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ORIGINAL RESEARCH ARTICLE

A survey of honey bee colony losses in the United States, fall 2008 to spring 2009

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Summary

This study records the third consecutive year of high winter losses in managed honey bee colonies in the USA. Over the winter of 2008-9 an estimated 29% of all US colonies died. Operations which pollinated Californian almond orchards over the survey period had lower average losses than those which did not. Beekeepers consider normal losses to be 17.6%, and 57.9% of all responding beekeepers suffered losses greater than that which they considered to be acceptable. The proportion of operations with the Colony Collapse Disorder (CCD) symptom of "no dead bees in the colony or apiary" decreased in this period as compared to the previous years. The proportion of colonies dying from apparently manageable conditions, however, such as starvation or a weak condition in the fall increased as compared to previous surveys.

Un estudio de las pérdidas de colonias de abeja melífera en los EE.UU, durante otoño del 2008 a la primavera del 2009

Resumen

Este estudio registra el tercer invierno consecutivo con altas pérdidas de colonias manejadas de abejas melíferas en los Estados Unidos. Se calcula que durante el invierno de 2008-2009, un 29% de todas las colonias de los Estados Unidos murieron. Las operaciones de polinización de campos de almendra durante el periodo de estudio tuvieron promedios más bajos en pérdidas que aquellos que no polinizaban almendras. Los apicultores consideran normal pérdidas de 17,6%, en este estudio el 57,9% de todos los apicultores encuestados sufrieron pérdidas superiores a lo que consideran normal. La proporción de operaciones potenciales que sufrían del Síndrome de despoblamiento de la colonia (CCD) disminuyó en este período con respecto a estudios previos, sin embargo, la proporción de colonias que mueren, aparentemente debido a condiciones de manejo - tales como falta de alimento, y a una condición débil en otoño aumentó con respecto a encuestas anteriores.

Keywords: honey bee, overwinter mortality, United States, Colony Collapse Disorder

Introduction

High rates of overwintering mortality in US honey bee colonies have been reported for the winters of 2006-7 and 2007-8 (vanEngelsdorp *et al.*, 2007; vanEngelsdorp *et al.*, 2008). These overwintering losses (32% and 36%, respectively) have not resulted in a pronounced decrease in the number of honey producing colonies managed by US beekeeping operations in the subsequent summers (USDA-NASS, 2009a; b). This apparent discrepancy is explained by beekeepers' ability to replace dead colonies by either purchasing package bees or splitting existing colonies. This practice does not come without cost, however, and the additional financial burden placed on beekeepers,

especially commercial beekeepers, will probably cause some to leave the industry (vanEngelsdorp and Meixner, 2009). The contraction in the number of beekeepers is not new. Since the 1980s, the number of large beekeeping operations has declined steadily, but those surviving operations tend to manage larger numbers of colonies (Darerkow *et al.*, 2010).

Honey bee colony losses are of concern not only to those operators who make their livelihood with honey bees, but also for those who rely on a movable honey bee force for pollination. Globally, the number of colonies available for pollination has been increasing steadily over the last 60 years, but this increase has not kept pace with the increased agricultural acreages planted with pollinator dependent crops (Aizen and Harder, 2009). Should this trend continue, a shortage of pollinators can be expected. This is especially true for the United States, where the number of managed honey bee colonies has decreased by 61% since 1947 (vanEngelsdorp and Meixner, 2009). Nowhere is the lack of potential pollinators more pronounced than in the almond groves of California, where by 2012, an estimated 2 million colonies (some 86% of current honey bee stocks) will be required for pollination (Sumner and Boriss, 2006). This estimate, however, is likely an over projection, as it could not have predicted the removal of mature almond orchards in the spring of 2009 due to severe water restrictions.

The underlying reason for high colony losses is not completely understood. In previous surveys, queen failure, starvation and *Varroa destructor* mites were identified as leading causes of winter mortality (vanEngelsdorp *et al.*, 2008). Another important contributor to mortality has been Colony Collapse Disorder (CCD). One of the key characteristics of this syndrome is that it leaves affected colonies and apiaries devoid of dead bees. Recent studies have implicated the presence of picorna-like viruses as the cause of death of these colonies (Johnson *et al.*, 2009; vanEngelsdorp *et al.*, 2009). A failure to identify a single organism in all affected colonies suggests, however, that some underlying factor may predispose colonies to infection (Cox -Foster and vanEngelsdorp; 2009; vanEngelsdorp *et al.*, 2009).

In keeping with previous years' efforts, this survey is an attempt to quantify the mortality of overwintered colonies in the US over the winter of 2008-9. It compares the rate of loss by operation size and activity, and also quantifies the suspected reasons for loss as reported by the surveyed beekeepers. There were three components to the survey: AIA; USDA; and e-mail which are explained below.

Materials and methods

AIA survey

All members of the Apiary Inspectors of America (AIA) were asked to survey beekeepers in their states between 30 March and 17 April 2009. They were asked to contact by telephone beekeepers that they felt were representative of their state's apiary industry, and to contact a minimum of 15 beekeepers: five part time (1-50 colonies); five sideline (51-499 colonies); and five commercial (500+ colonies) operations. They asked the following questions: 1. In what state(s) and county(s) do you keep your hives?; 2. How many hives did you have alive in September 2008?; 3. How many hives are alive now (March/April 2009)?; 4. How many splits, increases, and/or colonies did you make/buy since September 2008?; 5.What percentage of loss, over this time period, would you consider acceptable?; 6. What percentage of your hives that died had no dead bees in the hive or in the apiary?; 7. To what do you attribute the cause of death for the hives that died?; 8. What percentage of your hives did you send to CA for almond pollination?; and 9. How many times, on average, did you move your colonies last year?

USDA Survey

The United States Department of Agriculture (USDA) - Agricultural Research Service Beltsville Bee Research Laboratory conducted an identical survey by interviewing large commercial beekeepers operating across the continental Unites States.

Email survey

The same survey questions were sent by Email to BEE_L, an internet mailing list, and to all Pennsylvania state local association presidents (n = 13) who were requested to send the questionnaire to all beekeepers on their e-mail distribution lists. The letter asked beekeepers to respond to a dedicated Email account. The results of three surveys, AIA, USDA, and e-mail survey, are reported here. Submissions that appeared in more than one survey are only reported once.

Calculations

For the telephone survey, the results of eight beekeepers (who managed a total of 16,437 colonies in September) were removed because incomplete data prevented the calculation of winter losses. For the USDA survey, one respondent, managing 420 colonies in September 2008, did not give sufficient information to calculate losses, and was, therefore, removed from the dataset. Overall, only one of the 376 beekeepers contacted for the USDA and telephone surveys declined to participate in the survey. The surveys cannot be considered random, in that local and federal individuals selected beekeepers to contact. We recognize that this could introduce bias but the distribution between small, medium and large beekeeping operations was consistent with the pattern of US beekeeping and the sample size was large, covering beekeepers who manage approximately 20% of U.S. hives. This indicates to us that the results are robust and are likely to be indicative of US colony loss trends.

Total colony losses were calculated for each reporting operation, for the sum total of all respondents, and for various subgroup

classifications. The mean of individual operation losses was calculated to determine the average loss among subgroups. Point estimates of the 95% Confidence Intervals (CI) were also calculated (Koepsell and Weiss, 2003). In cases where the total number of respondents for a reported group was less than 60, a normal distribution was not assumed and a t-distribution (based on n-1) was used to calculate the 95% CI (Paoli *et al.*, 2002).

Comparisons of total losses between different groups of operations were conducted using the Chi Square test, while comparisons of average operational losses were made using the paired Student's t 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 operated 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

Total national losses

In the AIA survey, 16 state apiarist offices assisted in conducting the telephone survey in their respective states. In total, the AIA surveyed 358 beekeeping operations, representing a total of 227,677 managed colonies in September 2008. This represents approximately 9.9% of the 2.3 million honey producing colonies managed in the United States in 2008 (USDA-NASS, 2009a). The total loss reported over the surveyed period was 25.2% (95% CI: 20.6 - 29.7%) with an average loss of 32.7% (95% CI: 30.0-35.4%).

The USDA-ARS surveyed 25 additional operations representing a total of 242,982 colonies in September 2008, some 10.6% of the total colonies in the country. The total loss reported by those surveyed by the USDA was 24.1% (95% CI: 6.0-42.1%) with an average loss of 27.7% (95% CI: 22.3-33.1%).

Four hundred and four beekeepers responded to the Email survey. These beekeepers managed a total of 8,648 colonies. The total loss reported by this group was 56.9% (95% CI: 52.0-61.7%) with an average loss of 35.8% (95% CI: 32.5-39.3%).

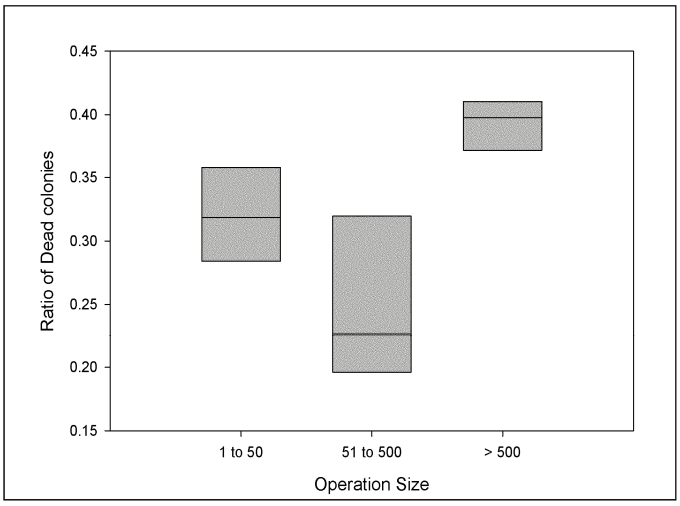

Fig. 1. Ratio of total loss experienced by all responding beekeepers grouped by operational size. Box plot represents upper and lower 95% CI around the mean.

The three datasets (AIA, USDA, and Email) were combined and included 778 operations. The total number of colonies managed by these beekeepers in September 2008 was 461,980 representing 20.1% of the estimated 2.3 million honey producing colonies in the US in the summer of 2008. The surveyed beekeepers reported that they had added a total of 160,616 new colonies to their operations between September 2008 and April 2009. In all, the total number of colonies living in early April 2009 was 444,594. This represents a total loss of 28.6% (95% CI: 25.4-31.8%) and an average loss across all operations of 34.2% (95% CI: 32.0-36.4%). Should these surveys be representative of the losses across all operations, this suggests that between 584,000 and 771,000 colonies died in the United States over the winter of 2008-9.

Losses by operation classification (size, multi state, and CA almond pollinators)

While commercial operations tended to have lower total and average losses, these losses were not significantly different from the losses reported by part time and sideline operations (Table 1; Fig. 1). Operations that managed bees in more than one state did not suffer appreciably greater losses than operations that managed bees in only one state (Table 2; Fig. 2). Commercial operations moved colonies more frequently (n = 100, 4.5±0.29 times) than sideline (n = 103, 1.8±0.21 times) and part time (n = 581, 0.2±0.02 times) operations,

Table 1. Average loss experienced by all responding beekeepers grouped by operation size.

Operation size	Number of respondents	Colonies managed in September 2008 plus increases	Average loss % (95% CI)
1 to 50	578	5,494	35.5 (32.7-38.2)
51 to 500	99	21,517	32.8 (28.2-37.3)
500 +	101	595,585	28.1 (24.6-31.7)

Table 2. Average loss experienced by all responding beekeepers who managed bees in one or more than one state.

More than one state	Number of respondents	Colonies managed in September 2008 plus increases	Average loss % (95% CI)
No	664	71,583	35.1 (32.8-37.4)
Yes	114	551,013	28.7 (23.1-34.7)

and sideline operations moved their colonies more frequently than part time operations (Student's t test $P < 0.0001$). There was a weak (Spearman $R^2 = 0.05$), but significant ($P = 0.039$) negative correlation between the frequency of hive movement and colony mortality. Operations that utilized some or all of their colonies for almond pollination in California had lower average losses than operations that were not used for almond pollination (Student's t test, $P = 0.002$; Table 3; Fig. 3).

Losses in operations reporting at least some CCD like symptoms

One of the symptoms of CCD is the complete absence of bees in dead colonies or apiaries. This survey did not allow differentiation between true cases of CCD and colonies that were lost due to other causes that share the "absence of dead bees" symptom. Only 26.2% of operations (n = 598) reported having colonies with this symptom. Although operations that experienced this symptom had elevated total losses (31.8%; 95% CI: 24.5-39.1%) as compared to losses in operations that did not report this symptom (26.8%; 95% CI: 22.6-30.9%), this difference was not statistically significant ($\chi^2 = 2.56$, $P = 0.10$). Commercial operations were 2.9 and 1.2 times more likely to report having some of their colonies die without the presence of dead bees when compared to part time and sideline beekeepers, respectively ($\chi^2 = 1592$, $P < 0.0001$; Table 4). When beekeepers reported having colonies with this symptom, they were asked what proportion of the colonies that died in their operation exhibited the symptom. In operations that answered this question, 60.3% of the 107,590 total dead colonies (Table 4) were devoid of bees. In all, this represents 36.4% of all colonies that died in operations participating in this survey.

Normal losses

Beekeepers were asked: "What percentage of loss, over this time period, would you consider acceptable?" On average, beekeepers felt that losing 17.6 % (95 % CI: 14.9-20.3 %; n=778) of their colonies would be acceptable. Operations that experienced losses higher than "acceptable" had an average loss of 51.6% (95% CI: 49.1-54.6%; n = 450). This was significantly higher than the losses in operations that had "acceptable" losses (mean = 10.0%; 95% CI: 8.2-11.8%; Student's t-test, $P < 0.0001$).

Perceived cause of loss

Respondents were asked to identify why they thought their colonies died. Two hundred and seven of the respondents did not answer this question. This group had distinctly lower average losses (4.4%; 95% CI: 1.0 – 7.7%) when compared to the 571 beekeepers who responded to this question (45.0%; 95% CI: 43.0 – 47.1%; Student's t test, $P < 0.0001$). The total loss also differed ($\chi^2 = 1663$, $P < 0.0001$), with operations not responding to the question reporting total losses

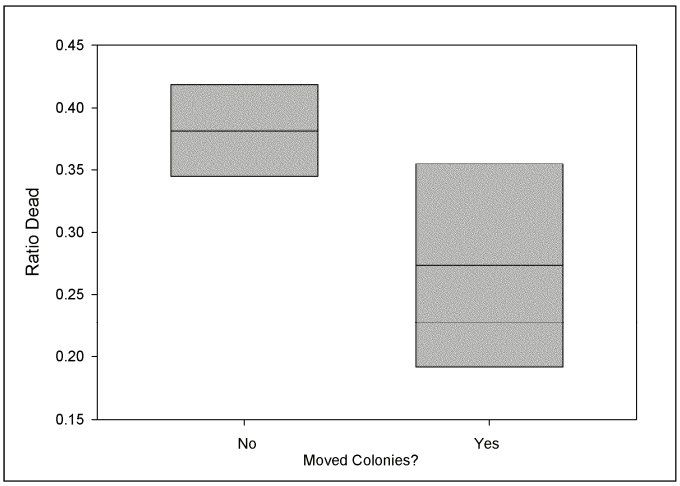

Fig. 2. Ratio of total loss experienced by all responding beekeepers grouped by operations who managed bees in more than one state. Box plot represents upper and lower 95% CI around the mean.

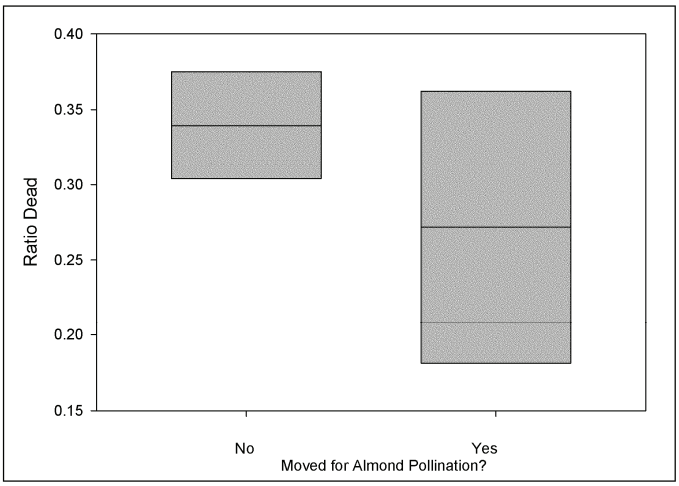

Fig. 3. Ratio of total loss experienced by all responding beekeepers grouped by operations that used or did not use some or all of their colonies for California almond pollination. Box plot represents upper and lower 95% CI around the mean.

Table 3. Average loss experienced by all responding beekeepers surveyed who moved or did not move some or all of their colonies into California almond groves for pollination. *Student's t-test; P = 0.0002

Moved to CA almonds	Number of respondents	Colonies managed in September 2008 plus increases	Average loss % (95 % CI)*
No	681	58,565	34.9 (32.6-37.4)
Yes	93	536,366	28.1 (24.2-32.0)

Table 4. The number of responding beekeepers reporting the presence of the CCD-like symptom "no dead bees in the dead colonies or apiaries" according to operation size and the proportion of dead colonies with this symptom.

Operation size	Number of respondents	% of respondents with some incidence of no dead bees	Number of colonies lost	% of colonies lost without dead bees
1 to 50	421	16.1	1,932	20.9
51 to 500	94	44.6	6,034	51.5
500 +	83	55.4	99,624	61.6
Total	**598**	**26.2**	**107,509**	**60.3**

Table 5. The nine most commonly reported suspected causes of colony loss in responding operations (n = 571).

Cause	Rank	% of operations reporting factor	Number of colonies managed	Total loss % (95% CI)
Starvation	1	41.5	37,002	26.9 (20.9-32.9)
Queens	2	22.8	207,584	27.1 (18.9-35.2)
Weather	3	17.9	9,608	39.0 (28.9 –49.1)
Mites	4	16.7	133,102	24.5 (15.2-33.8)
Weak in fall	5	12.4	5,428	51.8 (39.4-64.1)
Nosema	6	8.3	107,975	39.6 (14.4-41.5)
Management	7	8.3	68,930	39.6 (14.4-41.5)
CCD	8	6.5	42,630	34.5 (18.0-50.9)
Pesticides	9	4.1	35,672	40.7 (19.7-61.8)

of 13.4% (95% CI: 8.8 – 18.1%) and operations that responded reporting total losses of 29.0% (95% CI: 25.2 – 32.7%). This discrepancy is understandable considering that many (84%) of those that did not respond to the question had no losses at all and so could not assign a reason for their losses.

Of the operations that reported a reason for colony loss (n = 571), 69 (12%) said they did not know and 339 (59%) listed only one factor as being responsible for their losses. Those reporting more than one reason were counted multiple times. The top nine reasons given to explain colony loss were starvation, poor quality queens, weather, mites, colonies that were weak in the fall, *Nosema*, management, CCD, and pesticides (Table 5). Other factors that were mentioned, but were reported by fewer than 4% of respondents were mammals (including human vandalism, bears, and mice; 2.3%), viruses (2.1%), small hive beetles (1.9%), and nutrition (1.1%). All other factors, including disease, dwindle, and colonies knocked over by wind were reported by less than 1% of respondents.

The average operational loss experienced by operations reporting queen failure as the major reason for loss was lower than for those that did not (Table 6). However, operations that reported weather, CCD, and management as the principle reasons for their losses had higher average losses than those not reporting those factors (Table 6).

Losses by state

Considerable variability in total and average losses was reported from the various states (Table 7; Fig. 1). Only those states that had more than six respondents were included (disqualifying AL, AZ, CO, CT, DC, IL, IN, KY, MN, MT, NE, NH, NJ, NM, OR, RI, SC, VT, WV). In cases where bees were kept in more than one state, the losses were included in all states in which bees were kept. The number of beekeepers that were counted in more than one state and the total percentage of hives they managed in the respective states are presented (Table 7).

Table 6. Average loss in operations reporting and not reporting various factors as a major reason for colony mortality. Only those operations that responded to the appropriate question are represented.

Factor	Reporting factor		Not reporting factor		Student's t test
	n	Average loss % (95% CI)	n	Average loss % (95% CI)	
Starvation	210	46.8 (38.1-50.3)	361	44.0 (41.1-46.9)	
Queens	114	31.8 (26.8-36.9)	457	48.3 (45.7– 50.8)	P < 0.0001
Weather	89	59.8 (54.1 -65.5)	482	42.2 (39.8 – 44.7)	P < 0.0001
Mites	83	44.2 (38.1-50.3)	488	45.2 (42.7-47.7	
Weak in fall	63	46.4 (39.5-53.4	508	44.8 (42.4 – 47.3)	
Nosema	42	40.6 (32.1-49.1)	529	45.3 (43.0-47.7)	
Management	42	53.6 (45.1-62.2)	443	44.3(41.9-46.7)	P = 0.0281
CCD	32	57.0 (47.3-66.7)	539	44.3 (41.9-46.7)	P = 0.084
Pesticides	21	43.3 (31.3-55.4)	550	45.1 (42.7-47.1)	

Table 7. Total loss of colonies (%) over the winter of 2008-9 in states with six or more operations participating in the survey. Operations managing bees in more than one state are counted in each state in which they operate with the percentage of operations and colonies counted in multiple states is reported. *nd = not disclosed. When two or fewer operations operate in multiple states, the percent of total of colonies they manage is not disclosed to protect confidentiality.

State	All respondents			Operations reported in multiple states	
	Operations (N)	Number of colonies (September 2008 + increases)	Total loss (CI 95%)	N	% total col*
AR	29	7,940	22.4 (7.1 –37.4)	4	42
CA	106	538,417	27.4 (18.9 - 35.9)	88	98
FL	20	41,006	26.9. (7.4 – 46.3)	10	99
GA	44	9,192	18.2(6.9 – 29.7)	2	nd
IA	17	14,457	51.4 (27.2 – 75.2)	2	nd
ID	14	53,229	33.1 (8.5 – 57.8)	12	97
LA	10	86,681	41.8 (11.2 – 72.4)	5	69
MA	38	25,287	20.2 (7.4- 33.0)	1	nd
MD	15	6,134	13.5 (0-30.8)	3	79
ME	38	62,630	21.7 (8.6- 34.8)	3	99
MI	21	11,243	17.8 (1.4- 34.3)	3	79
MS	15	28,506	48.1(22.9-73.4)	4	95
NC	51	8,653	39.4 (26.0-52.8)	2	nd
ND	25	312,905	25.2 (8.3 – 42.3)	21	100
NY	28	42,550	24.1 (8.3 – 40.0)	7	83
OH	9	56	44.6 (12.1 – 77.1)	0	0
PA	256	13,359	40.5 (34.5 – 46.5)	7	52
RI	5	32	40.6 (34.5 – 46.6)	0	0
SD	27	241,966	27.0 (10.2 – 43.8)	22	100
TN	7	62	8.1(0 – 28.2)	0	0
TX	11	62,202	29.3 (2.4 – 56.2)	10	100
UT	27	22,526	36.4 (18.2-54.5)	12	99.6
VA	38	181	46.4 (30.6-62.3)	0	0
WA	8	49,708	20.4 (0-48.3)	3	99.9
WI	17	3,871	44.7 (21.0-68.3)	0	0

Discussion

Over the winter of 2008-9, and for the third consecutive year, managed honey bee colonies died at a rate well above what beekeepers consider normal or acceptable. The present survey substantiates the previous two winters' efforts which demonstrated that mortality was approximately equal among part time, sideline and commercial beekeeping operations (vanEngelsdorp *et al.*, 2007; vanEngelsdorp *et al.*, 2008).

Previous surveys did not identify a difference in the rate of mortality between operations utilizing or not utilizing their colonies for almond pollination. Operations that were moved between states had the same losses as those that remained in their home state. In addition, beekeepers pollinating almonds in CA in 2009 had fewer losses than those not pollinating almonds. These results suggest that moving colonies was not a significant factor in contributing to winter losses as is often cited as a possible underlying stress making bees more susceptible to disease in general and CCD specifically (Oldroyd, 2007). This is not to say that moving bees does not or cannot cause stress, especially when bees are moved many times in a year; rather it implies that the stress caused by moving (if any), is minimal or can be compensated for by beekeeper management.

A notable difference in the winter losses reported over the winter of 2008-9 and previous winters is the percentage of colonies that died with the CCD symptom "no dead bees in the colony." The total percentage of colonies that died with this symptom in the winter of 2007-8 was 60% as compared to 36% in the winter of 2008-9 (due to differences in survey reporting, data for the winter of 2006-7 are not available). Similarly, the percentage of operations reporting having colonies die with this symptom decreased in the winter of 2008-9 (26%) as compared to the winters of 2006-7 (36%) and 2007-8 (38%). Further, the total losses suffered by operations reporting the condition were lower in 2008-9 (32%) as compared to the previous two winters (45% and 41% for the winters 2006-7 and 2007-8, respectively). This suggests that both the incidence and severity of CCD has decreased over the last winter. This hypothesis is also supported by the responding beekeepers, who in 2007-8 ranked CCD as the 4th most important cause of mortality in their operations as compared to 2008-9 when the syndrome was consider the 8th most important cause of mortality (Table 5).

Despite the reduction in the incidence of CCD, the average (34%) and total losses (29%) reported over the winter of 2008-9 remain well above what is considered "acceptable" (17%; Question 5). Although beekeepers were asked a somewhat different question in the 2008-9 survey than in previous years, we can glean comparable information. For this survey, 58% of operations reported losses that were higher than what is considered acceptable. In previous years, 51 and 38% of operations in 2006-7 and 2007-8, respectively, reported that the losses they experienced were not "normal." The reason for this fluctuation is not immediately apparent. Some insight may, however, be gained by comparing the proportion of beekeepers suspecting certain factors as the leading cause of mortality and the total losses reported by those operations. The number of operations reporting "weather" (presumably poor weather) as a leading cause of winter mortality doubled between the winters of 2007-8 (9% of operations) and 2008-9 (18% of operations). The total loss experienced by these operations also nearly doubled from 20% in 2007-8 to 39% in 2008-9. While weather, in itself, is not a factor over which beekeepers have control, its adverse effects can be mitigated. Wrapping colonies over winter, providing supplemental feed, and ensuring adequate colony ventilation can improve winter survival in poor weather. Indeed, many of the factors ranked as the leading cause of mortality are closely linked to management; starvation was ranked either the leading or second leading cause of mortality in all three survey years, weakness in the fall was ranked as the 5th most important factor in 2008-9, and management itself was considered an important contributor to overwinter mortality by 8% of operations over the same winter. Understanding the root causes leading to poor management decisions would thus be an appropriate focus of future research and extension efforts.

In summary, this survey effort records a total loss of overwintering colonies of nearly 29% with average operational losses of 34% of colonies. This suggests that between 584,000 and 771,000 colonies were lost in the US over the winter of 2008-9. Losses in operations that pollinate almonds in California were lower than those in operations not pollinating almonds. While the proportion of colonies lost with the CCD symptoms of no dead bees in the colonies or apiary was lower when compared to previous years, the number of colonies lost to factors that can be mitigated by appropriate management practices seems to be increasing.

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