Journal of Apicultural Research 50(1): 1-10 (2011)
DOI 10.3896/IBRA.1.50.1.01

ORIGINAL RESEARCH ARTICLE

A survey of managed honey bee colony losses in the USA, fall 2009 to winter 2010

Dennis vanEngelsdorp[1*], Jerry Hayes Jr.[2], Robyn M Underwood[1, 3], Dewey Caron[4], and Jeffery Pettis[4]

[1]Department of Entomology, Penn State University, University Park, PA 16802, USA.
[2]Florida Department of Agriculture, Bureau of Plant and Apiary Inspection, Apiary Inspection Section, Division of Plant Industry, P.O. Box 147100, Gainesville, FL 32614, USA.
[3]Department of Biology, Kutztown University, Kutztown, PA 19530, USA.
[4]Department of Horticulture, Oregon State University, Corvallis, OR 97301, USA.
[5]USDA - ARS Bee Research Laboratory, Bldg. 476 BARC-E Beltsville, MD 20705, USA.

Received 4 October 2010, accepted subject to revision 11 October 2010, accepted for publication 19 November 2010.

*Corresponding author: Email: dennis.vanengelsdorp@gmail.com

Summary

This study records the fourth consecutive year of high winter losses in managed honey bee (*Apis mellifera)* colonies in the USA. Over the winter of 2009-2010, US beekeepers responding to this survey lost an average of 42.2% of their colonies, for a total loss of 34.4%. Commercial beekeepers (those operating more than 500 colonies) experienced lower total losses as compared to sideline and backyard beekeepers. Similarly, operations that maintained colonies in more than one state and operations that pollinated almond orchards over the survey period had lower total losses than operations either managing colonies in one state exclusively or those not pollinating almonds. On average beekeepers consider acceptable losses to be 14.5%, and 65% of all responding beekeepers suffered losses in excess of what they considered acceptable. The proportion of operations that experienced losses and reported having no dead bees in their colonies or apiaries was comparable to that reported in the winter of 2008-2009. Manageable conditions, such as starvation and a weak condition in the fall were the leading self-identified causes of mortality as reported by all beekeepers. Commercial beekeepers were, however, less likely to list such manageable causes, instead listing poor queens, mites, and pesticides most frequently as the self-identified causes of mortality in their operations.

Una encuesta sobre la gestión de las pérdidas de colmenas de abejas en los EE.UU., entre el otoño de 2009 hasta el invierno de 2010

Resumen

Este estudio documenta el cuarto año consecutivo de altas pérdidas invernales en las colmenas de abejas manejadas (*Apis mellifera*) en los EE.UU. Durante el invierno de 2009-2010, los apicultores de EE.UU. que respondieron a este estudio, perdieron un promedio del 42,2% de sus colmenas, siendo la pérdida total de un 34,4%. Los apicultores comerciales (los que operan con más de 500 colmenas) experimentaron pérdidas totales menores en comparación a los apicultores aficionados y sin organización. Del mismo modo, las operaciones que mantienen a las colmenas en más de un estado y las operaciones de polinización de almendros en el período de muestreo tuvieron menos pérdidas totales que las operaciones que mantienen a las colmenas en un estado exclusivamente o a las que no polinizaron almendros. Como media los apicultores consideraron que una pérdida aceptable era del 14,5%, y el 65% de todos los apicultores respondieron haber sufrido pérdidas superiores a lo que consideraban como aceptable. La proporción de operaciones que experimentaron pérdidas y que informaron de no tener abejas muertas en sus colmenas o apiarios fue comparable a la documentada en el invierno de 2008-2009. Las condiciones de manejo, tales como la inanición y una condición débil en el descenso fueron las principales causas auto-identificadas de la mortalidad según lo informado por todos los apicultores. Los apicultores comerciales fueron, sin embargo, menos críticos al listar las causas de manejo, en su lugar, auto-identificaron a las reinas malas, a los ácaros y a los pesticidas como las causas más probables de la mortalidad en sus operaciones.

Keywords: Honey bees, overwinter, mortality, USA, 2009-2010

Introduction

Over the last few years, high rates of overwintering mortality have been reported in honey bee (*Apis mellifera*) colonies in many European and North American countries (vanEngelsdorp *et al*., 2008, 2010; Currie *et al*., 2010; Neumann and Carreck, 2010; Nguyen *et al*., 2010). In the USA specifically, high overwintering losses (32%, 36% and 29% for the winters of 2006-2007, 2007-2008, and 2008-2009, respectively) have been reported (vanEngelsdorp *et al*., 2007, 2008, 2010).

It is clear that these losses have not resulted in a pronounced decrease in the number of honey producing colonies managed by US beekeepers in the subsequent summers (USDA-NASS, 2009). In fact, the 2007 US Agricultural Census, a survey conducted once every five years, reported a dramatic increase in the number of colonies managed on 31 December 2007, as compared to the total number of honey producing colonies enumerated the preceding summer (USDA-NASS, 2009). This apparent discrepancy may be explained by beekeepers who, fearing heavy losses, overwintered larger numbers of colonies to better ensure that they would have enough colonies to meet spring's pollination demands (vanEngelsdorp and Meixner, 2010). Beekeepers can easily increase the number of colonies they manage by either purchasing package bees or splitting existing hives. A recent survey of Pacific Northwest beekeepers revealed that in both 2008 and 2009, beekeepers replaced more colonies than they lost in the preceding winter (Caron *et al*., 2010).

The reason for the high level of losses is not completely understood. Whilst annual overwintering loss surveys are not designed to identify factors responsible for losses, each survey has asked beekeepers to self-identify the reasons why they believe they experienced high losses. Among the most mentioned factors have been queen failure, starvation and the parasitic mite *Varroa destructor* (vanEngelsdorp *et al*., 2007, 2008, 2010). While not conclusive, these self-identified causes of mortality do suggest that a multitude of factors are contributing to colony mortality, and so suggest that efforts aimed to reduce losses will likely need to be as diverse as the causes.

In keeping with previous years' efforts, this survey's objective was to quantify the mortality of overwintered colonies in the USA over the winter of 2009-2010. Here, we compare the rate of loss by operation size and activity, and also quantify the suspected reasons for loss as reported by the surveyed beekeepers.

Materials and methods

An email soliciting responses to an online survey posted at Surveymonkey.com was sent to state apiarists, presidents of national and state beekeeping organizations, and to online beekeeping lists. This email encouraged beekeepers to forward the request to other beekeepers that they knew. In addition to the state apiarists, 43 different state and county beekeeping organizations were contacted, and 42 of these agreed to forward the survey request to their distribution lists. Because of the nature of this approach, the exact number of beekeepers contacted cannot be calculated but based on the subscription rates of electronic list serves such as BEE-L and Catch the Buzz, it can be assumed to be above 20,000 (Flottum 2010). In an attempt to compare the web-based survey results with past efforts, the USDA also contacted commercial beekeepers by phone and asked the same questions.

Some of the questions asked were established by a working group of the international COST (European Cooperation in Science and Technology) network of bee researchers with the acronym COLOSS (Prevention of honey bee COLony LOSSes). The following questions were asked: 1. in what state(s) did you keep your hives in 2009?; 2. how many living colonies did you have on 1 October 2009?; 3. how many living colonies did you have on 1 April 2010?; 4. how many splits, increases, and / or colonies did you make / buy between 1 October 2009 and 1 April 2010?; 5. how many splits, increases, and / or colonies did you sell between 1 October 2009 and 1 April 2010?; 6. what percentage of the colonies that died between 1 October and 1 April were lost without dead bees in the hive or apiary?; 7. what percentage of loss, over this time period, would you consider acceptable?; 8. to what do you attribute the cause of death for the colonies that died?; 9. what percentage of your hives did you send to California for almond pollination?; 10. how many times, on average, did you move your colonies last year?; and 11. how many years have you been keeping honey bees?

Beekeepers were given the option to provide their email address if they were interested in seeing the results of the survey effort. In addition to recording the survey responses, the web-based survey tool also recorded the IP address of respondents. In all cases, except for question 1, the survey called for beekeepers to type in their answers (i.e. possible answers were not provided). Thus, responses to question 8 were categorized into broad groups (e.g. lack of food = starvation) for analysis. Beekeepers were assigned to operational size groups by the following criteria: beekeepers managing 50 or fewer colonies were classified as "backyard beekeepers"; those managing between 51 and 500 colonies were classified as "sideline beekeepers"; and beekeepers managing 501 or more colonies were classified as "commercial beekeepers".

Calculations and statistical analysis

Total colony losses were calculated for each reporting operation, for the sum total of all respondents, and for various subgroup classifications. Total losses were calculated by first calculating the total number of monitored colonies at risk of dying over the period (colonies 1 October (Q2) + colonies split or purchased (Q4) – colonies sold (Q5)). The total colonies that died over the period (total monitored colonies – total colonies 1 April (Q2)) was then divided by the total monitored colonies multiplied by 100%. To account for the nested nature of total loss data, the standard error of the intercept of a null General Linear Model with quasi-binomial family error distribution was used to calculate the confidence limits for total loss data (McCullagh and Nelder, 1989; R development Core Team, 2009 (code provided by Y Brostaux and B K Nguyen; pers. communication)). The mean of individual operation losses was calculated to determine the average loss among subgroups and 95% confidence intervals (CI) were also calculated (SAS, 2007).

Comparisons of total losses between different groups of operations were conducted using the chi-square test. When more than two groups were compared within a test, pair-wise comparisons between groups were conducted. When multiple comparisons were made, the α used to reject the null hypothesis was adjusted appropriately (Abdi, 2007). Comparisons of average operational losses were made using the Kruskal-Wallis rank sum test. Only significant results ($P < 0.05$) are reported.

The total number of colonies lost with the symptom of no dead bees in the colony was calculated for individual operations by multiplying the number of colonies lost in an operation by the reported percentage lost without dead bees. When calculating losses in individual states, colonies belonging to operations that managed colonies in more than one state were counted multiple times; once in each listed state. This same practice is used by the National Agricultural Statistics Service when calculating the number of honey-producing colonies in each state (USDA-NASS, 2009a).

Results

Average and total losses

National losses

The web-based survey recorded 4,284 responses, of which 4,262 provided all of the information needed to quantify overwintering losses. Of these, 34 respondents gave responses that suggested their losses were less than 0%, so these respondents were excluded. In all, 85 distinct IP addresses were used more than once to submit responses; of these, 24 responses were clearly duplicate data and were also excluded. The remaining 4,204 respondents managed a total of 296,507 living colonies on 1 October 2009, representing 12.0% of the 2.46 million honey-producing colonies estimated to have been managed in the US in 2009 (USDA-NASS, 2010). On average, the beekeepers in this group lost 42.4% (95% CI: 41.3-43.5%) of their colonies, while the total loss suffered was 32.2% (95% CI: 31.6-32.8%).

The USDA phone effort interviewed a total of 22 respondents. In total, this group reported managing 142,615 colonies on 1 October 2009; 5.8% of the total honey-producing colonies managed in the US in 2009. The average operational loss suffered by this group was 34.0% (95% CI: 23.9-44.0%), while the total loss suffered was 38.4% (95% CI 29.0–48.0%).

The average operational loss suffered by respondents in the two surveys did not differ ($\chi^2 = 0.20$, d.f. = 1, $P = 0.6472$), and so the databases were combined. The duplicate response provided by a beekeeper who answered both surveys was removed from the merged dataset. The combined dataset had a total of 4,225 respondents who collectively operated 436,802 colonies on 1 October 2009; 17.7% of the total colonies managed in the summer of 2009. These same beekeepers reported having 375,501 living colonies on 1 April 2010. When colonies made / bought (n = 143,973) or sold (n = 8,136) are considered in the calculation (see materials and methods) these beekeepers experienced an average operational loss of 42.2% (95% CI: 41.3-43.4%) and a total loss of 34.4% (95 % CI: 33.7-35.1%). Should these results be representative of national losses, between 829,020 and 863,460 of colonies were lost over the winter of 2009-2010.

Losses by state

There was considerable variation in both the average (Table 1; Fig. 1) and total (Table 1; Fig. 2) loss suffered by beekeepers operating in different states. When generating these figures, operations managing colonies in more than one state had their colonies counted in all states in which the operation managed bees. This is in keeping with the practice of NASS when they annually quantify honey producing colonies. The percentage of colonies and operations per state that operated exclusively in a given state is summarized in Table 1. It should be noted that operations that report managing colonies in more than one state, do not necessarily move all their colonies into and out of a given state. For instance, the one beekeeper in Hawaii who reported having colonies in more than one state almost certainly did not move colonies between Hawaii and the mainland. Thus, some caution is needed when comparing state colony losses where a large proportion of the colonies are managed by operations managing bees in several states.

Losses by operation classification

Average losses suffered by commercial beekeepers tended to be lower than that suffered by sideline and backyard beekeepers, but this difference was not significant (Table 2). There was, however, a difference in the total losses suffered by these groups ($\chi^2 = 2,125$, d.f. = 2, $P < 0.0001$; Table 2). Pairwise chi-square comparisons of total loss data suffered by the sub-groups revealed that sideline beekeepers suffered the largest total loss as compared to all other groups, while the total losses suffered by commercial beekeepers was the lowest.

Fewer than 4% of survey respondents reported maintaining colonies in more than one state. There was no difference in the average loss experienced by those beekeepers who maintained / did not maintain colonies in more than one state (P > 0.9). The two groups did differ, however, in the total losses reported (χ^2 = 731, d.f. = 1, P < 0.0001). Total losses experienced by beekeepers maintaining colonies in more than one state (33.6% (95% CI: 30.5–36.8%), *n* = 469,962) was lower than the total loss experienced by beekeepers maintaining colonies in only one state (38.3% (95% CI: 37.5–39.1%), *n* = 102,787).

Fewer than 2.5% of responding beekeepers reported moving at least some of their operations into almonds for pollination during the survey period. On average, beekeepers pollinating almonds moved 80.4 ± 2.94% (*n* = 460,607) of their colonies into the almond orchards. The average loss experienced by beekeepers who moved or did not move bees into almond orchards for pollination was not different (P > 0.2). Beekeepers who pollinated almonds experienced lower total losses than those not pollinating almonds (χ^2 = 6,332, d.f. = 1, P < 0.0001; Table 3).

On average all responding beekeepers moved their colonies 0.31 ± 0.02 times (*n* = 4,209). There was no correlation between the number of times beekeepers moved their colonies and total losses suffered by operations (P = 0.23). On average responding beekeepers reported keeping bees for 8.85 ± 0.85 years (*n* = 4,214). There was no correlation between years of beekeeper experience and total losses suffered by operations and the number of years beekeepers reported keeping bees (P = 0.56).

Table 1. The number of operations and colonies contributing to the average and total and losses by state (also summarized in Fig. 1 and Fig. 2) and the percentage of operations and colonies in each state that operated exclusively in that state. Operations reporting managing colonies in more than one state have their colonies counted in all states in which they report managing colonies. Results for states with fewer than six responders are not presented.

State	No. Operations	operations exclusively in state (%)	Total Colonies	colonies exclusively in state (%)	Average Loss (mean (95% CI))	Total Loss (mean (95% CI))
Alabama	46	95.7	1,441	93.5	35.7 (25.6-45.7)	26.6 (23.7-34.8)
Alaska	3					
Arizona	5					
Arkansas	50	96.0	460	23.5	26.8 (18.2-35.4)	23.3 (16.8-31.3)
California	166	38.0	445,639	5.2	39.4 (34.8-44.0)	31.7 (28.9-34.6)
Colorado	99	96.0	7,714	12.2	42.4 (35.2-49.7)	33.0 (30.3-35.9)
Connecticut	58	87.9	760	39.1	50.6 (40.3-61.0)	50.5 (43.5-57.5)
Delaware	15	93.3	104	93.3	54.8 (32.7-77.0)	54.8 (33.5-72.2)
Florida	155	89.7	56,508	9.4	28.6 (23.7-33.4)	53.4 (48.8-56.8)
Georgia	87	92.0	8,548	8.9	43.2 (36.0-50.4)	47.7 (43.2-52.1)
Hawaii	9	88.9	58	93.1	10.2 (0-22.1)	20.7 (11.9-33.6)
Idaho	27	92.6	27,034	0.8	43.8 (30.2-57.4)	27.3 (23.1-31.9)
Illinois	49	87.8	968	27.9	48.2 (37.6-58.9)	73.0 (66.2-78.9)
Indiana	85	95.3	4,574	17.3	47.5 (39.7-55.3)	57.1 (54.3-59.9)
Iowa	56	94.6	1,167	56.7	57.0 (47.9-66.3)	73.4 (67.6-78.4)
Kansas	10	70.0	5,753	1.4	41.0 (19.8-62.1)	39.6 (33.1-45.7)
Kentucky	25	88.0	790	69.9	38.1 (24.1-52.0)	48.8 (34.4-63.5)
Louisiana	3					
Maine	89	92.1	29,790	1.7	22.9 (15.7-30.1)	56.9 (52.4-61.4)
Maryland	171	94.2	4,763	81.8	36.3 (30.6-41.9)	38.7 (35.6-41.9)
Massachusetts	196	96.9	25,224	6.2	45.5 (39.8-51.1)	63.2 (61.1-65.3)
Michigan	231	96.5	13,446	31.9	49.9 (45.2-54.6)	44.9 (41.2-48.6)
Minnesota	37	75.7	158,846	0.6	50.0 (38.5-61.5)	31.8 (29.2-34.5)
Mississippi	14	85.7	17,454	2.3	38.4 (21.3-55.4)	45.8 (35.5-56.5)
Missouri	42	95.2	1,058	73.5	36.4 (25.9-46.9)	28.9 (23.0-35.7)
Montana	24	37.5	123,459	0.1	28.6 (18.5-39.0)	29.5 (20.0-39.8)
Nebraska	17	70.6	139,286	0.1	57.9 (39.5-76.3)	28.5 (24.0-33.5)
Nevada	5					
New Hampshire	76	93.4	821	79.9	37.2 (28.3-46.1)	26.2 (20.3-33.1)

Table 1. Cont.

State	No. Operations	operations exclusively in state (%)	Total Colonies	colonies exclusively in state (%)	Average Loss (mean (95% CI))	Total Loss (mean (95% CI))
New Jersey	31	77.4	3,966	3.4	34.0 (20.0-47.9)	10.4 (6.1-17.2)
New Mexico	9	100.0	3,248	100.0	58.2 (30.0-86.5)	31.8 (34.4-41.1)
New York	163	85.3	28,740	24.7	43.5 (35.6-48.4)	40.1 (36.9-43.4)
North Carolina	191	95.8	3,689	78.9	36.0 (31.1-40.8)	45.7 (41.3-50.0)
North Dakota	30	26.7	243,331	4.7	31.6 (22.2-41.0)	26.6 (4.8-32.0)
Ohio	203	97.0	5,330	33.4	44.0 (39.0-48.9)	52.4 (50.0-54.4)
Oklahoma	10	90.0	141	96.5	32.9 (19.0-46.8)	39.0 (29.4-49.6)
Oregon	49	89.8	30,927	3.5	53.2 (42.8-63.5)	29.7 (23.6-36.6)
Pennsylvania	546	96.9	10,619	50.4	46.3 (43.7-49.9)	42.6 (40.8-44.5)
Rhode Island	67	92.5	279	92.5	41.4 (31.9-50.9)	37.3 (29.5-45.8)
South Carolina	127	88.2	14,747	11.6	38.1 (32.3-43.9)	37.2 (33.1-41.6)
South Dakota	16	12.5	212,653	0.0	34.3 (21.0-47.6)	28.1 (20.8-36.8)
Tennessee	62	98.4	702	85.3	39.6 (30.1-40.1)	28.9 (22.0-36.9)
Texas	59	83.1	61,907	8.6	32.7 (25.4-40.0)	38.6 (35.0-42.4)
Utah	65	93.8	8,184	12.7	45.4 (36.3-54.5)	20.8 (17.0-25.2)
Vermont	68	94.1	3,189	58.1	40.0 (31.7-48.3)	29.0 (24.7-33.7)
Virginia	481	97.1	3,498	93.2	37.8 (34.6-41.0)	38.0 (35.3-40.7)
Washington	144	92.4	84,674	1.4	40.9 (34.8-47.1)	32.5 (29.6-35.5)
Washington, D.C.	2					
West Virginia	117	91.5	1,461	61.5	52.6 (46.2-59.1)	50.1 (44.4-55.8)
Wisconsin	155	92.3	12,119	25.5	59.2 (53.7-64.7)	33.2 (28.9-37.9)
Wyoming	4					

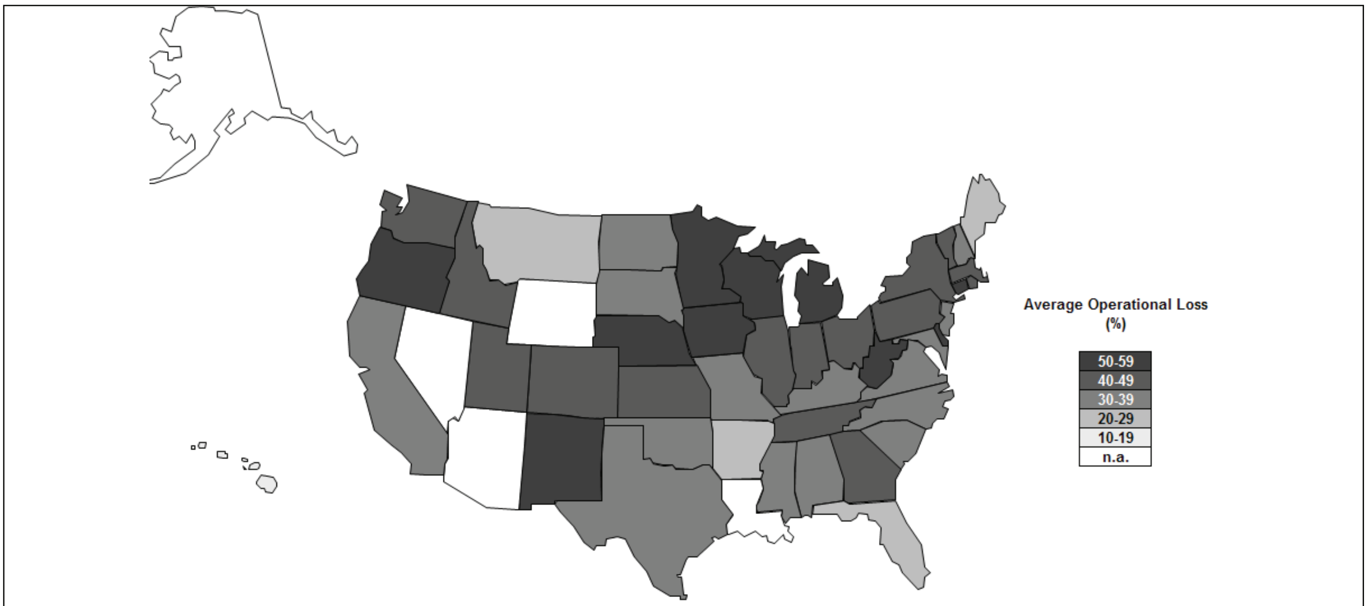

Fig. 1. Average operational loss by US state. Operations who reported managing colonies in more than one state had their losses included in all of the states in which they reported managing colonies (see Table 1). States which had fewer than six responders (n.a.) are not included.

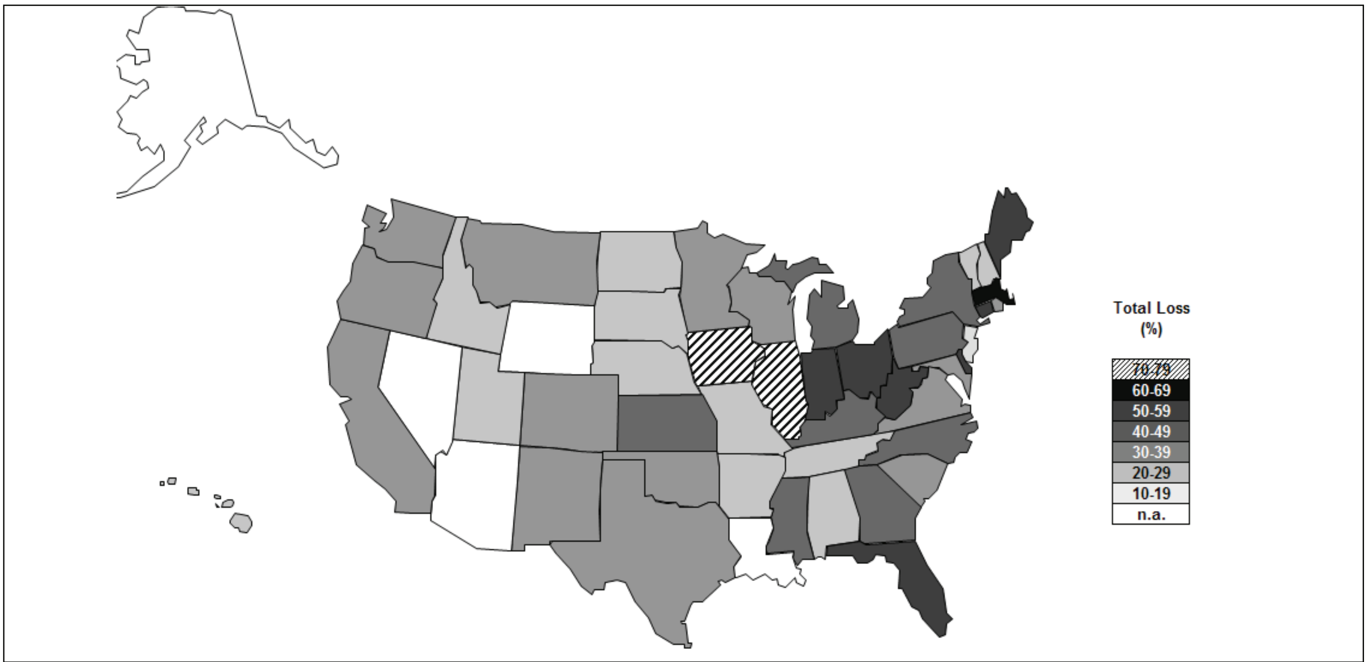

Fig. 2. Total colony losses by state. Operations who reported managing colonies in more than one state had their losses included in all of the states in which they reported managing colonies (see Table 1). States which had fewer than six responders (n.a.) are not included.

Table 2. Average and total losses suffered by beekeepers grouped by the size of their operation. * indicates a significance difference between groups. Different letters in different rows indicate differences between groups in pair-wise chi-square comparisons (P < 0.0001).

Operation Type	Respondents	Average Loss Mean (95 % CI)	Total colonies	Total Losses* Mean (95 % CI)
Backyard	3,944	42.5 (41.3 – 43.6)	25,954	42.9 (41.9 – 43.8)[a]
Sideline	174	42.5 (38.5 - 46.4)	28,217	44.5 (40.6 – 48.4)[b]
Commercial	107	36.0 (31.7 – 40.4)	518,518	33.5 (29.7 - 37.4)[c]

Table 3. Comparison of average and total losses in operations that moved or did not move colonies into almonds for pollination. *indicates significant difference between groups.

	Respondents	Average Loss Mean (95 % CI)	Total colonies	Total Loss Mean (95 % CI)*
Moved into Almonds?				
No	4,063	42.5 (41.4 - 43.6)	112,082	44.6 (43.8 -45.3)
Yes	103	35.5 (30.2 - 40.0)	460,607	32.0 (28.2 – 35.9)

Table 4. Percentage of respondents reporting and the estimated percentage of colonies found dead with the condition of "no dead bees in the colony or apiary" by size of operation. The percentage of beekeepers reporting the condition differed between beekeepers when grouped by operation size (see text).

Operation Type	Respondents	% of respondents reporting condition	Total colonies lost by respondents	% of total colonies lost with condition
Backyard	2,535	25.3	10,261	13.1
Sideline	158	59.0	11,453	35.2
Commercial	88	80.0	135,367	57.3

Losses in operations reporting the symptom of "no dead bees in the hive or apiary"

One of the defining characteristics of Colony Collapse Disorder (CCD) is the complete absence of dead bees in the colony or apiary (vanEngelsdorp *et al.*, 2009), but this survey cannot differentiate between colonies lost to CCD and other conditions that may cause the same symptom. In all, 65% of surveyed beekeepers answered the question "What percentage of the colonies that died between 1 October and 1 April were lost without dead bees in the hive or apiary?"; of those 28.9% reported at least some of their colonies died with the absence of dead bees condition. Average losses were elevated in operations reporting this condition (62.2% (95% CI: 60.2-64.2%), n = 805) when compared to operations that did not report the condition (58.2% (95% CI: 57.0-59.6%), n = 1,976; χ^2 = 10.3, d.f.= 1, P = 0.0014). Beekeepers reporting the condition also experienced higher total losses (44.1% (95% CI: 42.8–45.5%), n = 287,234) as compared to those not reporting the condition (26.7% (95% CI: 25.7-27.7%), n = 113,703; χ^2 = 9,491, d.f. = 1, P < 0.0001).

Commercial beekeepers were 3.1 and 1.4 times more likely to report having some of their dead colonies die with an absence of dead beesthan were backyard and sideline beekeepers (χ^2 = 194, d.f. = 2, P < 0.001; Table 4). By multiplying the self reported proportion of colonies without dead bees by the number of colonies lost in operations reporting this condition we can therefore surmise that 42.1% of all colonies reported dead in this survey died with the "absence of dead bees" condition.

Table 5. Total loss experienced by different beekeeping operations groups classified by operation size and by self-identified leading cause or causes of mortality. *indicates total loss significantly different (Bonferroni-corrected P < 0.006) than total loss experienced by group; chi-square test.

Operation type	**Commercial**			**Sideline**			**Hobby**			**Total**		
No. Respondents	105			170			2,673			2,948		
No. Colonies	513,122			27,745			21,585			562,452		
Total Loss	33.5% (29.7-37.5)			45.0% (41.1-49.0)			49.9% (48.9-51.0)			34.7% (33.9-35.5)		
Factor	**Rank**	**% Resp**	**Total Loss**	**Rank**	**% Resp**	**Total Loss**	**Rank**	**% Resp**	**Total Loss**	**Rank**	**% Resp**	**Total Loss**
Starvation	5	18	18.3% (23.2-26.7) *	1	41	38.4% (32.5-44.6) *	1	31	44.5% (48.1-55.1) *	1	32	24.0% (22.7-25.4) *
Weather	7	7	43.6% (31.8-56.2) *	2	29	45.3% (37.6 49.6)	2	29	56.8% (55.1-58.5) *	2	29	45.1% (43.3-46.3) *
Weak in Fall	8	1	-	7	7	44.7% (27.9-62.8)	3	14	41.7% (39.1-42.3)	3	23	36.8% (29.4-49.6) *
Mites	2	22	40.1% (30.4-50.6) *	3	28	45.5% (32.8-52.8)	4	10	49.7% (46.5-53.0)	4	12	46.8% (38.2-43.4) *
Queen	1	35	27.2% (21.5-33.8) *	4	16	28.7% (20.9-38.4) *	5	9	35.7% (32.4-39.2) *	5	16	45.1% (43.8-46.3) *
CCD	4	20	36.4% (28.4-45.1) *	5	11	53.3% (44.7-61.6) *	6	3	65.6% (60.0-70.8) *	6	4	27.3% (25.2-29.5) *
Nosema	6	12	19.1% (12.1-28.7) *	5	11	45.1% (39.6-56.0)	6	3	45.0% (39.4-50.1)	6	4	37.5% (31.1-40.3) *
Pesticides	3	21	45.4% (37.7-53.7) *	8	4	59.7% (47.2-71.9) *	8	2	65.7% (58.5-73.2) *	8	3	45.6% (41.7-49.6) *

Table 6. Average losses reported by beekeepers who listed one or more factors as the leading cause of mortality in their beekeeping operation as compared to responding beekeepers not listing that particular cause as important.

	Responding			Not responding				
Factor	***N***	**Avg Loss % (95%CI)**		***n***	**Avg Loss % (95%CI)**		χ^2	**P**
Starvation	930	54.2 (52.4 – 56.1)		657	62.5 (60.2 - 69.8)		28.6	<0.0001
Weather	825	65.8 (63.9-67.7)		790	56.8 (54.6-59.0)		38.3	<0.0001
Weak in fall	385	54.0 (50.9-57.0)		961	60.0 (58.1-61.9)		11.8	0.0006
Mites	339	55.7 (52.6-58.9)		1000	59.9 (58.1-61.8)		4.48	0.034
Queen	274	45.1 (41.6-48.7)		1045	60.4 (58.6-62.2)		56.2	<0.0001
CCD	124	64.5 (59.7-69.3)		1097	58.8 (57.0-60.6)		4.19	0.1212
Nosema	113	51.6 (46.4-56.8)		1093	59.3 (57.5-61.1)		7.51	0.0061
Pesticides	79	62.9 (56.8 - 69.0)		1,120	59.0 (57.3 - 60.8)		1.27	0.2598

Acceptable losses

Surveyed beekeepers were asked "What percentage of loss, over this time period, would you consider acceptable?" On average, responding beekeepers (*n* = 3,979) reported that a winter loss of 14.5% (95% CI: 13.9-15.1%) was considered acceptable. Sixty-five percent of responding beekeepers experienced losses higher than that which they considered acceptable. The average losses experienced by this group were higher than the average loss experienced by those who had losses below that which they considered to be acceptable (61.6% (95% CI: 60.6–62.5%) *vs.* 6.9% (95% CI: 5.6-8.3%) respectively; χ^2 = 2,301, d.f.= 1, P < 0.0001).

Perceived causes of losses

Seventy percent of responding beekeepers answered the question "To what do you attribute the cause of death for the colonies that died?" Of these, 413 responded that they did not know. Beekeepers listed eight different potential causes of winter mortality most frequently (Table 5). The frequency with which these causes were listed by beekeepers differed between beekeeper groups when classified by operational size. For instance, 31% of all beekeepers listed "starvation" as a leading cause of mortality. While starvation was the most frequently listed self identified cause reported by backyard and sideline beekeepers, only 18% of responding commercial beekeepers mentioned starvation as an important cause, ranking it below poor queens, mites, CCD, and pesticides for this sub-group of beekeepers. Total losses suffered by beekeepers reporting starvation as an important factor were lower than the total loss suffered by responding beekeepers overall (Table 5). Pesticides were considered an important cause of mortality by only 3% of all responding beekeepers, but 21% of responding commercial beekeepers listed pesticides as an important cause, ranking it as the third most frequently mentioned cause by this group. The total losses experienced by those listing pesticides as a cause of mortality was higher than the overall total losses reported by all responding beekeepers and subgroups of beekeepers (Table 5). The average loss experienced by all those listing pesticides as an important cause of mortality was no different than the average loss experienced by beekeepers not reporting pesticides as an important cause (Table 6). While average losses were also similar between those reporting CCD as a principle cause of loss and those not reporting CCD, for all other factors differences were noted. Beekeepers listing starvation, weak colonies in the fall, mites, queens, and nosema as a principal cause of mortality lost, on average, fewer colonies than those not reporting the condition. Only those reporting weather as a major contributor to their winter losses had higher average losses than those that did not (Table 6).

Discussion

This survey records the fourth consecutive year of overwintering colony losses well above the level US beekeepers consider acceptable. Survey respondents reported total colony losses at 34.4% and average operational losses at 42%. Should these survey results be representative of national losses, between 829,020 and 863,460 of colonies were lost in the US over the winter of 2009-2010, but caution should be used when interpreting this projection. This survey cannot be considered random, and the email solicitation of beekeeper respondents probably biased participation to the subgroup of beekeepers that are internet literate. As no comprehensive census of US beekeepers exists, we have no way to quantify and adjust for this potential bias. For a second consecutive year, beekeepers that used at least part of their operation for almond pollination had significantly lower total losses than their non-almond pollinating counterparts (Table 3). Furthermore, this survey found that operations that managed colonies in more than one state had lower losses than those that did not. While we were unable to find relationships between the numbers of times colonies were moved the previous year and total or average colony losses, all told our data do not support the hypothesis that moving colonies causes increased mortality (Oldroyd, 2007). If transporting colonies does indeed have negative effects on colony health, these data suggests that these effects can be mitigated by beekeeper management.

While larger operations had lower total losses when compared to smaller sized operations (Table 2), larger operations were also more likely to report having some of the colonies in their operation die with colonies and apiaries absent of dead bees (Table 4). This symptom is one of the defining characteristics of CCD, and as in previous years, those losing some of their colonies to this condition experienced greater total losses than those not reporting the condition (Table 5).

Responding beekeepers most frequently self identified "manageable" conditions, such as starvation, poor weather, and weak in the fall, as the leading causes of mortality in their operations (Table 5), but there was a distinct difference in how beekeepers of different sized operations answered this question. Commercial beekeepers were much more likely to identify non-manageable conditions, such as poor queens and pesticides as leading causes of their losses. While *V. destructor* remained a concern for all beekeepers, it ranked as the second most frequently self-identified cause among commercial beekeepers, and total losses experienced by those identifying mites as a leading cause of mortality were elevated. These differences between groups suggest that extension efforts aimed at curbing high overwintering losses should not be uniform and should be tailored to specific apicultural subgroups.

In summary, this survey effort once again records high rates of mortality in overwintering colonies in the US. Losses suffered by smaller sized operations were higher than the losses suffered by larger operations, even though larger operations were more likely to report having some of their losses occur in the absence of dead bees in the colony or apiary, a defining symptom of CCD. While smaller operations were more likely to self-identify manageable conditions as the cause of mortality, larger operations were more likely to report non-manageable conditions such as queen failure and pesticides as the leading cause of mortality.

These results all point to the continuing need to describe colony losses on an annual basis. Concentrated efforts aimed at understanding the underlying causes of these losses are also needed.

Acknowledgements

We thank the individual bee inspectors for their assistance in conducting this survey. We thank all respondents, including those contacted by phone and e-mail for their participation. We thank Mike Andree, Karen Roccasecca, and Nathan Rice for compiling data and Karen Rennich for assistance in figure creation.

References

ABDI, H (2007) The Bonferonni and Šidák corrections for multiple comparisons. In N Salkind (Ed.) *Encyclopedia of Measurement and Statistics*. Thousand Oaks; Sage, CA, USA. pp. 103-107.

CARON, D M; BURGETT, M; RUCKER, R; THURMAN, W (2010) Honey bee colony mortality in the Pacific Northwest winter 2008/2009. *Americian Bee Journal* 150: 265-269.

CURRIE, R W; PERNAL, S F; GUZMÁN-NOVOA, D E (2010) Honey bee colony losses in Canada. *Journal of Apicultural Research* 49(1): 104-106. DOI: 10.3896/IBRA.1.49.1.18

DABERKOW, S; KORB, P; HOFF, F (2009) Structure of the US beekeeping industry: 1982-2002. *Journal of Economic Entomology* 103: 868-886. http://hdl.handle.net/10113/29783

FLOTTUM, K (2010) Inner cover. *Bee Culture* 138(6): 10.

MCCULLAGH, P; NELDER, J (1989) *Generalized Linear Models* (2 Ed.). Chapman and Hall / CRC. London

NEUMANN, P; CARRECK, N L (2010) Honey bee colony losses. *Journal of Apicultural Research* 49(1): 1-6. DOI: 10.3896/IBRA.1.49.1.01

NGUYEN, B K; MIGNON, J; LAGET, J; DE GRAAF, D C; JACOBS, F J; VANENGELSDORP, D; BROSTAUX, Y; SAEGERMAN, C; HAUBRUGE, E (2010) Honey bee colony losses in Belgium during the 2008-2009 winter. *Journal of Apicultural Research* 49(4): 333-339. DOI: 10.3896/IBRA.1.49.4.07

OLDROYD, B P (2007) What's killing American honey bees*? PLoS Biology* 5: e168. DOI:10.1371/journal.pbio.0050168

PAOLI, B; HAGGARD, L; SHAH, G; (2002) *Confidence intervals in public health.* Office of Public Health Assessment, Utah Department of Health, USA. 8 pp.

R DEVELOPMENT CORE TEAM. (2009) R: A language and environment for statistical computing. R Foundation for Statistical Computing; Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

SAS (2007) JMP computer program. Cary, NC, USA.

UNITED STATES DEPARTMENT OF AGRICULTURE NATIONAL STATISTICS SERVICE (USDA-NASS) (2009) *2007 Census of Agriculture.* Department of Agriculture; Washington, D.C., USA. 6 pp.

UNITED STATES DEPARTMENT OF AGRICULTURE NATIONAL STATISTICS SERVICE (USDA-NASS) (2010) *Honey*. Department of Agriculture; Washington, D.C., USA. 6 pp.

VANENGELSDORP, D; MEIXNER, M D (2010) A historical review of managed honey bee populations in Europe and the United States and the factors that may affect them. *Journal of Invertebrate Pathology* 103: S80-S95. DOI:10.1016/j.jip.2009.06.011

VANENGELSDORP, D; UNDERWOOD, R; CARON, D; HAYES, J Jr (2007) An estimate of managed colony losses in the winter of 2006-2007: a report commissioned by the Apiary Inspectors of America. *American Bee Journal* 147: 599-603.

VANENGELSDORP, D; HAYES, J Jr; UNDERWOOD, R M; PETTIS, J (2008) A survey of honey bee colony losses in the US, Fall 2007 to Spring 2008. *PLoS ONE* 3: e4071. DOI: 10.1371/journal.pone.0004071

VANENGELSDORP, D.; EVANS, J D; SAEGERMAN, C; MULLIN, C; HAUBRUGE, E; NGUYEN, B K; FRAZIER, M; FRAZIER, J ; COX-FOSTER, D; CHEN, Y; UNDERWOOD, R; TARPY, D R; PETTIS, J S (2009) Colony Collapse Disorder: A descriptive study. *PloS ONE* 4: e6481. DOI: 10.1371/journal.pone.0006481

VANENGELSDORP, D; HAYES, J Jr; UNDERWOOD, R M; PETTIS, J S (2010) A survey of honey bee colony losses in the United States, fall 2008 to spring 2009. *Journal of Apicultural Research* 49(1): 7-14. DOI: 10.3896/IBRA.1.49.1.03