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Severe Honey Bee (*Apis mellifera*) Losses Correlate with Geomagnetic and Proton Disturbances in Earth's Atmosphere

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Abstract

Incoming and outgoing rates of honeybees (*Apis mellifera*) were monitored from an observation hive daily over three, six-month periods in 2012, 2013 and 2014. Sensors at the hive entrance measured differences between the numbers of outgoing versus returning bees on a per minute basis. Disturbances were also monitored in (A) Earth's magnetosphere and (B) proton flux intensity in Earth's outer atmosphere. Data indicated bee losses were highly correlated (R^2= 0.970) with days when severe geomagnetic storm activity (K-Index ≥5) occurred in Earth's magnetosphere, and monthly losses increased as the intensity of geomagnetic disturbances increased. Bee losses were also highly correlated (R^2=0.978) with intensity of extraterrestrial protons that impacted Earth's outer atmosphere. For the three-year study, estimated losses were 2.71-times greater on storm days compared to non-storm days. Greatest losses - from 16,920 to 56,640 bees - occurred during the 3 longest and most severe storms. Collectively, data indicated geomagnetic disturbances in Earth's atmosphere - produced by coronal eruptions on the Sun - are involved with the interference of a forager's homing ability here on Earth, thereby leading to their sudden disappearance from a hive.

Keywords: Colony collapse disorder; Honeybee losses; Magneto reception

Introduction

An unexpected, abrupt and severe disappearance of adult honeybees from a colony has been causing concern for beekeepers and entomologists for over a century [1-8]. Over time, the incident has been called Colony Collapse Disorder, Disappearance Disease, Evaporation, Dwindling Disease, Autumn Collapse and May Disease. What is most significant regarding the disorder is the absence of victims in or near the hive [1]. Remaining bees appear healthy and afflicted colonies can recover, indicating a contagion or pest is not involved [1].

A growing body of evidence indicates honey bees possess a magnetic sense and when interfered with, it causes changes in their orientation [9-12]. Prior evidence indicates that foragers' homing ability was interfered with when exposed to (A) induced static or (B) oscillating magnetic fields, or (C) natural disturbances occurring in Earth's geomagnetic field [9]. Bee losses were also found to increase as intensity of exposure to altered magnetic fields and release distances increased: the syndrome was identified as a magneto reception disorder (MRD) [9].

The present study quantifies and documents the loss of honey bees from a colony during naturally occurring atmospheric disturbances from 2012 to 2014. Measurements were obtained from three independent sources. (1) An observation hive located at the University of Wurzburg, Germany, which was used to monitor the number of incoming and outgoing bees on a daily basis. (2) Geomagnetic fluctuations in Earth's atmosphere were obtained from the Solar Weather Prediction Center (SWPC) and National Oceanographic and Atmospheric Administration (NOAA) observatory located at College, Alaska. (3) Proton flux activity was obtained from the SWPC/NOAA Geostationary Orbiting Environmental Satellite (GOES-13). Significantly higher than normal bee losses occurred during severe disturbances in Earth's geomagnetic field and as intensity of protons arriving at Earth's outer atmosphere increased. Both phenomena are caused by coronal eruptions on the Sun. The bee losses are consistent with the sudden loss of bees observed in the past 100 years by beekeepers and recently renamed Colony Collapse Disorder (CCD).

Materials and Methods

The experimental colony used in this study was located and maintained at the University of Wurzburg, Germany. Established in 2006, the hive body possesses sensors that monitor temperature, humidity, time, and both incoming and outgoing honeybees during daily bee activity (www.hobos.de). At the hive entrance, bees entered and departed through 20 parallel passages and they were counted on a per minute basis using infrared photoelectric detectors, which determined their walking direction (http://hobos.de/en/students/hobos-live/chart.html). Both "incoming" and "outgoing" bee flight data was compiled daily from April through September, during 2012, 2013 and 2014.

"Percent loss" values were based on the difference in the number of bees that left the hive and those that returned during daily peak flight activity. In some cases, bee "in-and-out" data was bimodal. Then, differences were summed for each peak (examples, April 18 & 22, 2012, Table 1). An "excessive" daily bee loss was considered to be those values in the upper 30-percentile range (9 days) of worst bee loss data for each month. Because bloom periods for different plant varieties vary with time and are not continuous, data for each month were examined separately. For example, during 30 days of April 2012

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there were 9 days - the 30 percentile with greatest bee loss values - when losses were equal to, or greater than 38.6% (Table 1). Next, for each day when those excessive losses were observed, the number of days from the nearest major geomagnetic storm or atmospheric proton disturbance were determined (0=same day as a storm, 1, 2, 3 or >3 days before or after the loss incident). On days when swarms left the hive, data was omitted from analyses. To estimate total daily bee losses, per minute incoming and outgoing rate differences were obtained at the beginning of each hour during the daily flight period (Figure 1) and then the total was multiplied by 60 minutes.

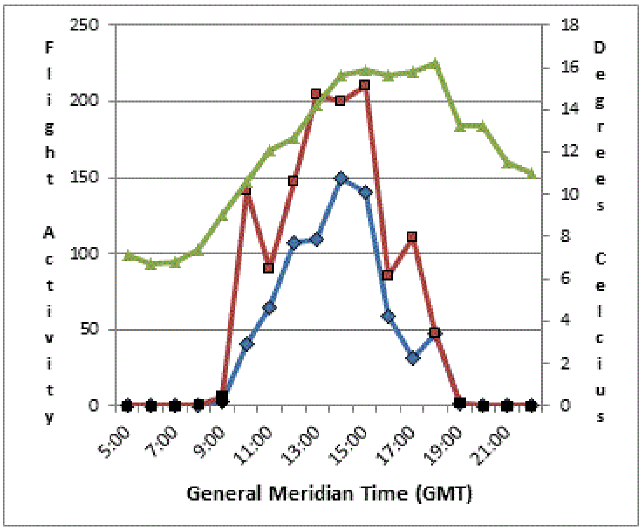

Figure 1: Daily bee flight activity from an observation hive. Outgoing bees are in red, incoming bees are in blue and temperature is in green. Each point (square or diamond) represents per minute flight activity at the beginning of the hour (9 hours total). Data is for 25 April, 2012.

The measurement used for Earth's geomagnetic disturbance activity was the K-index, a 0 to 9 scale, measured by the Solar Weather Prediction Center (SWPC) and the National Oceanographic and Atmospheric Agency (NOAA). Data used was recorded by the College Alaska observatory. (http://www.swpc.noaa.gov/ftpdir/indices/old_indices/). A major storm has been defined as a category "K=5" or greater (http:maar.us/geomagnetic_storm_scale.html). The geomagnetic fluctuation scale measures the intensity (nt) of the horizontal component in the magnetosphere's three-dimensional status. Protons entering Earth's atmosphere were those reported by the SWPC/NOAA and recorded by the Geostationary Orbiting Environmental Satellite (GOES-13). Daily values at intensities exceeding 1 MeV were evaluated. Again, those proton flux (per cm2) values in the upper 30 percentile for each month were analyzed (ftp://ftp.swpc.noaa.gpv/pub/indices/old_indices/). Then, those days which coincided with days when bee losses were excessive were determined (0=same day as a major proton storm, 1, 2 or 3 days before or after a storm).

Results

Presentation of daily honey bee loss data for April 2012 (Table 1) typifies monthly data accumulated from April thru September for 2012, 2013 and 2014 (total, 18 months). It was the month that the greatest bee losses were logged and they ranged from 38.6% to 55.4% (upper 30 percentile): i.e., during April 2012, there were 9 days when bee losses equaled or exceeded 38.6% of bees leaving the hive. For 2012, 2013 and 2014, the severest losses occurred most frequently (59.3%) within 24 hours of a major geomagnetic storm (Figure 2); thereafter, during the following 2 days, losses declined exponentially. The correlation coefficient was highly significant (R^2= 0.970) in the association of bee losses with days from a storm. The majority of serious bee losses (84.3%) occurred within 3 days of a major geomagnetic storm; from then on, they appeared random. Therefore, when differences in bee losses and geomagnetic storm dates exceeded 3 days (15.7%), the events were considered unrelated. Such cases were omitted from data analysis because there are incidents - other than atmospheric disturbances - that can cause severe bee losses (such as swarming, diseases, pests) [13].

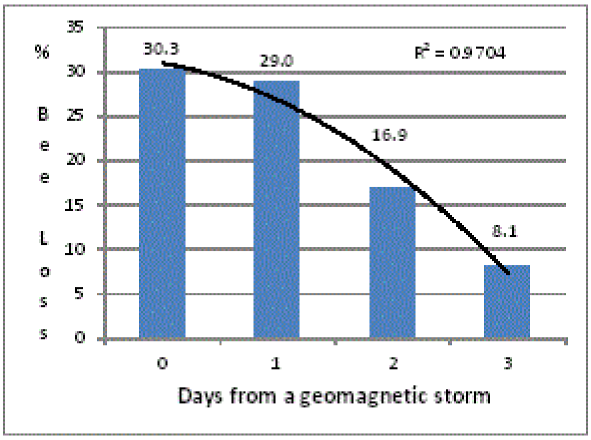

Figure 2: Days from a geomagnetic storm when greatest bee losses occurred. Data are the averages for 2012, 2013 and 2014. Severest daily losses were those in the upper 30 percentile for each month from April thru September. Data for bee losses that occurred more than 3 days after a storm (15.7 %) are not included.

Similarly, the greatest daily bee losses also occurred within 24 hours of a major proton storm (75.7%, Figure 3); thereafter, losses declined rapidly during the following 2 days (R^2=0.978). Again, thereafter losses appeared at random. Most of the bee losses (73.2%) occurred within 3 days of a major proton storm. Bee losses increased as monthly geomagnetic and proton storm intensities increased (Figures 4 and 5).

April 2012	Out	In	# Loss	% Loss	≥30 Percentile	Geomag. nT ≥ K=5	**Days	Proton ≥5 MeV	*** Days
1	80.9	60.9	-20.0	-24.7%				**12.0**	
2	141.4	93.4	-48.0	-33.9%		95		**9.5**	
3	86.9	61.5	-25.4	-29.2%				**6.5**	
4	52.3	23.3	-29.0	**-55.4%**	≥38.6%		1		1
5	115.6	95.1	-20.5	*-17.7%*		360			
6	19.0	10.2	-8.8	**-46.3%**	≥38.6%		1		1
7	77.1	43.9	-33.2	**-43.1%**	≥38.6%	255	0	**6.5**	0
8	37.9	34.1	-3.8	*-10.0%*					
9	44.9	28.3	-16.6	-37.0%				**5.0**	
10	159.2	116.0	-43.2	-27.1%					
11	51.5	48.3	-3.2	-6.2%				**14.0**	
12	134.6	82.7	-51.9	**-38.6%**	≥38.6%		1		1
13	196.3	132.8	-63.5	*-32.3%*		255			
14	186.1	144.2	-41.9	-22.5%					
15	143.6	70.1	-73.5	**-51.2%**	≥38.6%		2	**8.2**	0
16	152.3	118.2	-34.1	*-22.4%*				**6.8**	
17	206.4	118.5	-87.9	**-42.6%**	≥38.6%		>3		1
*18A	217.9	155.7	-62.2	-28.5%					
*18B	219.9	133.6	-86.3	-39.2%					
sum	437.8	289.3	-148.5	*-33.9%*					
19	229.5	143.6	-85.9	-37.4%					
20	211.3	116.1	-95.2	**-45.1%**	≥38.6%		3		>3
21	193.5	136.0	-57.5	*-29.7%*					
*22A	229.0	134.6	-94.4	-41.2%					
*22B	244.4	114.3	-130.1	-53.2%					
sum	473.4	248.9	-224.5	**-47.4%**	≥38.6%		1		3
23	222.1	160.0	-62.1	*-28.0%*		190			
24	310.4	153.0	-157.4	**-50.7%**	≥38.6%	160	0		1
25	208.5	155.9	-52.6	*-25.2%*		360		**7.0**	
26	224.1	150.5	-73.6	-32.8%					
27	260.9	194.6	-66.3	-25.4%					
28	212.3	187.5	-24.8	-11.7%					
29	198.5	178.9	-19.6	-9.9%					
30	208.9	167.8	-41.1	-19.7%				1.6	

Table 1: Daily bee losses for the month of April, 2012 * Indicates 2 peaks (A and B) of incoming and outgoing bees on that particular day (the 18th and 22nd). "Days" represents the number of days severe losses occurred from a geomagnetic (**) or proton (***) storm. Loss values in bold equaled or exceeded the upper 30-percentile rule. Only intensity values for major geomagnetic storms (K-index ≥ 5, total in nT) or proton storms (≥5.0 Me V) are included.

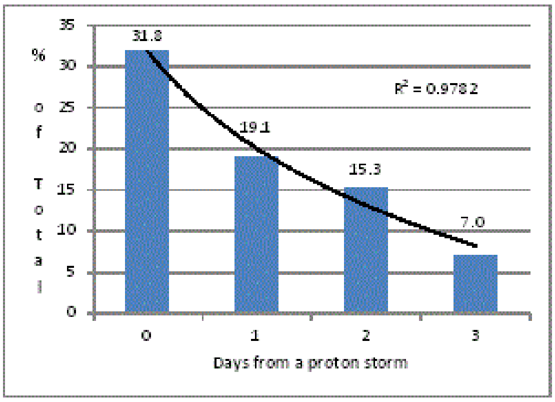

Figure 3: Days from a proton storm when greatest bee losses occurred. Data are the averages for 2012, 2013 and 2014. Severest daily losses were those in the upper 30 percentile for each month from April thru September. Data for bee losses that occurred more than 3 days after a storm (26.8 %) are not included.

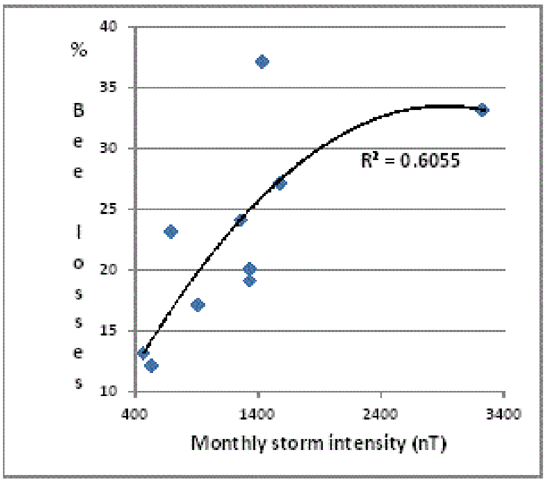

Figure 4: Monthly bee losses correlate with increasing geomagnetic storm intensity. Losses are the upper 30 percentile values for 2012, 2013 and 2014.

Throughout the three annual 6-month periods examined, upper 30-percentile bee losses were followed the next day with a decline in bee losses in the majority (79.2%) of all cases. (See % Loss values (italics) in Table 1, for example). Thereafter the loss pattern appeared random.

Total bee losses during "isolated" geomagnetic storms were compared with losses during similar non-storm periods (Table 2). Losses per minute were obtained at the beginning of each hour during daily flight periods, which ranged from 7 to 18 hours. To obtain a daily loss estimate, values were totaled and multiplied by 60 minutes. During storms, which ranged from 1 to 3 days, bee losses were 145 per minute versus a loss of 49 per minute on non-storm days – a 3-fold difference. Severest total losses were 56,640 during a 3-day storm versus 22,500 during three non-storm days (Table 2).

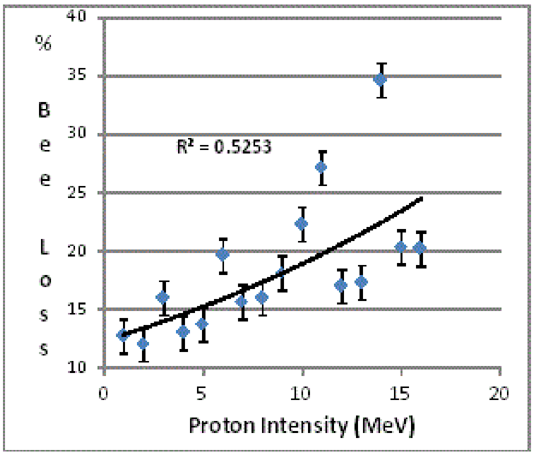

Figure 5: Excessive bee losses increase with increasing proton flux activity. Losses examined are those in the upper 30 percentile. Bars represent the standard error of the means.

Discussion

The experimental hive used in this study was maintained and monitored regularly by the staff at the University of Wurzburg, Germany, and despite extreme losses of bees (>30% of foraging bees) at times, it showed no disease or pest symptoms during this investigation. Moreover, at no time was there a presence of an excessive amount of dead bees in or around the hive. Such observations are consistent with past reports of the sudden "disappearance" of adult bees from a hive or apiary. Moreover, it is noteworthy that the storm-related acute loss of bees detected during two, three-day geomagnetic storms ranged from 25,560 to 56,640 and did not result in death of the colony. Nor did those losses produce an accumulation of dead bees in or near the hive. Moreover, diseases, pests, starvation or other environmental causes could not have produced the sudden bee losses. Furthermore, the hive was maintained in an urban environment; for that reason, agricultural pesticides could not have been a likely cause either.

Storm*Date	Duration Days	**Bee Loss/ Gain Total	Non-Storm Date	**Bee Loss/ Gain Total
4/23-25/2012	3	-56640	5/1-3/2012	-22500
4/24-26/2013	3	-25560	6/14-16/2013	-18240
4/12-13/2014	2	-16920	5/16-17/2014	-4080
6/8-9/2014	2	-2880	6/2-3/2014	180
6/20/2014	1	-3540	6/16/2014	-660
6/28/2014	1	1380	6/24/2014	3000
7/6/2013	1	-9300	7/3/2013	180
5/1/2013	1	-8220	4/18/2014	660
	Avg. >	-15210	Avg. >	-5182.5

Table 2: Comparison of total bee losses during 8 "isolated" geomagnetic storms vs losses on comparable non-storm days. *Only storm incidents that were more than 3 days from a prior or subsequent storm ("isolated") were evaluated. Bee departures and arrivals were first obtained on a per minute basis at the beginning of each hourly period during daily bee flight activity (Figure 1). **The daily loss or gain was estimated after the per minute values at the beginning of each hour of daily flight time were totaled and multiplied by 60 minutes.

For unknown reasons, not all excessive bee losses occurred on the exact same day that a geomagnetic storm was reported. This may be because geomagnetic fluctuations occur in three dimensions – north/south, east/west and "up/down" (vertical). Disturbance measurements used in this study involved only the east/west horizontal component. One possible cause for the daily variance is that the other two vectors of geomagnetic storms were also involved in disruption in honey bee guidance and resulted in their losses. For example, severe bee losses that occurred the day before a storm was detected in the east-west horizontal component could have been due to a disturbance in the north-south or vertical components. In addition, it is possible that other sub atomic components (or interactions between them) within a geomagnetic storm cause bees to become disoriented and lost. Besides protons, electrons and electromagnetic waves, there are numerous other atomic and subatomic particles that impact Earth (gamma rays, ultraviolet rays, X-rays, ionized atomic nuclei etc.). Proton flux intensity was used as a second indicator of a solar storm, and it too showed a strong correlation with daily bee losses. Furthermore, it is not known what effect space weather has on the time of arrival of the "active ingredient(s)" when travelling from the Sun to Earth.

It is noteworthy that in 78% of all excessive bee loss cases that occurred during the study period, losses consistently declined the following day (Table 1); thereafter, fluctuation in daily losses appeared random. One probable reason for this observation is that those foragers gathering pollen or nectar at long distances from their hive were most vulnerable to becoming disoriented and lost because they depended on their magneto reception sense for orientation, whereas those bees foraging sites closer to the hive suffered fewer losses because they relied on other senses for homing, such as visual [9,14]. It appears logical, therefore, that fewer adult foragers were involved with performing foraging duties the day following a storm-induced severe loss. Such an explanation is consistent with the observation that foragers harvest pollen from different sites, based on different colored pellets in their corbicula, as reported earlier [9]. A magneto receptive sense would be less important at short distances when visual or other cues would be functioning for orientation purposes.

Intense proton fluxes and severe magnetic disturbances are both associated with solar storms created by coronal eruptions on the Sun. As they impact Earth they disturb Earth's magnetosphere and produce excessive proton fluxes in its atmosphere. Based on statistically significant correlation coefficients, evidence obtained from the observation hive indicated that the severest of honey bee losses occurred on the same day that intense geomagnetic disturbances and proton fluxes occurred in Earth's atmosphere. Normally, statistical correlations would not relate to "cause and effect" relationships between two variables. However, that rule makes little sense in the present case because we are faced with an illogical consequence: (A) Do geomagnetic disturbances cause bees to get lost; or, (B) do lost bees cause Earth's geomagnetic disturbances? The answer is obvious: "A" causes "B" to occur. Furthermore, correlation of experimentally induced magnetic field fluctuations with impairment of a honey bees homing ability reported earlier [9] is consistent with a cause and effect relationship. Again, winter colony losses in the northeast USA also correlated with annual geomagnetic storm occurrences [9]. Finally, the serendipitous discovery that the angle of departure of the stingless bee Girucu (Schwarziana quadripunctata) from its earthen hive was altered significantly during a spontaneous geomagnetic storm is further evidence that a magneto receptive sense is involved with orientation [15]. Thus, research strongly supports the theory that a magneto receptive disorder (MRD) is involved with a sudden and extreme loss of honey bees from a hive.

The extreme bee losses that occurred during geomagnetic storms accounts for the sudden loss of adult bees from a hive that have been observed in the past and recently renamed "Colony Collapse Disorder" An accumulating body of evidence is consistent with coronal eruptions on the Sun as being involved with interference of a forager's magneto reception sense here on Earth. How abnormal magnetic fields and fluctuations relate to the epidemiology of honeybee losses is consistent with their behavior and development [9]. In conclusion, it is likely that the mysterious, severe bee losses recorded in the past 100 years or more were caused by disturbances in Earth's magnetosphere.

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