer and annual losses.

The online survey was open from 29 March to 30 April 2013. The paper versions were distributed through mail on 13 March and all the completed surveys sent back before 30 April were integrated into the survey database.

The database was then edited for processing (i.e., replacing text with numbers – 2 instead of "two") where appropriate, and filters were developed to exclude invalid responses from the analytical dataset. All obvious duplicate answers, all non-US entries (information from Survey Question 1), those with insufficient answers to calculate a valid winter

Box 1: Questions as presented to the participating beekeepers and associated validation rules. Questions 1-13 are consistent to the survey questions developed by COLOSS. Participants who accepted to continue to the second part of the survey were presented with questions 14-18 (among others). The * indicates required questions that would not allow a blank response on the online survey.

Box 1: The survey questions		
The following questions pertain to any losses you may have suffered over the winter (defined as the period between Oct 1 2012 and April 1 2013).		
1.	In what state(s) did you keep your colonies in between April 2012 - April 2013?*	
		Multiple choice question, multiple selection allowed.
		Possible answers presented all US States, the District of Columbia, Puerto Rico and an "other" category to specify in open entry.
2.	How many living colonies did you have on October 1, 2012?*	
	A colony is a queen right unit of bees that include full size colonies and queen right nucs (do NOT include mating nucs).	
		Numeric entry (positive integers).
3.	How many splits, increases, and / or colonies did you make / buy between October 1, 2012 and April 1, 2013?*	
	(increases surviving on April 1, 2013 should have been included in the total provided in the question above.)	
		Numeric entry (positive integers).
4.	How many splits, increases, and / or colonies did you sell / give away between October 1, 2012 and April 1, 2013?*	
		Numeric entry (positive integers).
5.	How many living colonies did you have on April 1, 2013?*	
	A colony is a queen right unit of bees that include full size colonies and queen right nucs (do NOT include mating nucs).	
		Numeric entry (positive integers).
6.	Is this year's winter loss higher or lower than last year?	
	○ Higher	
	○ Lower	
	○ Same	
	○ Don't Know	
	○ Did not keep bees last year	
		Multiple choice, single selection allowed.
7.	What percentage of the colonies that died between October 1st and April 1st were lost without dead bees in the hive or apiary?	
		Percentage: The value must be between 0 and 100, inclusive.
8.	What percentage of loss, over this time period, would you consider acceptable?	
		Percentage: The value must be between 0 and 100, inclusive.

Box 1 Cont'd: Questions as presented to the participating beekeepers and associated validation rules. Questions 1-13 are consistent to the survey questions developed by COLOSS. Participants who accepted to continue to the second part of the survey were presented with questions 14-18 (among others). The * indicates required questions that would not allow a blank response on the online survey.

9. In your opinion, what factors were the main cause (or causes) of colony death in your operation between October 1, 2012 and April 1, 2013? Select all that apply.

- ☐ Queen failure
- ☐ Starvation
- ☐ Varroa mites
- ☐ Nosema disease
- ☐ Small Hive Beetles
- ☐ Poor wintering conditions
- ☐ Pesticides
- ☐ Weak in the fall
- ☐ Colony Collapse Disorder (CCD)
- ☐ Don't know
- ☐ Other, please specify:

Multiple choice question, multiple selection allowed.

10. What percentage of your hives did you send to or move into California almond orchards for pollination?

Percentage: The value must be between 0 and 100, inclusive.

11. How many times, on average, did you move your colonies last year?

Numeric entry (positive integers)

12. In what zip code is your operation based (optional)?

13. Would you be willing to be contacted by our survey team in order to participate in other honey bee related surveys and review this survey?

- ○ Yes
- ○ No

Multiple choice, single selection allowed

End of Winter Loss Survey

(…)

14. What was the largest number of living colonies you owned between April 1, 2012 and April 1, 2013?

A colony is a queen right unit of bees that include full size colonies and queen right nucs (do NOT include mating nucs).

Numeric entry (positive integers).

15. What was the smallest number of living colonies you owned between April 1, 2012 and April 1, 2013?

A colony is a queen right unit of bees that include full size colonies and queen right nucs (do NOT include mating nucs).

Numeric entry (positive integers).

16. How many living colonies did you have last spring (on April 1, 2012)?*

A colony is a queen right unit of bees that include full size colonies and queen right nucs (do NOT include mating nucs).

Numeric entry (positive integers).

17. How many splits, increases, and / or colonies did you make / buy between April 1, 2012 and October 1, 2012?*

"Increases" include successfully hived swarms and/or feral colonies. A colony is a queen right unit of bees that include full size colonies and queen right nucs (do NOT include mating nucs).

Numeric entry (positive integers).

18. How many splits, increases, and / or colonies did you sell or give away between April 1, 2012 and October 1, 2012?*

A colony is a queen right unit of bees that include full size colonies and queen right nucs (do NOT include mating nucs).

Numeric entry (positive integers).

or summer loss (between 0 and 100%), and obvious typing errors (e.g., number of colonies either non-integer or exceedingly large >80,000) were excluded from our analyses.

As in previous studies, beekeepers were assigned to 3 levels of operational size groups according to the number of colonies managed on 1 October 2012: beekeepers managing 50 or fewer colonies are referred hereafter and in the analyses as "backyard beekeepers"; those managing between 51 and 500 colonies as "sideline beekeepers"; and those managing 501 or more as "commercial beekeepers".

Statistical analyses

Based on the numbers provided by the respondents, we calculated total and average colony losses, following the standard outlined by vanEngelsdorp *et al.* (2013a). Each beekeeper manages one operation, which may or may not be divided into several apiaries, comprised of various numbers of colonies. For each respondent, his or her individual operational overwintering loss was calculated using equation 1:

Equation 1:

$$\text{Operational Winter Losses} = \frac{\#\,\text{Colonies on 1 Oct. 2012} + \#\,\text{of increases} - \#\,\text{of reductions} - \#\,\text{Colonies on 1 Apr. 2013}}{\#\,\text{Colonies on 1 Oct. 2012} + \#\,\text{of increases} - \#\,\text{of reductions}} \times 100$$

Where the number of colonies on 1 October 2012 was provided by survey question #2; the number of increases between October 2012 and April 2013 by question #3; the number of reductions during the same period by question #4 and finally the number of colonies managed on 1 April 2013 by question #5. The numerator of this quotient is also referred to as the number of colonies 'lost' and the denominator as the number of colonies 'at risk' over the winter period.

From there, the total overwintering colony loss (TWL) of the population of concern was calculated as the quotient of the total number of colonies lost and colonies at risk in that population (Equation 2) while the average colony losses (AWL) was calculated as the mean of the individual operational overwintering loss (obtained from Equation 1) of all beekeepers in the population (Equation 3).

Equation 2:

$$TWL = \frac{Total\ \#\ Colonies\ lost\ in\ the\ population}{Total\ \#\ Colonies\ at\ risk\ in\ the\ population} \times 100$$

Equation 3:

$$AWL = \frac{\sum Operational\ loss\ (see\ Equation\ 1)}{\#\ Operations}$$

For the first time in this series of surveys, we also calculated and report summer and annual losses. For each respondent, his/her individual operational summer (Equation 4) and annual loss (Equation 5) were calculated.

Equation 4:

Operational Summer Losses

$$= \frac{\#\ Colonies\ on\ 1\ Apr. 2012 + \#\ of\ increases - \#\ of\ reductions - \#\ Colonies\ on\ 1\ Oct. 2012}{\#\ Colonies\ on\ 1\ Apr. 2012 + \#\ of\ increases - \#\ of\ reductions} \times 10$$

Equation 5:

Operational Annual Losses

$$= \frac{\#\ Colonies\ on\ 1\ Apr. 2012 + \#\ of\ increases - \#\ of\ reductions - \#\ Colonies\ on\ 1\ Apr. 2013}{\#\ Colonies\ on\ 1\ Apr. 2012 + \#\ of\ increases - \#\ of\ reductions} \times 10$$

Where the number of colonies on 1 April 2012 was provided by survey question #16 and the number of increases and reductions that pertain to the relevant period: by question #17 for the number of increases between April 2012 and October 2012 for the calculation of summer loss and by the sum of question # 3 and # 17 for the number of increases during the whole year for annual loss. Similarly, the relevant number of reductions was provided by question #18 for summer loss and by the sum of question #4 and #18 for annual loss.

The **total colony loss** (for winter TWL, summer TSL, and annual TAL) corresponds to the accepted method for averaging proportions, but in our case it is highly influenced by the responses of commercial beekeepers who manage a disproportionate number of colonies in the US. It is, however, a more appropriate representation of the total loss experienced in an area.

The mean of the individual losses method used to calculate **average colony loss** (for winter AWL, summer ASL, and annual AAL) gives each beekeeper the same weight, independently of the size of its operation, providing more relevance when comparing sub-groups of beekeepers. Given the non-independence of colonies managed by the same beekeeper, averaging out the pseudo-replication is an accepted method for dealing with this kind of spatial pseudo-replication (Crawley, 2007). One disadvantage of this is that smaller operations can only have a limited number of loss outcomes and have a higher chance of zero or 100% loss than larger operations (vanEngelsdorp *et al.*, 2011b).

Therefore, we calculated total loss (TL) for national and regional losses, while average colony loss (AL) was used to contrast sub-groups of beekeepers, using the Kruskal-Wallis rank sum test and its follow-up Mann-Whitney U test (also called Wilcoxon Rank Sum test). Those tests compare two (or more) vectors of numeric data for a difference in their medians, without assuming normal distributions, but assuming that the vectors share an identically shaped distribution.

The 95% confidence intervals (95% CI) for total loss (TL) were calculated using the standard outlined by vanEngelsdorp *et al.* (2013a) using a glm model (of family quasibinomial) to account for the structure of the data (R Development Core Team, 2009; code provided by Y Brostaux and B K Nguyen). The confidence intervals for average loss (AL) were calculated using the general Wald formula (vanEngelsdorp *et al.*, 2013a). The Wald formula is a normal approximation interval which is appropriate given the large sample size.

For the calculation of the number of colonies managed in each state, colonies belonging to beekeepers reporting managed colonies in more than one state were counted in each of those selected states, according to the practice used by the USDA National Agricultural Statistics Service (NASS) for their calculation of the state-level number of honey-producing colonies (USDA-NASS, 2013). The percentage of colonies lost with the symptom of "no dead bees in the hive or apiary" (survey Question #7) was used to calculate the total number of colonies lost with that symptom after multiplication with the reported number of lost colonies. The ratios of beekeepers grouped by operation size who suffered losses with the symptom of "no dead bees in the hive or apiary" were compared using the Chi square test.

All analyses were performed using the statistical program R (version 3.0.1 (2013-05-16)). All statistical tests were two-sided and used a level of significance of $\alpha = 0.05$. Responses for any group containing fewer than five respondents were not published to protect the privacy of the respondents.

Results

National losses

Average and total losses

The survey recorded 6,876 responses, from which 200 duplicates and 55 non-US residents were removed. From there, 3 subsets were created. The winter loss subset was reduced by an additional 139 responses for missing or invalid information needed for the calculation of winter loss (numbers leading to a negative or over 100% loss, zero colonies

Table 1. Self-reported 2012-2013 US colony loss (total and average loss (%) [95% CI]), showing the sample size (n) as the number of beekeepers having provided valid responses for each period of interest, the total number of colonies at the start of the respective period, the number of increases (+) and decreases (-) and the total number of colonies at the start of the respective period. Summer Loss represents loss between April 1, 2012 and October 1, 2012; Winter Loss between October 1, 2012 and April 1, 2013; and Annual Loss between April 1, 2012 and April 1, 2013.

Period	n	Total number of colonies managed on: 04/01/2012		10/01/2012		04/01/2013	Total Loss (%)	Average Loss (%)
Summer Loss	4,181	509,038	(+234,454) (-23,979)	537,694		.	25.3 [24.8-25.74]	12.5 [11.91-13.06]
Winter Loss	6,482	.		635,971	(+145,584) (-30,437)	520,965	30.6 [30.16-31.13]	44.8 [43.88-45.67]
Annual Loss	4,429	520,168	(+238,020) (-27,973)	555,454	(+122,529) (-24,705)	454,072	45.2 [44.58-45.75]	49.4 [48.45-50.43]

at the start of the period or an obvious typing error). All analyses regarding winter loss were performed on the remaining 6,482 valid respondents. Similarly, two other subsets of responses were created by filtering out 2,440 responses for missing or invalid information needed for the calculation of summer loss and 2,192 responses for annual loss, leaving an analytical sample size of 4,181 for summer loss and 4,429 for annual loss.

On 1 October 2012, those 6,482 respondents managed a total of 635,971 living colonies, representing 25.5% of the estimated 2.491 million honey-producing colonies managed in the US in 2012 (USDA-NASS, 2013). The same 6,482 beekeepers reported managing 520,965 colonies on 1 April 2013, after having made or bought a total of 145,581 colonies and having sold a total of 30,437 colonies. According to those numbers, we calculated a total overwintering loss of 30.6% (TWL; 95% CI: 30.16-31.13%) of the US managed honey bee colonies, while individual respondent beekeepers lost on average 44.8% (AWL; 95% CI: 43.88-45.66%) of their colonies over the winter 2012-2013 (see Table 1). Approximately 24% (99.1% of which were backyard beekeepers) reported no (zero) overwintering colony loss. We also asked beekeepers to directly compare their winter losses to the previous year (Question 6). Of the 6,193 beekeepers who responded to this Question, 1,123 did not keep bees the previous year. Of the remaining beekeepers who did keep bees the previous year, 52.3% (n = 2,651) indicated that they lost more colonies over the 2012-2013 winter than the previous year.

The 4,181 beekeepers who provided valid responses for the calculation of loss between 1 April 2012 and 1 October 2012 (hereafter referred to as "summer" loss) managed a total of 509,038 colonies at the start of the period, increased their operation by adding a total of 234,454 colonies, and sold a total of 23,979 during the same period. At the end of the period, on 1 October 2012, they managed a total of 537,694 colonies, leading to a total summer loss of 25.3% (TSL; 95% CI: 24.80-25.74%) of the US managed honey bee colonies while individual respondent beekeepers lost on average 12.5% (ASL; 96% CI: 11.91-13.06%) of their colonies over the summer 2012 (see Table 1). More than 58% of the respondents reported no (zero) summer colony loss.

Beekeepers (n = 429) who provided valid responses toward an annual loss calculation managed a total of 520,168 colonies on 1 April 2012. These beekeepers increased their operations during that year by a total of 360,549 colonies and sold a total of 52,678 colonies over the course of the year. On 1 April 2013, these beekeepers reported that they managed a total of 454,072 colonies. We calculated a total annual loss of 45.2% (TAL; 95% CI: 44.5-45.75%) of the US managed honey bee colonies. On average, individual respondent beekeepers lost 49.4% (AAL; 95% CI: 48.46-50.43%) of their colonies over the one year period between April 1, 2012 and April 1, 2013 (see Table 1). Less than 16% of the respondents reported no (zero) annual colony loss.

Losses by operation type

The differences between total and average loss are explained by the difference in operation size from our respondents. Looking at the winter loss dataset (see Table 2), of the 6,482 participating beekeepers, 94.3% (n = 6,114) qualified as "backyard beekeepers", 3.6% (n = 233) as "sideline beekeepers" and 2.1% (n = 135) as "commercial beekeepers". However, each of those operation types managed a total of 39,414 (6.2%), 35,937 (5.6%), and 560,620 (88.2%) colonies, respectively, on 1 October 2012. Therefore, more than 88% of the colonies represented in our study were managed by approximately 2% of the respondents.

The 3 operation types differed significantly in their levels of seasonal losses (Kruskall-Wallis rank sum test: χ^2 = 124.5253; 18.5757 and 15.881 for ASL, AWL and AAL, respectively, between Operation Types; all df = 2, all p-value < 0.001; see Fig.1 and Table 2 for loss estimates for each category). For all operation types, the winter period brought about a higher mortality than the preceding summer (Mann Whitney U test: U = 5765637, p-value < 0.001 for backyard beekeepers; U = 9128, p-value < 0.001 for sideline beekeepers and U = 5489.5, p-value < 0.05 for commercial beekeepers; see Table 2 for loss estimates). Where commercial beekeepers lost, on average, fewer colonies than backyard beekeepers over the winter (U = 487737, p-value < 0.001, see Table 3) (AWL 30.2% for commercial vs. 45.3% for backyard beekeepers, see Table 2), this was reversed in the summer,

Table 2. Self-reported 2012-2013 US colony loss by operation type (total and average loss (%) [95% CI]), showing the sample size (n) as the number of beekeepers having provided valid responses for each period of interest, the total (#Colonies (start)) and proportional (% Colonies (start) (%)) number of colonies at the start of the respective period for each of the operation type categories: backyard beekeepers (≤ 50 colonies), sideline beekeepers (>50 and ≤ 500 colonies) and commercial beekeepers (>500 colonies).

	Operation Type	n	# Colonies (start)	% Colonies (start) (%)	Total Loss	Average Loss
Summer Loss	Backyard	3,936	21,066	4.14	14.8 [14.22-15.37]	12.1 [11.46-12.65]
	Sideline	141	23,204	4.56	18.3 [15.78-20.97]	17.8 [14.96-20.54]
	Commercial	104	464,768	91.30	26.3 [23.42-29.24]	21.6 [18.4-24.79]
Winter Loss	Backyard	6,114	39,414	6.20	42.7 [41.96-43.53]	45.4 [44.46-46.32]
	Sideline	233	35,937	5.65	35.6 [32.44-38.85]	36.9 [33.56-40.26]
	Commercial	135	560,620	88.15	29.6 [26.54-32.71]	30.2 [26.54-33.93]
Annual Loss	Backyard	4,164	22,924	4.41	49.6 [48.75-50.5]	49.9 [48.91-50.98]
	Sideline	156	25,218	4.85	45.3 [41.55-49]	42.7 [38.7-46.76]
	Commercial	109	472,026	90.74	44.9 [41.36-48.49]	40.1 [36.17-44.04]

Table 3. Comparison of average seasonal colony loss (ASL, AWL and AAL) among operation types, showing the value of the statistical tests (Mann-Whitney "U", or Wilcoxon Rank Sum test with continuity correction) and the associated p-value. The "*" indicates significance (α = 0.05).

	Operation Type	n		Operation Type	n	U	p-value	
Summer Loss	Backyard	3936	vs.	Sideline	141	177880	< 0.0001	*
	Backyard	3936	vs.	Commercial	104	122055	< 0.0001	*
	Sideline	141	vs.	Commercial	104	6143.5	0.03003	*
Winter Loss	Backyard	6114	vs.	Sideline	233	776077	0.01867	*
	Backyard	6114	vs.	Commercial	135	487737	0.0002473	*
	Sideline	233	vs.	Commercial	135	17853	0.03071	*
Annual Loss	Backyard	4164	vs.	Sideline	156	365968	0.006803	*
	Backyard	4164	vs.	Commercial	109	264999	0.002615	*
	Sideline	156	vs.	Commercial	109	8773.5	0.6589	

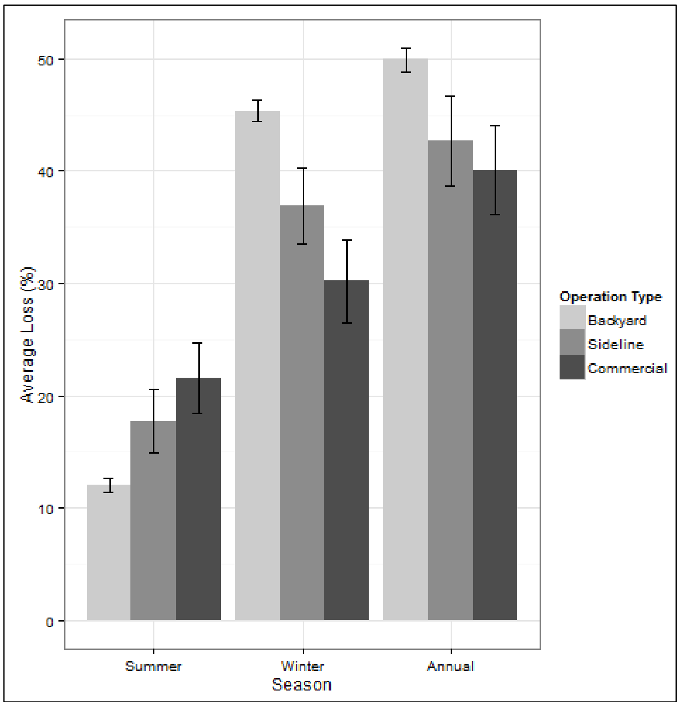

Fig. 1. Average seasonal colony loss by operation type for summer 2012, winter 2012-2013, and for the complete annual period from April 2012 to April 2013. Bars represent 95% CI.

where commercial beekeepers experienced higher average mortality rate than backyard beekeepers (U = 122055, p-value < 0.001, see Table 3) (ASL 21.6% for commercial vs. 12.1% for backyard beekeepers, see Table 2).

Looking only at commercial and sideline beekeepers, we did not detect a difference between average winter loss (AWL) of beekeepers who indicated they moved at least part of their colonies to California almond orchards for pollination in 2012 and those who did not (see Table 4), nor between those who indicated that they moved their colonies at least once during the last year ("migratory") and those who did not (see Table 4).

Reported cause of overwintering loss

Of the 4,680 beekeepers who experienced at least some loss and answered Question #7, 38.8% (n = 1,816) answered that at least some of their colonies died without visible dead bees in the hive or the apiary. Those beekeepers experienced a significantly higher average winter loss than beekeepers who did not report this symptom, whether we looked at the overall population (U = 2806325, p-value < 0.01) or by specific operation types (U = 2472222, 5976, and 1369 respectively; all p-values < 0.05; see Table 5). Of the 230,153 colonies lost during

Table 4. Comparison of average winter colony loss (AWL (%) [95%CI]) between sub-groups based on activities (for commercial and sideline beekeepers), showing the value of the statistical test (Mann-Whitney "U", or Wilcoxon Rank Sum test with continuity correction) and the associate p-value. Beekeepers are considered to be present for almond pollination in California if they indicated that they rented at least part of their operation when asked Question 10 of the survey. Beekeepers are considered "migratory" if they indicated at least 1 move during the year in Question 11 of the survey. We considered only commercial and sideline beekeepers for those 2 questions.

Factor	Selection	n	AWL (%) [95%CI]	U	p-value
Almond pollination (CA)	Yes	126	32.04 [28.43-35.65]		
	No	223	36.35 [32.8-39.91]	13370	0.4535
Migratory	Yes	238	33.81 [30.76-36.87]		
	No	108	35.08 [30.13-40.03]	12733.5	0.8911

Table 5. Average winter colony loss (AWL (%) [95%CI]) by CCD symptom and operation type, showing the value of the statistical test (Mann -Whitney "U", or Wilcoxon Rank Sum test with continuity correction) and the associated p-value. Presence of CCD symptom was attributed to the beekeepers who reported that at least part of their dead colonies did not show any dead bees in the hive or in the apiary. The "*" indicates significance (α = 0.05).

Operation Type	CCD symptom	n	AWL (%) [95%CI]	U	p-value	
All	Present	1816	61.58 [60.22-62.93]			
	Absent	2864	57.41 [56.27-58.55]	2806325	< 0.0001	*
Backyard	Present	1582	65.09 [63.67-66.5]			
	Absent	2773	58.33 [57.18-59.48]	2472222	< 0.0001	*
Sideline	Present	133	41.03 [36.92-45.14]			
	Absent	72	31.54 [25.45-37.63]	5976	0.003402	*
Commercial	Present	101	33.63 [29.59-37.68]			
	Absent	19	21.56 [10.98-32.14]	1369	0.003279	*

Table 6. Average winter colony loss (AWL (%) [95%CI]) by self-reported cause of death, showing the value of the statistical test (Mann-Whitney "U", or Wilcoxon Rank Sum test with continuity correction) and the associated p-value. Contrasts between groups of beekeepers having selected or not the respective factor as main cause of death for their reported winter losses. The "*" indicates a significant (α = 0.05) difference between the 2 sub-groups.

	Factor selected		Factor not selected				
Factor	n	AWL [95%CI]	n	AWL (%) [95%CI]	U	p-value	
Weak in the fall	1,516	56.13 [54.62-57.64]	3,165	60.58 [59.50-61.65]	2197083	< 0.0001	*
Starvation	1,406	55.4 [53.86-56.94]	3,275	60.74 [59.68-61.8]	2078126	< 0.0001	*
Queen Failure	1,199	51.1 [49.41-52.8]	3,482	61.90 [60.89-62.91]	1662428	< 0.0001	*
Varroa	1,082	57.41 [55.65-59.17]	3,599	59.65 [58.64-60.66]	1867732	0.03989	*
Poor Winter	850	65.26 [63.31-67.22]	3,831	57.78 [56.8-58.75]	1857328	< 0.0001	*
CCD	507	67.36 [65-69.73]	4,174	58.14 [57.2-59.07]	1241739	< 0.0001	*
Pesticides	379	63.02 [60.17-65.86]	4,302	58.79 [57.87-59.71]	877497	0.01267	*
SHB	299	59.94 [56.59-63.29]	4,382	59.08 [58.17-59.99]	667709.5	0.5736	
Nosema	298	54.33 [51.24-57.43]	4,383	59.46 [58.55-60.37]	593141	0.007354	*
Don't know	1,344	68.01 [66.48-69.54]	3,337	55.56 [54.52-56.60]	2769497	< 0.0001	*

the winter, an estimated 51.3% (n = 117,960) died with the symptom "no dead bees in the hive or apiary". When reporting loss, commercial beekeepers were 2.32- and 1.30-times as likely to report this symptom as were backyard and sideline beekeepers (χ^2 = 113.9, df = 1, p-value < 0.001 and χ^2 = 13.97, df = 1, p-value < 0.001, respectively).

Of the 4,892 respondents who reported a winter loss, 95.7% (n = 4,681) recorded at least one answer to Question # 9 relating to self-reported main cause of colony death overwinter. Respondents could select multiple answers. Of the 4,681 respondents, 28.7% (n = 1,344) indicated that they did not know the cause of death of the colonies that died in their operation (see Table 6). Those beekeepers lost over the winter, on average, 68% of their colonies (see Table 6); significantly more than those who lost colonies and identified at least one reason for their loss (AWL = 55.6%, U = 2769497, p-value < 0.001, see Table 6).

Overall, the most frequently self-reported causes of death included: colony weak in the fall, starvation, queen failure, and varroa mites (see Table 6). This list is highly biased towards backyard beekeeper's

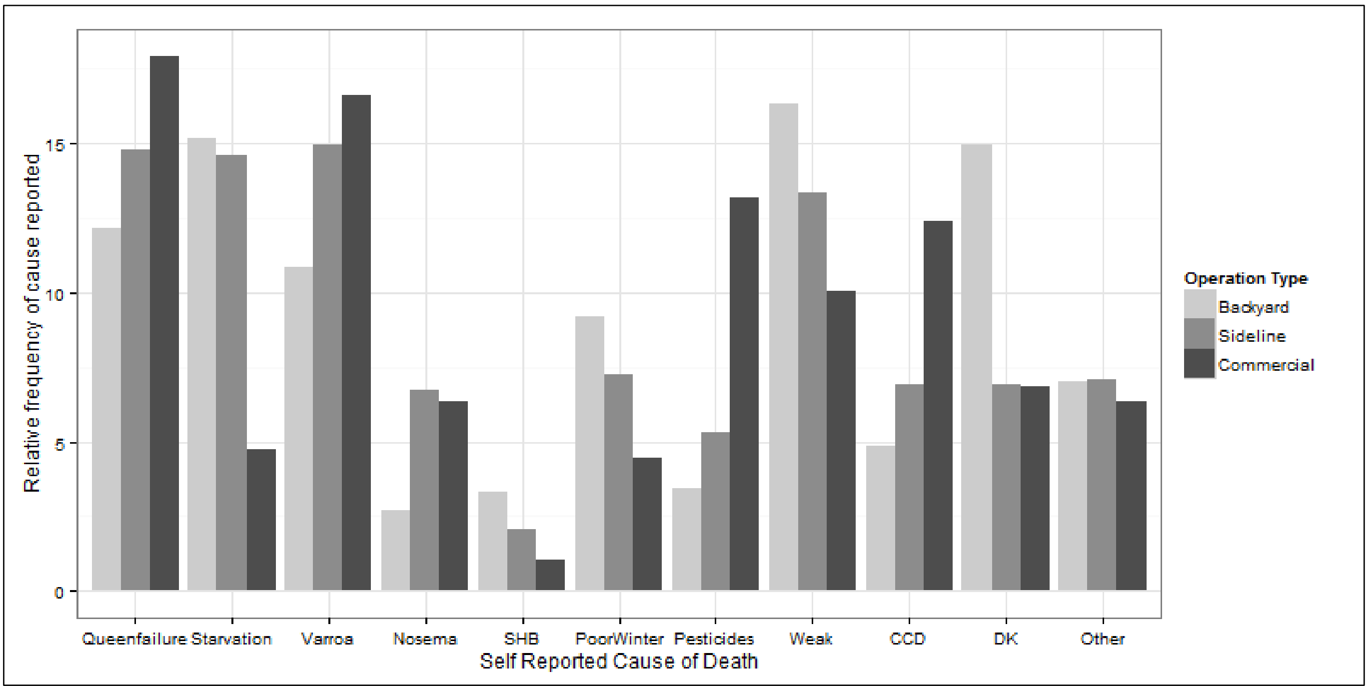

Fig. 2. Frequency of self reported cause of colony death by operation type. Shows the frequency of selection from beekeepers of each factor as a main cause of death for colonies that died in their apiaries over the winter.

responses. When accounted separately, commercial beekeepers have a contrasting list of "top" self-reported cause of death (see Fig. 2): their most frequently self-reported causes of death included queen failure, varroa mites, pesticides, and Colony Collapse Disorder (CCD).

Survey respondents who selected poor wintering conditions, CCD, or pesticides as a main cause of winter colony loss suffered significantly higher losses on average than respondents who did not select these items (U = 1857328, 1241739, and 877497, respectively; all p-values < 0.05; see Table 6). Conversely, beekeepers who selected weak in the fall, starvation, queen failure, varroa mites, or nosema (*Nosema apis* or *Nosema ceranae*) as a factor contributing to their winter colony loss experienced significantly lower losses on average than respondents who did not select those factors (U = 2197083, 2078126, 1662428, 1867732, and 593141, respectively; all p-values < 0.05; see Table 6).

Acceptable overwintering losses

For the question "What percentage of loss, over this time period, would you consider acceptable?", responding beekeepers (n = 5,876) reported on average that they would consider a winter loss of 14.6% (95% CI: 14.21-15.09) to be acceptable. The answer provided was very similar

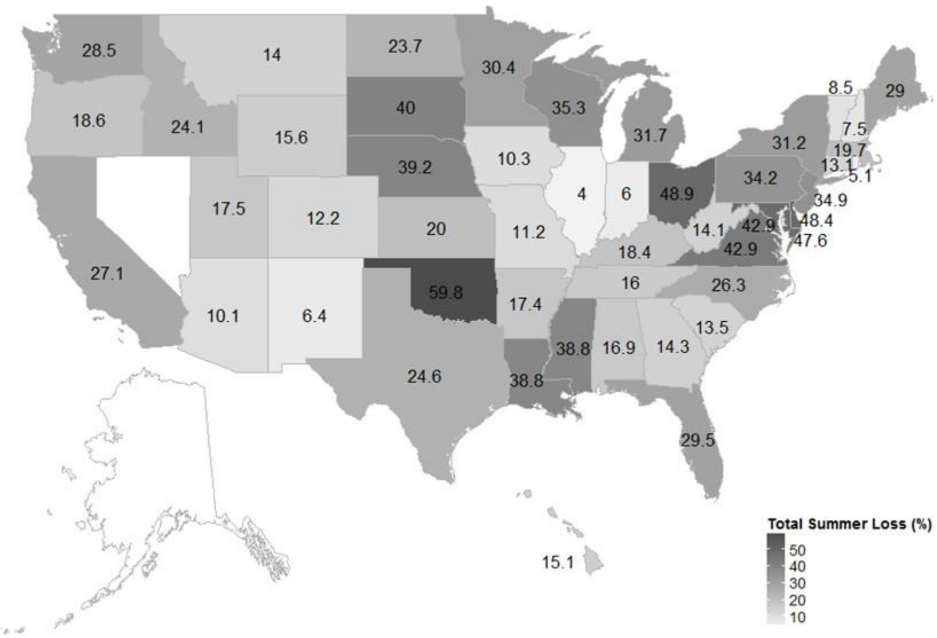

Fig. 3. Total summer colony loss (%) by state. Respondents who managed colonies in more than one state had all of their colonies counted in each state in which they reported managing colonies. Data for states with fewer than five respondents are withheld.

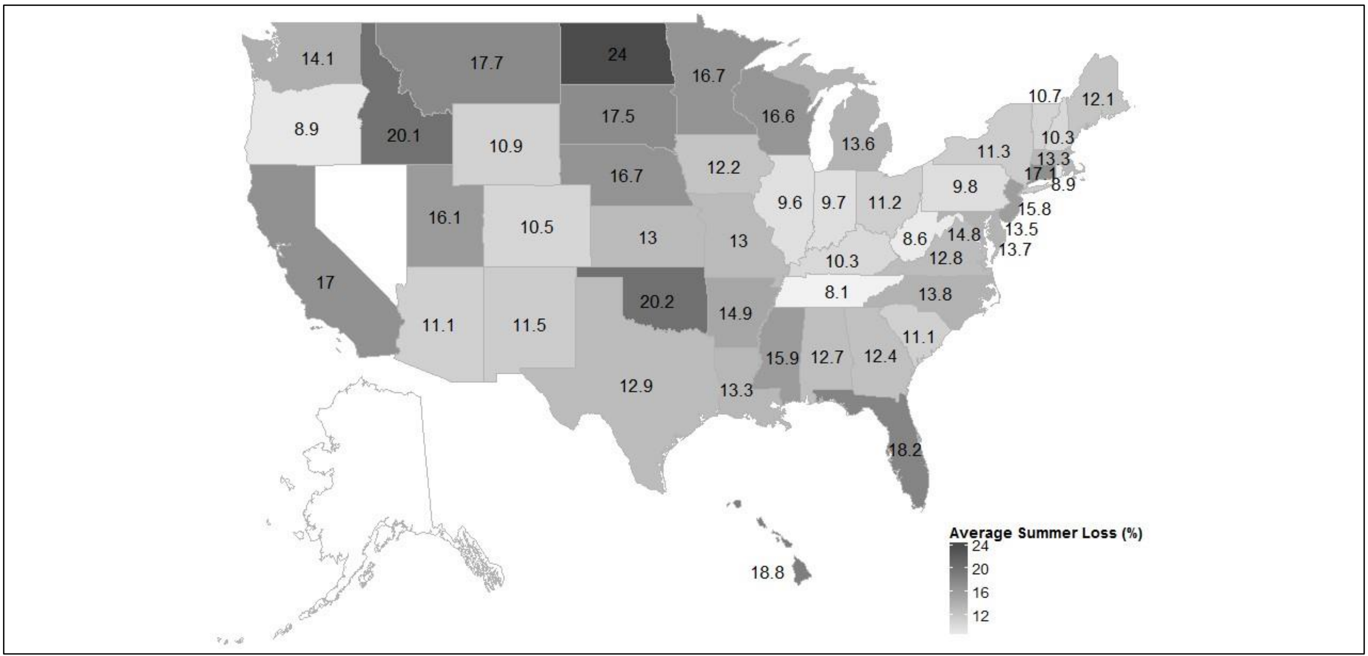

Fig. 4. Average summer colony loss (%) by state. Respondents who managed colonies in more than one state had all of their colonies counted in each state in which they reported managing colonies. Data for states with fewer than five respondents are withheld.

across operation types (backyard beekeepers: n = 5,533 reported 14.6% (95% CI: 14.15-15.08); sideline beekeepers: n = 216 reported 15.0% (13.59-16.36) and commercial beekeepers: n = 127 reported 15.7% (95% CI: 13.66-17.8)). 73.2% (n = 4,300) of the responding beekeepers suffered losses higher than this average acceptability level. When compared to their individual acceptable level, 70.2% (n = 4,122) of the beekeepers experienced winter loss above the level they judge acceptable.

State losses

The number of respondents to the survey was highly variable across states (see Table 7, number of operations). The total and average seasonal losses calculated from beekeepers' reports also varied substantially across states. The total winter loss (TWL) experienced by a state ranged from 11.0% to 54.7% with a median of 27.0% (see Table 7 and Fig. 5), while total summer loss at the state level ranged from 4.0% to 59.8% with a median of 20.0% (see Table 7 and Fig. 3).

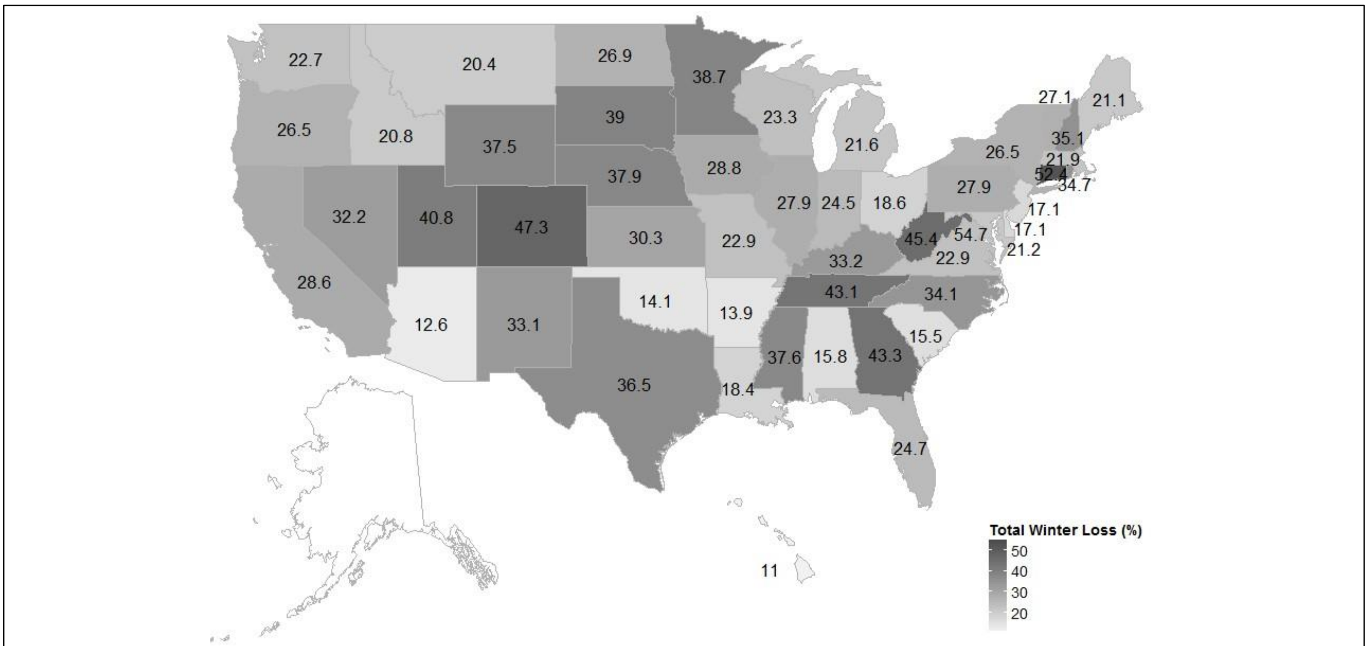

Fig. 5. Total winter colony loss (%) by state. Respondents who managed colonies in more than one state had all of their colonies counted in each state in which they reported managing colonies. Data for states with fewer than five respondents are withheld.

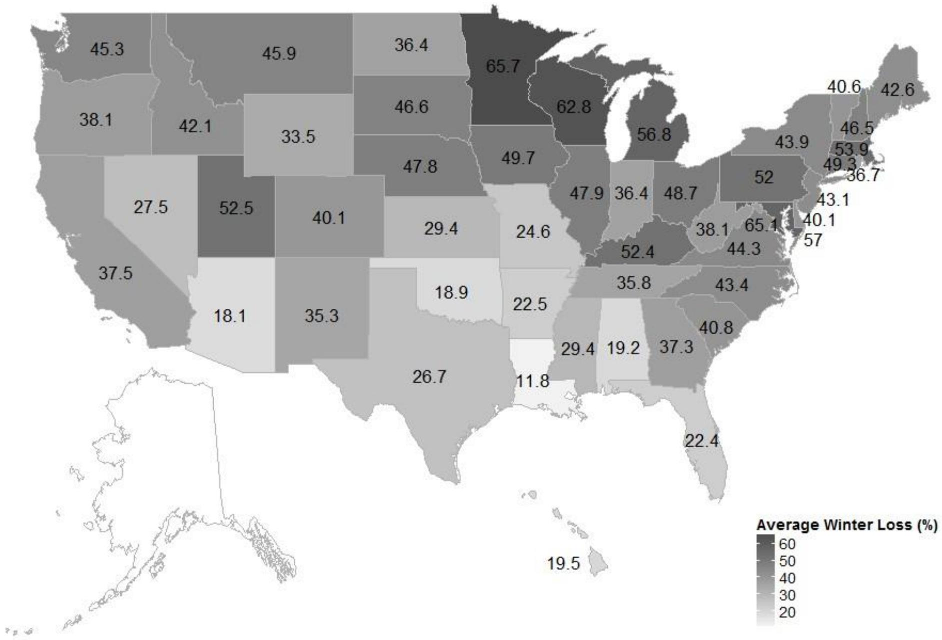

Fig. 6. Average winter colony loss (%) by state. Respondents who managed colonies in more than one state had all of their colonies counted in each state in which they reported managing colonies. Data for states with fewer than five respondents are withheld.

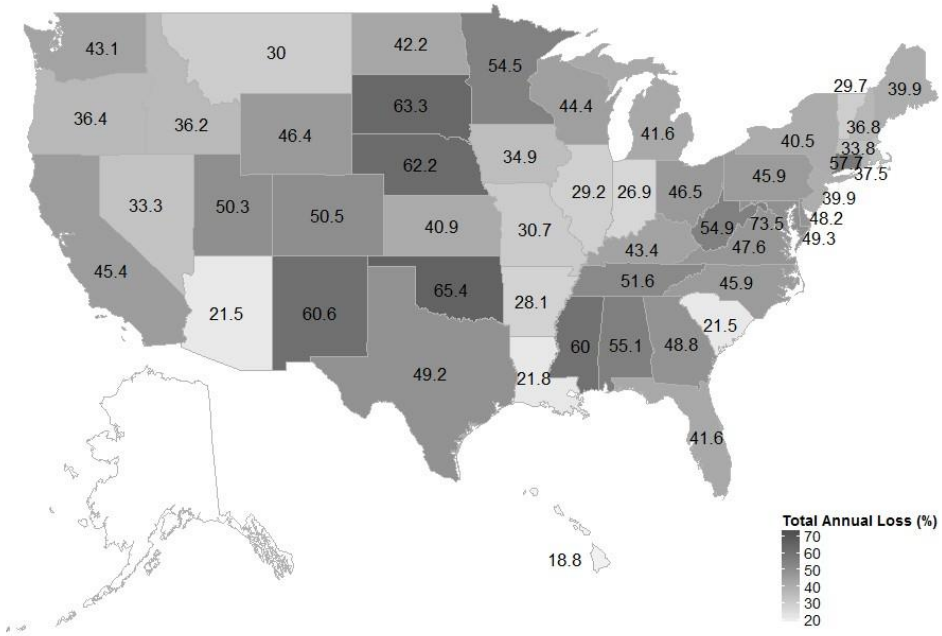

Fig. 7. Total annual loss (%) by state. Respondents who managed colonies in more than one state had all of their colonies counted in each state in which they reported managing colonies. Data for states with fewer than five respondents are withheld.

Between April 2012 and April 2013, the total annual loss experienced by US states ranged from 18.8% to 73.5% with a median of 43.2% (see Table 7 and Fig. 7). See Table 7 for the average winter, summer and annual loss reported by individual respondents for each state (AWL (see Fig. 6), ASL (see Fig. 4) and AAL (see Fig. 8)).

Table 7. Estimates of total and average summer, winter and annual colony loss by US states, showing the number of operations (or number of valid respondents), number of colonies at the start of the period of interest, total colony loss (%), and average colony loss (%), by state of operation, for each season (summer, winter and annual). Each loss estimate (%) is presented along with its 95% CI. Data for states with fewer than five respondents are withheld. Total Loss was calculated by dividing the sum of colonies lost[a] by the sum of colonies at risk[b] of all participants combined.

[a] Colonies Lost: the sum of colonies at risk minus the sum of the number of colonies managed on April 2013. [b] Colonies at risk: the sum of the total number of colonies managed on October 2012 and colonies bought or made between October 2012 and April 2013 subtracting the total number of colonies sold between October 2012 and April 2013. Average Loss was calculated as the mean of all individual winter loss (a mean of proportions).

	Summer Loss				**Winter Loss**									**Annual Loss**		
	n (# of operations)	**Total # of colonies (04/2012)**	**Total Loss mean [95% CI]**	**Average Loss mean [95% CI]**	**n (# of operations)**	**n Backyard BK**	**n Sideline BK**	**n Commercial BK**	**Median # of colonies (10/2012)**	**Mean # of colonies (10/2012)**	**Total # of colonies (10/2012)**	**Total Loss mean [95% CI]**	**Average Loss mean [95% CI]**	**n (# of operations)**	**Total Loss mean [95% CI]**	**Average Loss mean [95% CI]**
US	4,181	509,038	25.27 [24.8-25.75]	12.49 [11.91-13.06]	6,482	6,114	233	135	4	98.11	635,971	30.64 [30.16-31.13]	44.77 [43.88-45.67]	4,429	45.16 [44.58-45.75]	49.44 [48.46-50.43]
STATE:																
Alabama	36	422	16.89 [12.26-22.33]	12.67 [7.05-18.3]	50	45	4	1	5	53.34	2,667	15.76 [9.92-23.1]	19.16 [11.44-26.88]	36	55.08 [45.34-64.57]	25.54 [16.5-34.58]
Alaska	2	.	.	.	2	.	.	.	.	.	.	.	.	2	.	.
Arizona	9	1,770	10.07 [8.78-11.45]	11.12 [1.21-21.02]	13	12	0	1	3	159.15	2,069	12.6 [10.4-15.05]	18.13 [6.13-30.13]	9	21.45 [18.75-24.32]	30.68 [11.91-49.44]
Arkansas	37	1,312	17.35 [14.51-20.46]	14.91 [7.39-22.43]	56	53	1	2	3	35.50	1,988	13.93 [11.66-16.43]	22.53 [14.19-30.87]	38	28.13 [25.72-30.63]	30.25 [21.34-39.17]
California	216	404,981	27.1 [25.17-29.08]	17.03 [14.69-19.36]	291	163	36	92	18	1652.02	480,737	28.58 [26.67-30.54]	37.5 [33.92-41.08]	226	45.38 [43.01-47.75]	46.27 [42.66-49.89]
Colorado	167	819	12.22 [9.8-14.95]	10.52 [7.6-13.44]	314	310	4	0	2	5.39	1,694	47.27 [44.08-50.48]	40.12 [35.73-44.52]	178	50.46 [46.43-54.49]	43.77 [38.3-49.24]
Connecticut	57	517	13.1 [9.33-17.61]	17.15 [11.51-22.78]	78	75	3	0	3.5	12.94	1,009	52.43 [46.11-58.7]	49.29 [40.53-58.06]	58	57.69 [51.34-63.86]	55.72 [46.97-64.47]
District of Columbia	10	242	42.91 [30.72-55.71]	14.77 [1.06-28.48]	14	12	2	0	2	21.43	300	54.72 [43.91-65.24]	65.05 [49.27-80.84]	10	73.48 [68.37-78.2]	67.43 [48.47-86.39]
Delaware	23	11,817	48.43 [43.28-53.6]	13.53 [5.92-21.13]	33	29	2	2	4	303.33	10,010	17.07 [12.14-22.9]	40.07 [29.23-50.9]	25	48.15 [46.04-50.27]	45.87 [35.17-56.57]
Florida	103	46,986	29.46 [25.9-33.2]	18.23 [14.31-22.14]	136	107	14	15	6	365.46	49,702	24.66 [21.8-27.69]	22.42 [18.18-26.67]	107	41.55 [38.92-44.22]	32.77 [28.2-37.33]
Georgia	74	6,874	14.3 [12.01-16.81]	12.41 [8.34-16.47]	117	108	6	3	5	81.05	9,483	43.31 [38.86-47.84]	37.3 [31.21-43.4]	78	48.78 [44.15-53.41]	37.38 [30.09-44.67]
Hawaii	45	10,107	15.08 [8.8-23.24]	18.78 [10.94-26.63]	61	50	7	4	9	211.48	12,900	11 [7.28-15.65]	19.46 [12.38-26.55]	46	18.84 [13.81-24.67]	29.42 [21.13-37.71]
Idaho	31	64,792	24.08 [20.25-28.2]	20.11 [12.96-27.27]	41	24	5	12	23	1625.85	66,660	20.78 [16.5-25.54]	42.13 [32.69-51.57]	31	36.15 [31.44-41.06]	49.29 [41.18-57.4]
Illinois	132	3,694	4.04 [2.1-6.85]	9.64 [6.59-12.7]	202	199	2	1	4	26.14	5,281	27.91 [25.27-30.65]	47.93 [42.69-53.17]	136	29.16 [25.8-32.68]	50.53 [44.41-56.64]
Indiana	108	2,625	6.03 [4.6-7.71]	9.74 [6.82-12.66]	173	166	6	1	5	23.29	4,030	24.5 [22.19-26.92]	36.37 [31.82-40.93]	115	26.88 [24.21-29.66]	38.87 [33.6-44.15]
Iowa	45	4,701	10.29 [6.18-15.69]	12.18 [7.24-17.13]	63	51	10	2	8	103.73	6,535	28.77 [23.99-33.89]	49.67 [41.92-57.42]	49	34.88 [28.93-41.17]	51.19 [43.29-59.08]
Kansas	39	1,382	19.97 [14.91-25.76]	13 [7.5-18.51]	51	44	6	1	6	45.67	2,329	30.31 [25.52-35.42]	29.39 [20.94-37.85]	40	40.9 [34.96-47.02]	41.3 [32.01-50.58]
Kentucky	46	421	18.35 [12.79-24.95]	10.28 [5.24-15.33]	67	63	4	0	5	11.18	749	33.25 [27.28-39.59]	52.37 [43.96-60.78]	49	43.42 [36.5-50.51]	55.62 [46.22-65.02]
Louisiana	14	490	38.83 [31.39-46.62]	13.27 [3.85-22.7]	22	20	1	1	9	102.91	2,264	18.36 [16.69-20.12]	11.81 [6.55-17.07]	14	21.78 [15.71-28.8]	23.25 [14.32-32.19]
Maine	103	45,213	29.01 [26.12-32.01]	12.07 [8.46-15.68]	177	169	3	5	3	270.34	47,851	21.08 [19.46-22.76]	42.59 [37.18-48.01]	108	39.85 [38.19-41.53]	48.22 [42.22-54.22]

Table 7 Cont'd.

	Summer Loss				Winter Loss									Annual Loss		
	n (# of operations)	Total # of colonies (04/2012)	Total Loss mean [95% CI]	Average Loss mean [95% CI]	n (# of operations)	n Backyard BK	n Sideline BK	n Commercial BK	Median # of colonies (10/2012)	Mean # of colonies (10/2012)	Total # of colonies (10/2012)	Total Loss mean [95% CI]	Average Loss mean [95% CI]	n (# of operations)	Total Loss mean [95% CI]	Average Loss mean [95% CI]
Maryland	182	12,840	47.59 [45.53-49.66]	13.74 [10.74-16.75]	271	260	9	2	3	43.69	11,840	21.18 [18.78-23.72]	57.04 [52.7-61.38]	198	49.34 [48.08-50.59]	59.75 [55.03-64.46]
Massachusetts	151	14,518	19.75 [19.17-20.34]	13.29 [10.19-16.39]	245	241	2	2	2	73.04	17,896	21.91 [20.47-23.41]	53.85 [48.9-58.8]	160	33.83 [32.37-35.3]	58.7 [53.49-63.91]
Michigan	205	22,462	31.75 [28.58-35.04]	13.64 [10.94-16.34]	313	293	15	5	4	75.14	23,519	21.56 [19.21-24.03]	56.8 [52.77-60.82]	220	41.58 [39.33-43.86]	61.72 [57.27-66.17]
Minnesota	75	45,195	30.39 [26.43-34.56]	16.67 [11.92-21.43]	117	101	2	14	5	459.26	53,734	38.73 [35.17-42.38]	65.68 [59.97-71.39]	81	54.48 [51.27-57.68]	70.33 [64.68-75.99]
Mississippi	27	108,564	38.85 [36.35-41.39]	15.95 [9.03-22.86]	41	31	6	4	9	2187.93	89,705	37.57 [35.25-39.91]	29.41 [20.72-38.09]	31	60.03 [56.54-63.46]	34.27 [24.86-43.67]
Missouri	76	937	11.21 [8.24-14.72]	13.04 [8.87-17.21]	104	98	6	0	5	15.35	1,596	22.94 [18.98-27.24]	24.62 [19.31-29.93]	78	30.69 [25.77-35.94]	34.4 [28.27-40.53]
Montana	26	30,236	13.97 [9.7-19.12]	17.66 [10.05-25.27]	45	30	3	12	5	1178.09	53,014	20.39 [15.99-25.31]	45.9 [36.59-55.21]	27	30.01 [21.47-39.6]	54.51 [43.58-65.44]
Nebraska	14	85,765	39.22 [35-43.55]	16.73 [2.19-31.27]	23	19	1	3	8	3355.35	77,173	37.85 [34.21-41.59]	47.77 [34.86-60.68]	16	62.18 [56.26-67.85]	47.41 [32.37-62.45]
Nevada	4	.	.	.	11	7	2	2	4	610.91	6,720	32.24 [24.44-40.76]	27.52 [7.9-47.14]	6	33.27 [24.44-42.96]	31.57 [10.85-52.29]
New Hampshire	57	511	7.46 [4.85-10.78]	10.33 [5.76-14.9]	96	93	3	0	2	9.35	898	35.12 [29.36-41.18]	46.52 [38.15-54.89]	58	36.77 [29.7-44.25]	53.74 [43.9-63.58]
New Jersey	61	24,259	34.93 [30.84-39.19]	15.81 [10.86-20.76]	87	84	1	2	4	284.44	24,746	17.07 [15.56-18.66]	43.13 [35.09-51.16]	65	39.91 [38.09-41.75]	49.32 [40.9-57.73]
New Mexico	9	42	6.41 [1.19-17.93]	11.48 [0.71-22.25]	27	27	0	0	3	4.74	128	33.15 [21.53-46.34]	35.35 [22.6-48.1]	9	60.56 [39.75-79.03]	50.37 [27.46-73.28]
New York	178	39,988	31.19 [28.72-33.72]	11.33 [8.83-13.83]	270	247	11	12	5	171.10	46,196	26.54 [23.98-29.21]	43.91 [39.85-47.98]	189	40.46 [38.45-42.5]	47.74 [43.41-52.07]
North Carolina	277	3,578	26.26 [23.45-29.21]	13.76 [11.34-16.18]	415	405	9	1	4	12.48	5,181	34.1 [31.45-36.81]	43.37 [39.87-46.87]	295	45.89 [43.42-48.38]	49.4 [45.58-53.22]
North Dakota	36	189,516	23.7 [19.78-27.96]	24.03 [18.78-29.28]	38	5	1	32	2894	5532.37	210,230	26.89 [22.02-32.15]	36.42 [28.15-44.69]	35	42.23 [36.62-47.97]	47.65 [39.98-55.33]
Ohio	182	11,444	48.93 [46.88-50.98]	11.16 [8.57-13.75]	281	273	6	2	4	42.67	11,989	18.56 [16.53-20.72]	48.69 [44.58-52.8]	200	46.53 [45.41-47.65]	51.5 [47.02-55.97]
Oklahoma	29	3,632	59.79 [55.16-64.31]	20.22 [11.5-28.94]	37	34	2	1	5	91.59	3,389	14.1 [11.46-17.04]	18.85 [10.62-27.09]	29	65.41 [61.21-69.45]	34.54 [25.78-43.31]
Oregon	123	22,059	18.56 [17.02-20.17]	8.94 [6.13-11.75]	194	178	10	6	3	195.56	37,938	26.54 [24.31-28.85]	38.14 [33.1-43.18]	125	36.35 [34.2-38.54]	44.45 [38.51-50.4]
Pennsylvania	351	22,097	34.22 [32.15-36.33]	9.82 [8.14-11.5]	565	538	22	5	4	45.03	25,443	27.94 [25.91-30.03]	51.99 [48.91-55.07]	376	45.91 [44.43-47.4]	54.73 [51.34-58.13]
Puerto Rico	0	.	.	.	1	.	.	.	.	.	.	.	.	0	.	.
Rhode island	15	62	5.06 [0.5-17.67]	8.93 [-1.49-19.35]	28	28	0	0	3	7.32	205	34.7 [27.03-42.95]	36.66 [23.64-49.67]	15	37.5 [27.69-48.06]	36.26 [21.51-51.02]
South Carolina	67	4,059	13.51 [11.93-15.21]	11.06 [7.23-14.89]	96	93	2	1	4	42.57	4,087	15.53 [11.65-20.03]	40.79 [34.34-47.23]	72	21.5 [17.57-25.82]	44.08 [37.03-51.13]
South Dakota	6	85,132	39.96 [35.38-44.66]	17.49 [4.56-30.41]	8	4	0	4	1026	9723.75	77,790	39.03 [35.52-42.61]	46.58 [24.72-68.43]	6	63.32 [57.31-69.06]	51.19 [29.28-73.11]
Tennessee	56	626	16.03 [13.1-19.28]	8.07 [4.4-11.74]	94	88	6	0	5.5	13.62	1,280	43.06 [37.29-48.96]	35.77 [29.34-42.2]	61	51.57 [44.82-58.29]	38.09 [30.5-45.68]
Texas	56	66,951	24.56 [22.39-26.83]	12.88 [8.51-17.26]	77	58	4	15	7	1039.14	80,014	36.53 [32.87-40.3]	26.71 [20.81-32.61]	56	49.17 [45.17-53.17]	31.49 [24.31-38.67]
Utah	46	9,736	17.5 [15.49-19.65]	16.08 [10.24-21.93]	80	70	6	4	5	161.21	12,897	40.83 [34.64-47.22]	52.5 [45.01-60]	50	50.25 [43.62-56.88]	58.64 [50.96-66.33]

Table 7 Cont'd.

	Summer Loss				Winter Loss									Annual Loss		
	n (# of operations)	Total # of colonies (04/2012)	Total Loss mean [95% CI]	Average Loss mean [95% CI]	n (# of operations)	n Backyard BK	n Sideline BK	n Commercial BK	Median # of colonies (10/2012)	Mean # of colonies (10/2012)	Total # of colonies (10/2012)	Total Loss mean [95% CI]	Average Loss mean [95% CI]	n (# of operations)	Total Loss mean [95% CI]	Average Loss mean [95% CI]
Vermont	39	2,854	8.53 [6.38-11.06]	10.74 [4.71-16.77]	76	67	6	3	4	54.63	4,152	27.09 [23.29-31.14]	40.62 [32.72-48.52]	45	29.67 [26.35-33.14]	41.9 [32.81-50.99]
Virginia	470	14,497	42.94 [41.29-44.6]	12.82 [11.04-14.6]	698	684	12	2	3	21.13	14,750	22.91 [21.26-24.62]	44.26 [41.57-46.95]	493	47.62 [46.49-48.76]	48.85 [45.86-51.84]
Washington	110	49,972	28.52 [26.84-30.23]	14.14 [10.18-18.09]	178	164	6	8	4	390.97	69,593	22.71 [21.33-24.12]	45.32 [39.83-50.8]	116	43.06 [41.19-44.94]	50.44 [44.07-56.82]
West Virginia	60	2,124	14.12 [12.57-15.77]	8.65 [5.3-12]	86	83	2	1	6	29.79	2,562	45.41 [40.99-49.88]	38.07 [30.82-45.32]	64	54.85 [50.19-59.45]	40.02 [32.17-47.88]
Wisconsin	131	19,153	35.33 [31.46-39.32]	16.55 [12.71-20.39]	184	165	12	7	5	113.34	20,854	23.31 [20.26-26.55]	62.76 [57.79-67.74]	138	44.42 [41.89-46.98]	67.29 [62.49-72.09]
Wyoming	13	13,370	15.58 [11.17-20.8]	10.89 [3.47-18.31]	21	13	3	5	15	778.81	16,355	37.52 [26.96-48.94]	33.53 [18.27-48.8]	13	46.37 [32.13-61.02]	38.65 [22.86-54.44]

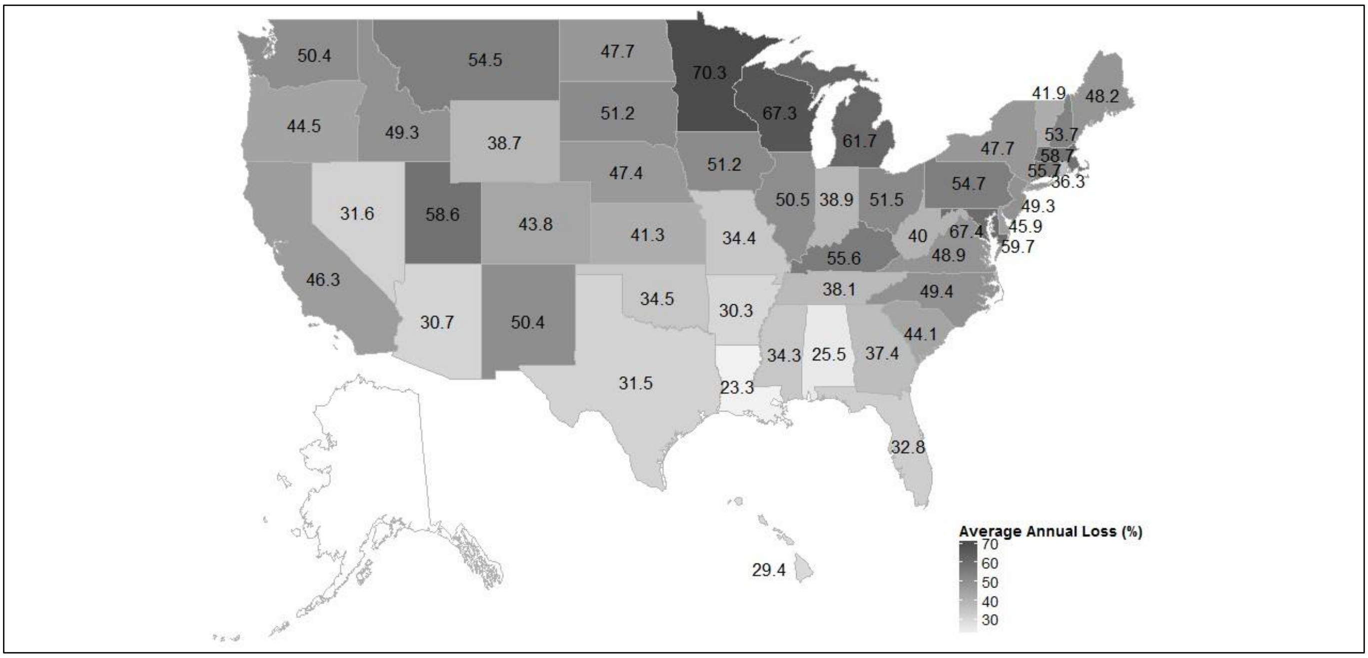

Fig. 8. Average annual loss (%) by state. Respondents who managed colonies in more than one state had all of their colonies counted in each state in which they reported managing colonies. Data for states with fewer than five respondents are withheld.

Discussion

This survey reports the seventh year of consecutive estimates of overwintering colony losses for the US and for the first time reports summer and annual losses. With the exception of the winter of 2011-2012 (TWL = 22.5%; Spleen *et al.*, 2013), US total overwintering loss estimates have fluctuated around 30% (31.8%, 35.8%, 28.6%, 34.4%, and 29.9% for the winters of 2006-7, 2007-8, 2008-9, 2009-10 and 2010-11, respectively; vanEngelsdorp *et al.*, 2007, 2008, 2010, 2011a, 2012). Our estimate for the winter 2012-2013 at 30.6% (TWL) conforms to the current pattern of high overwintering colony losses.

Several of our results point out that the 2012-2013 winter has been particularly challenging for beekeepers to keep their colonies alive. Since winter losses have been quantified by surveys, average winter loss has mostly been higher than total winter loss (with total *vs.* averages of 31.8% vs 37.6%, 35.8% vs 31.3%, 28.6% vs 34.2%, 34.4% vs 42.2%, 29.9% vs 38.4%, 22.5% vs 25.4% for the winters of 2006-7, 2007-8, 2008-9, 2009-10, 2010-11 and 2011-12, respectively; vanEngelsdorp *et al.*, 2007, 2008, 2010, 2011a, 2012; Spleen *et al.*, 2013) and it is yet again the case with the estimates in the current study. However, this survey year's average winter loss was higher than in previous years at 44.8%. This means that during this winter 2012-2013, while the US region as a whole lost 30.6% of its colonies, each beekeeper lost on average 44.8% of his/her colonies. Moreover, during the winter of 2012-13, only 24% of respondents reported zero colony losses, while over the previous two winters, 45% and 33% of respondents, respectively, made this claim (Spleen *et al.*, 2013; vanEngelsdorp *et al.*, 2012). Finally, 52.3% of respondents to this survey claimed that their overwintering losses were higher in 2013 compared to the previous year. A higher average loss per beekeeper, fewer individual beekeepers reporting no loss and more than one in two beekeepers reporting worse losses compared to the previous year, all indicate a particularly difficult 2012-2013 wintering season.

Even though our survey size represents 25.5% of the colonies managed in the US as compared to USDA-NASS population estimate mentioned earlier, there is no census of the US beekeepers available, which prevents us from quantifying and adjusting for potential bias in our respondent pool. Despite our efforts to multiply the channels of solicitations, most of our approaches still rely on the internet, which might bias participation towards internet-savvy beekeepers. Knowing that previous results had repeatedly under-represented commercial beekeepers, strong efforts have been deployed this year to seek to increase their participation, with success, as their representation in the analytic sample for winter loss rose from 1.22% (n = 67 of 5,500 respondents in 2012; Spleen *et al.*, 2013) to 2.08% (n = 135 of 6,482 respondents in this survey). Overall, the number of colonies represented in our survey (on 1 October) increased by 78.9% compared to the previous year's survey (635,971 colonies compared to 355,532 colonies; Spleen *et al.*, 2013), perhaps indicating that the outreach efforts were productive.

This survey was not designed to identify causes of winter colony losses but instead to document trends in reported levels of loss and self-reported causes of death as identified by the beekeeper themselves. Difference in results from past surveys may result from changes in the respondent pool, which are difficult to correct without a comprehensive census of US beekeepers.

Commercial beekeepers lost, on average, a significantly lower percentage of colonies than sideline beekeepers and backyard beekeepers over the winter. They were also more likely to report the symptom "no dead bees in the hive or apiary" when experiencing winter loss, a symptom which is one of the defining characteristics of CCD (Cox-Foster *et al.*, 2007; vanEngelsdorp *et al.*, 2009).

This study's estimate of the proportion of colonies that died with the symptom "no dead bees in the hive or apiary" is more than double compared to past years (51.3% of the colonies lost this winter 2012-2013 compared to 20.5% in 2012 and 26.3% in 2011; Spleen *et al.*, 2013 and vanEngelsdorp *et al.*, 2012). This was also reflected in the frequency of selecting "CCD" as a main cause of colony loss over the winter: 10.83% of the respondents who suffered a certain amount of loss identified CCD as main cause of overwintering loss in this survey. Only 8.6% (n = 247 on 2,887 respondents) and 5.9% (n = 199 on 3,389 respondents) did the same last year (Spleen *et al.*, 2013; vanEngelsdorp *et al.*, 2012). Beekeepers who reported they lost at least part of their colonies to the symptom "no dead bees in the hive or apiary" experienced greater loss on average than those not reporting this condition. Similarly, beekeepers who selected "CCD" as a self-reported cause of overwintering colony loss also experienced greater losses compared to beekeepers who did not select this factor. Only commercial beekeepers listed "CCD" as one of their most frequently reported factors of overwintering colony loss. Typically, as was the case in previous years (vanEngelsdorp *et al.*, 2011a), we see that commercial beekeepers self-identified mostly non-manageable conditions (queen failure, pesticides or CCD) as leading causes of overwintering loss, while backyard beekeepers were more likely to report manageable conditions (starvation, colony weak in the fall).

Ideally we would compare our survey results with loss data from in field longitudinal studies. Unfortunately, few in field studies are available. A total loss of 56% was reported in a cohort of migratory honey bee colonies monitored for 10 months, which is higher than the estimate in this study (vanEngelsdorp *et al.*, 2013b). The same study also identified "queen event" as one of the major risk factor of short-term colony mortality (vanEngelsdorp *et al.*, 2013b), which supports our participating beekeepers' judgment of identifying this factor as one of the leading cause of colony mortality. A field study in Ontario Canada identified fall varroa mite levels, small fall bee populations, and low food reserves as leading causes of colony mortality (Guzmán-Novoa *et al.*, 2010). Our ranking of the top-4 leading self-reported cause of death (colony weak in the fall, starvation, queen failure and varroa mites) appears well supported by those two in the field studies, however, more in field verification of losses and causes of losses should be done to test the accuracy of our survey results.

Overall, more than 70% of the beekeepers experienced overwintering loss above the level US beekeepers consider acceptable in this winter 2012-2013, which might reflect the unusually high level of average winter loss, though there was considerable variation across states. In addition to a high overwintering loss, beekeepers also lost colonies during the summer period. On average, US beekeepers lost 12.5% of their colonies last summer and 49.4% over the entire course of the year. Commercial beekeepers lost significantly fewer colonies than backyard beekeepers in the winter but the situation is reversed in the summer where they experience a higher average loss than backyard beekeepers (30.2% (95% CI: 26.54-33.93 % vs 45.4 % (44.46-46.32 %) respectively). This also explains the inversion between total and average loss for the summer estimates where total loss, strongly influenced by larger apiaries, is higher than average loss. This, together with the contrasted results concerning CCD symptoms and other self-reported causes of death, strongly suggests that beekeepers from different operation types are facing divergent challenges and encourages us to consider operation type as an important factor in understanding the causes of colony mortality.

We selected 1 October to 1 April to estimate overwintering colony loss because this period is thought to encompass the traditional inactive season of the colony and enables the beekeeper to make a first spring visit to estimate the mortality in his/her operation. However, the length of the inactive season varies according to the region and some important pollination activities occur during that period. While somewhat subjective, this constant reference period throughout studies enables for comparison of rates across time and regions. Overwintering has always been seen as the period of the year with the highest mortality risk, but with a total loss of 25.3% (95% CI: 24.8-25.75%) and an average loss per beekeeper of 12.5 % (95% CI: 11.91-13.06%), the mortality over summer is far from negligible. Those results suggest that to capture a more complete picture of honey bee colony mortality and understand its drivers, survey studies documenting colony losses should report annual losses rather than winter losses only.

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