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Effect of the climate change on honey bee colonies in a temperate Mediterranean zone assessed through remote hive weight monitoring system in conjunction with exhaustive colonies assessment

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HIGHLIGHTS

- Climate change is an important risk for honey bee and the apiculture.
- Apiculture of precision is an advance for bee colony understanding.
- Dry weather and high temperatures generate important stress for bees.
- Climate change is a threat for beekeeping productions.

GRAPHICAL ABSTRACT

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ABSTRACT

Honey bee plays the leading role in the pollination of many wild plants and crops, but it currently faces serious threats. Climate change is pointed out as one of the causes of the colony collapse disorder. Understanding the response of bees to the new climate change scenario is essential to face this challenge. Especially in the most sensitive bioclimatic zones, such as the Mediterranean areas. In this work, we remotely monitored the weight of the hives with an electronic device during a flowering period in the beekeeping seasons of 2016 and 2017, marked by extreme episodes of drought and high temperatures. We assessed bee colonies at the beginning, middle and at the end of the flowering as well, considering the adult bee population, bee brood, and pollen and honey reserves. The results showed that the flowering was reduced in three weeks in 2017 in comparison to 2016. In those years weight gain was 7.67 kg and 18.92 kg, respectively. The adverse conditions affected the evolution of the populations of bees and the reserves of honey and pollen in a meaningful way, increasing food stress for bees. It also affected the pollen spectrum and commercial characteristics of honey. Our results provide objective data about the effect of climate change on bees, but it also proved the relevant role of bees in the study of changes in the environment.

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1. Introduction

The current climate change scenario generates a hard impact on the ecosystems and affects the viability of living organisms. Mediterranean bioclimatic areas are some of the zones that can be more affected in Europe, with a high risk of animals and plants being affected due to the exposition to extreme weather events, such as prolonged droughts or heat waves (Giorgi and Lionello, 2008; Amblar-Francés et al., 2017). At this juncture, the honey bee (*A. pismellifera* L.) plays a crucial role in the conservation of the environment, since it pollinates a myriad of wild plant species and a large number of crops which are vital for human beings (Potts et al., 2010). However, the honey bee is currently being affected by severe threats. In recent years the interest on bees has increased, mainly because of the high losses of bees suffering from the colony collapse disorder (CCD) and the severe repercussions that the reduction of bee populations can have on the environment and the own society (Klein et al., 2018). Climate change is remarkable for being one possible cause of the CCD (Gordo and Sanz, 2006; Le Conte and Navajas, 2008; Switanek et al., 2017). Beekeepers usually signal the effects of climate change on honey bees, but transforming these opinions into scientific data is crucial as it may be useful to understand what is happening to honey bees, by generating mathematical models and proposing corrective measures.

The main problem with the study of bee colonies is that they form a complex society, consisting of adult bees, brood, and reserves of honey and pollen. These elements hold a very close relationship (Hernando et al., 2018), constituting a macroorganism that inhabits at a closed space (Moritz and Southwick, 1992). Hence, the simple fact of opening the hive causes alterations, what should prevent researchers from opening them repeatedly.

In this sense, precision beekeeping becomes a handy tool for the study of bee colonies. For instance, the application of electronic systems and communication developments is becoming more and more frequent to reach this objective (Dunham, 1931; Woods, 1958; Kronenberg and Heller, 1982; Dietlein, 1985; Fahrenholz et al., 1989; Reynolds and Riley, 2002; Vornicu and Olah, 2004; Human et al., 2006; Ferrari et al., 2008; Atauri and Llorente, 2009; Meitalovs et al., 2009; Bencsik et al., 2011; Eskov and Toboev, 2011; Rice, 2013; Stalidzans and Berzonis, 2013; Zacepins and Karasha, 2013; Meikle and Holst, 2015; Murphy et al., 2015; Sánchez et al., 2015; Zacepins et al., 2015; Gil-Lebrero et al., 2017). The possibility of applying commercial electronic systems, known as data loggers, is the base of precision beekeeping. These devices are specifically designed for data acquisition in bee hives. Data collection can provide extensive knowledge about honey bee and its adaptations to climate change, giving answers to the new challenges of beekeeping at XXI century. They are also useful for evaluating changes in the environment. However, precision beekeeping is still at a developmental stage and further research is required aiming at designing specific tools and gadgets to be used in the hives. It must nonetheless go hand in hand with extensive knowledge about bee colonies and their management to contrast the information provided by monitoring devices with what happens in the bee hives. On the other hand, we can apply precision beekeeping for research purposes and routine beekeeping practices. Especially for professional beekeepers owning hundreds or thousands of hives, who can benefit from the information provided on hive status to schedule visits to the apiaries, which sometimes locate hundreds of kilometers away.

Hive weight is one of the most informative variables to keep track of the colonies through non-invasive methods of precision beekeeping. Weight is usually recorded during the hive assessment. Its fluctuations can provide interesting information on the colony evolution, since recording it is an easy method to evaluate the whole colony, including all the parts contributing to it, such as the building of new combs, adult bee population, brood, and honey and pollen stores (Meikle and Holst, 2015; Bayir and Albayrak, 2016; Zacepins et al., 2017; Smart et al., 2018). Usually, when we want to know the weight progress, the hives are manually weighed during the apiary visits. It is a laborious task, and often it is also difficult to obtain more detailed data sets. In a more advanced way, it is possible to use permanent scales connected to electronic devices. These devices can automatically weigh and store the information at a desired frequency and precision, and data can be loaded when visiting the apiary. In these previous cases, visiting the apiary becomes a limiting factor when it comes to access to the data. However, we can avoid it if we have permanent remote access to the information. These devices are not only in charge of remote monitoring of the bee hive, what allows developing descriptive methods, but it also provides predictive and warning systems that help to anticipate events and make decisions. Even, development artificial intelligence applications for notifying those events and suggesting any solution can be carried out.

In any case, we cannot forget that this information is incomplete if it is not accompanied by some exhaustive evaluations of the hives. Such evaluations allow us to confirm the information that we are guessing from the data that the electronic devices offer us.

The objective of this research is to provide information on possible effects on honey bees and beekeeping, related to variations in bioclimatic conditions. These conditions may be the result of climate change, in a temperate Mediterranean climate zone, where a large number of European professional beekeepers are concentrated (European Commission, 2016; Rossi, 2017). We used an electronic communication device to remotely monitor bee colonies activities, which also provides real-time access to the weight data of bee hives, in conjunction with exhaustive evaluations of the colonies at critical times. The work was developed over a period of flowering in an apiary during two consecutive beekeeping seasons: 2016 and 2017. Both years were dry, especially in 2017, registering successive records of the highest temperatures of the whole historical series recorded in Spain (AEMET, 2018). The results allowed us to provide contrasted information about the effects of extreme climatic events on bees, as well as to discuss advantages about the implementation of apiculture of precision.

2. Materials and methods

The essay was carried out during two consecutive beekeeping seasons: 2016 and 2017. We used the same apiary in both years, and it was located at the University of Córdoba (37° 55′33.5″N, 4° 43′26.1″ W). The area presents a Mediterranean Continental and Oceanic climatic zone, characterized by mild autumns and springs, not very cold winters and scorching summers. The rainfalls are distributed among autumn, winter and spring, although this is a very irregular characteristic since it may change every year. The rainfalls during the summer are very scarce or null (Capel-Molina, 1981).

The same flowering period, from May 2nd to the third week of July (July 18th in 2016 and July 17th in 2017), was evaluated. During the trial period, crop blooms, *Eucalyptus* and natural flowering overlapped. Each year the evolution of the weight of the hives was remotely monitored. Exhaustive evaluations of the bee colonies were carried out at the beginning, middle and end of the trial.

2.1. Application of the electronic system Wbee in honey bee colonies

The weight of the bee hives was remotely monitored with the Wbee system (Gil-Lebrero et al., 2017). The system bases on wireless communication through a three tier hierarchical model (see Fig. 1). The wireless nodes monitoring the bee hives and sending the data through protocol IEEE 802.15.4 are located at the lowest level. An industrial computer is placed (http://cdn.viaembedded.com/eol_products/docs/amos-3001/datasheet/VIA%2BAMOS-3001_datasheet_v150210.pdf) at the intermediate level, and it is in charge of controlling the wireless network of the whole apiary acting as the coordinator of the network. This computer also executes the applications which process the information sent by the nodes of each bee hive and stores them in a local database. The

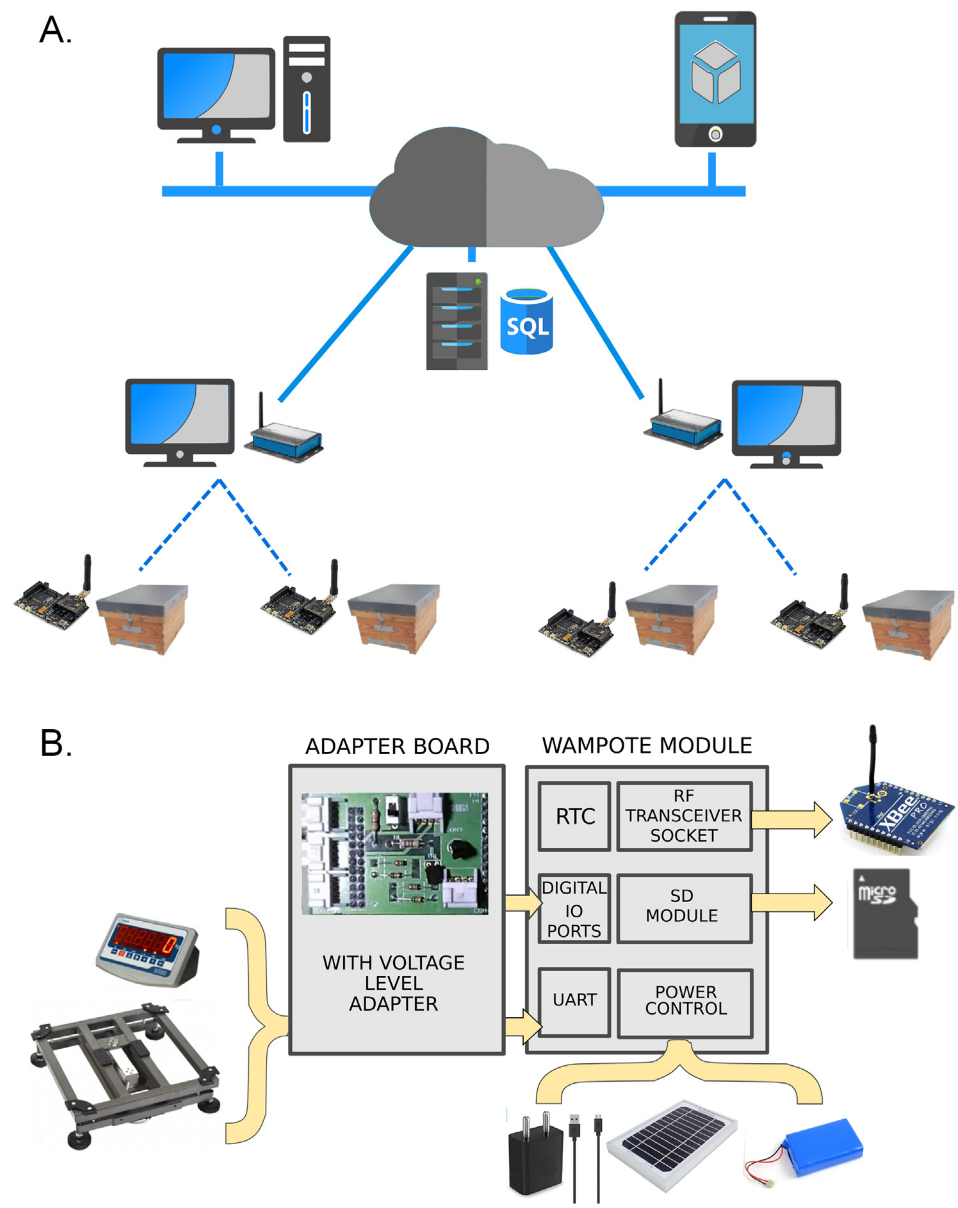

Fig. 1. Architecture of the monitoring system, structured in three levels: hive, apiary and cloud server (A). Block diagram of the wireless node that monitors each hive (B).

upper level contains the internet data server which groups all the information on the different apiaries.

The wireless node bases on the basic version of Waspmote® by Libelium (http://www.libelium.com/downloads/documentation/waspmote_datasheet.pdf). An adapting board inserted into the Waspmote® (see Fig. 1B) was designed for this purpose. The system consists of a Waspmote module with the Atmega1281 microcontroller (https://www.microchip.com/wwwproducts/en/ATmega1281), microSD card socket, real-time clock, a socket for different types of communication modules, a general purpose connector where the peripherals of the microcontroller are available and a power control block. The microSD card stores the data gathered if the node cannot connect to the network or if there are any communication problems. The RTC is used to insert a time-stamp in the collected samples and to wake the microcontroller as often as programmed. The data collection is carried out with a scale used as a base for the bee hives. The scale consists of a metallic frame (50 cm × 40 cm) with a 150 kg load cell associated, connected to a BR80 display by Baxtran.

[(https://www.comprabascula.com/documentos_ap/manuales/Manual%20BAXTRAN%20BR80%20-%20BR90.pdf) (accessed on 18 October 2016)]. The scale periodically sends the measurements through its series interface with a programmed resolution of 100 g. The Waspmote receives seven bytes through one of its series interfaces with the weight of the bee hive. An adapting board enables the adaptation of the voltage levels of the series interface of the scale to the levels of the Waspmote.

The nodes are connected to 5 V with a power supply connected to the main electricity network and have a battery to prevent the system from stopping in the case of a possible power failure.

The local computer, located in the apiary, executes two applications. On the one hand, a SCADA (Supervisory Control And Data Acquisition system) responsible for synchronizing, requesting, and processing the data of the node in each bee hive and on the other hand, MySQL, freeware software for the management of the database. The global server also executes MySQL and replicates the local database for each bee hive. This server ensures an extra security level and makes the data acquired in each bee hive available for the cloud.

The data acquisition from the bee hive took place on a periodic base using a user interface in the local computer which selects the sampling period of the data sent to all nodes located in the apiary. The wireless node stays in a stand-by mode and periodically wakes according to the previously established pattern to minimize power consumption. When it wakes up, the node waits for the local computer to send an acquisition request using a broadcast message to the whole network. Then, all nodes collect the weight data, achieving a synchronized acquisition from all bee hives. Then, all nodes send their collected data, together with their corresponding time-stamp. If the node does not receive any collection order after waking up, it collects the data after the set period and stores such data in the microSD card. In this way, we can ensure that the node collects data within the established periods of time in the event of communication failures or any other problem which may arise with the local computer.

2.2. Honey bee colonies

For this research native honey bees (*Apis mellifera iberiensis*, Engel) were used. Six colonies in 2016 and nine colonies in 2017. The bee colonies were housed in Langstroth hives placed on platforms raised 50 cm above ground level. The swarms, which were formed every year in early March, received a young queen free mated. The swarms were allowed to develop until later April. At the beginning of May, we exhaustively evaluated the colonies for the first time and placed bee hives on scales, what marked the beginning of the trial. From this moment on, the weight of the hives was remotely recorded every 15 min. The colonies were again exhaustively evaluated at the middle of each trial period and the end. During the trial, we maintained bee hives with the normal handling of a beekeeper. Super was added to the hives when needed. The weight of the empty super added to the hives was subtracted and not considered in the evolution of the weight.

We recorded the number of adult bees, the surface of bee brood, and the surface of pollen and honey stores during the exhaustive assessments of the colonies. To quantify the number of adult bees, we opened each colony, and all combs were sequentially removed and weighed with the adult bees on a digital scale (EKS. SWEET 8231 SW). Then, we placed the frames in a box compatible with Langstroth hive. When all combs had been removed, we estimated the number of adult bees remaining on the walls and bottom of the hive according to the Liebefeld method (Imdorf and Gerig, 2001). Next, we brushed adult bees from each frame into the hive, and the combs were weighed again without bees. A sample of bees was weighed (approximately 10 g of bees) and counted to obtain the average weight per bee. Finally, the total number of bees was calculated based on the total weight of the bees in the bee hive. We took a picture of both sides of each frame without bees (Nikon reflex camera D5100; 18/55VR lens). The photographs were later processed with an image analysis software (ImageJ®. Version1.51j8 software. W. Rasband, National Institutes of Health, USA) to determine the area in cm^2 occupied by bee brood, honey and pollen. The presence of the original queen was checked in each colony (Hernando et al., 2018).

2.3. Pollen analysis of honey

We collected a representative honey sample of all the apiary both years to determine its botanical origin. This melissopalinological analysis was carried out according to the methods established by The International Commission for Bee Botany (Erdtman, 1960; Louveaux et al., 1978). The pollen count was conducted using an optical microscope. For the determination of the botanical origin of the honey, we excluded the relative frequency of pollen from nectarless plants (Von-der-Oher et al., 2004).

2.4. Statistical analysis

We used SPSS software for Windows 17.0® to statistically process the results. For data analysis, non-Parametric statistics were applied. The tests are specified in the results.

3. Results

Both 2016 and 2017, were warm and very dry years in Spain, especially 2017, in which high temperatures reached the highest records in the historical series. Annual rainfalls were very low, with 2017 being the second driest year in the historical registry according to weather records (AEMET, 2018; Del Campo, 2018) (see Fig. 2).

The evolution of the weight of the hives and the environmental conditions showed a connection that led us to divide the trial into three well-defined periods: i) First period, considered as pre-flowering, beginning on May 2nd and ending when a gradual and continuous increasing of the hive weight was detected, which in both years extended until May16th. Adverse climatic conditions characterized by cloudy and rainy days and the lowest average temperatures during the essay were recorded during this period in both years as well, but these temperatures disappeared at the end of the period. The weight of the bee hives was maintained or even reduced during the pre-flowering period (see Fig. 3). ii) The second period, considered as flowering itself, began on May16th. During this stage rainfalls only were recorded on May 17th and 28th and June 28th in 2016, although they were very scarce (0.2, 4.0 and 0.2 l/m^2, respectively). In 2017, rainfall only was recorded on June 16th (0.7 l/m^2) (Weather Station of Córdoba. A network of Agro-Climatic Stations. Regional Council for the Agriculture and Fisheries of Andalucía, Spain. https://www.juntadeandalucia.es/agriculturaypesca/ifapa/ria/servlet/FrontController?action=Init). During all period, the temperatures where we developed the trials increased until they reached the highest temperatures of the summer in the area. This stage was characterized by the change of the climatic conditions and a continuous increasing of the daily average weight of the hives, which was maintained until July 11th in 2016 and June18th in 2017. iii) The third period, post-flowering, was set from the end of the previous one to the end of the trials, when colonies were exhaustively assessed for the last time (July 18th in 2016 and July 17th in 2017). The weather conditions were the usual ones in the area, with high temperatures and without precipitation in 2016 and only 7.3 l/m^2 on July 6th in 2017. During this stage, the bee hive weight did not increase, even slightly decreased, which might be probably related to the depletion of essential nectar sources for the bees. The average weight gained by the bee hives throughout the trial was 18.92 kg in 2016 and 7.67 kg in 2017. The variations of the hive weight of each period are shown in table1.

The colonies were exhaustively assessed every year for three times: at the beginning, middle and end of the trial, although the central evaluation did not exactly fall in the middle of the trial, due to the duration of flowering could not be predicted in advance. In 2016, the colonies began the trial with greater adult bee population and brood. However, their food stores (pollen and honey) were lower than in 2017. In both years, all the variables studied (adult bees, and the surface of brood, pollen and honey) had increased between the first and the second evaluation. Nonetheless, we only detected significant differences in the increase of stored honey between 2016 and 2017, showing a higher raise in 2017 (non-parametric statistic, Mann-Whitney U test, $p < 0.05$).

In contrast, between the second and third evaluations, there were important differences between the two beekeeping seasons. While in 2016 the adult bee population and pollen and honey stores continued increasing, these three variables decreased in 2017. We similarly reduced the brood area in both annuities. In this period, significant differences happened (Non-parametric statistic. Mann-Whitney U test, $p < 0.05$) between 2016 and 2017, both in the increase of the surface of stored honey and surface of stored pollen. The variations of both were positives in 2016 and negative in 2017 (see Table 2).

When we consider the differences in the status of the honey bee colonies between the beginning and the end of the trial, we recorded that all variables studied had a positive evolution in 2016, while in 2017 it was positive for the number of adult bees and surface of stored honey. In contrast, brood surface and bee bread (pollen) surface showed

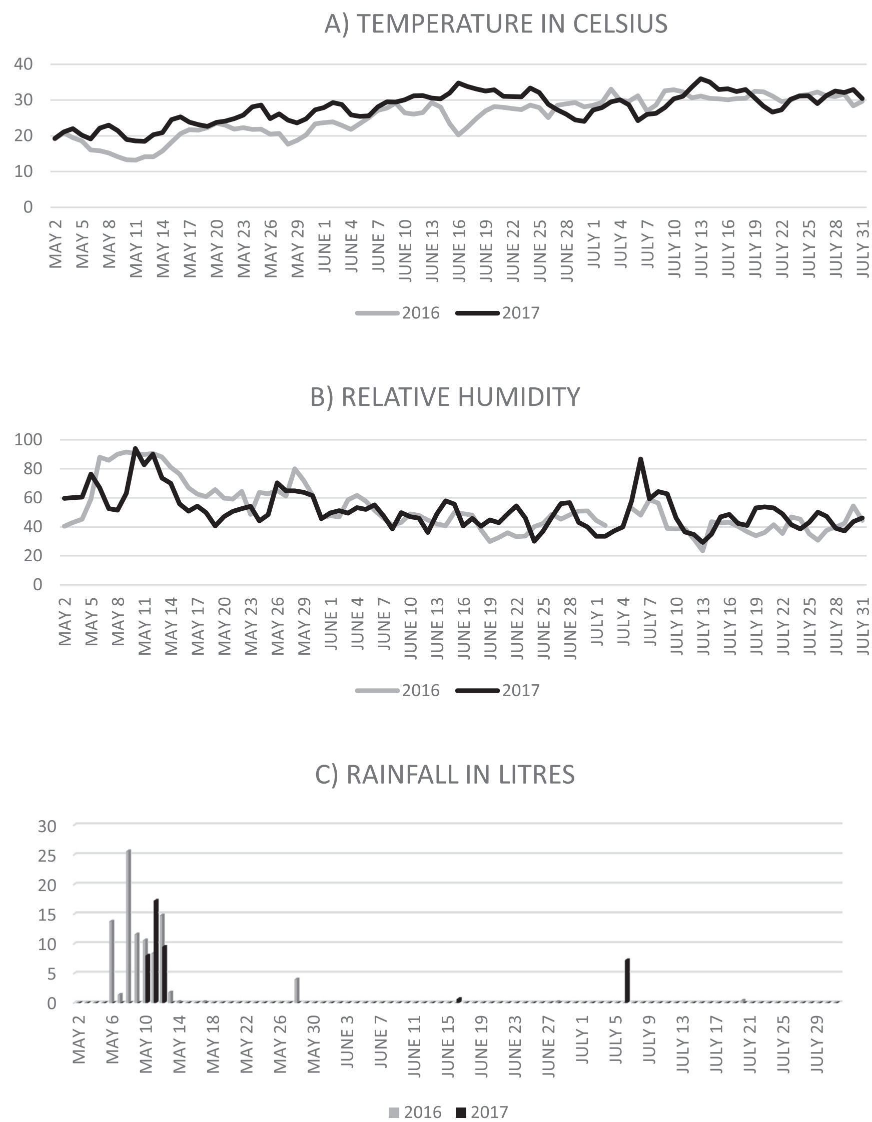

Fig. 2. Climatic information during essay period in 2016 and 2017: A) average temperature, B) average relative humidity and C) rainfall.

lower values at the end versus the begin of the trial, detecting significant differences in the latter two variables between the variations showed in 2016 and 2017 (Non-parametric statistics. Mann-Whitney *U* test, $p < 0.05$) (see Table 2).

Finally, the botanical origin of a representative honey sample from the same apiary was determined for each year. In both of them, *Eucalyptus* was the most predominant pollen type. However, while in 2016 its percentage was 81%, in 2017 was 66%. Furthermore, in 2017, the pollen

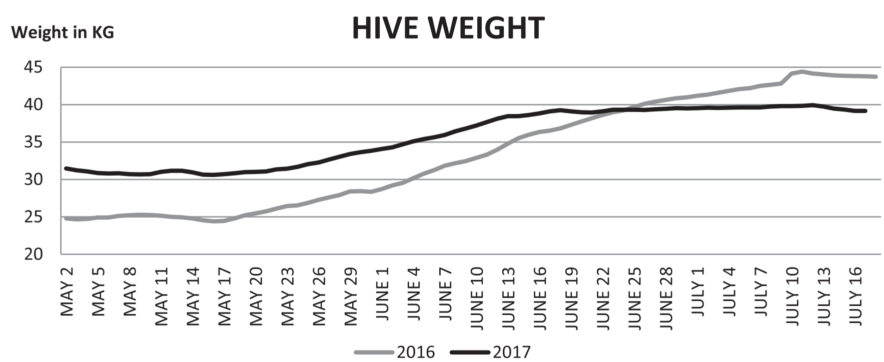

Fig. 3. Mean bee hive weight evolution in the whole of the colonies reported each year in Kg (six colonies in 2016 and nine colonies in 2017).

corresponding to accompanying pollen species of Boraginaceae and Rosaceae families increased considerably (see Table 3).

4. Discussion

The effects of climate change affect the development of ecosystems. Their implications impact both in natural areas and in humane environments, which affects to living organisms and the available natural resources. Climate change is also pointed out as one possible cause of the CCD in honey bee and as a source of the beekeeping products decreasing. Thus, it is crucial to establish these effects.

The understanding of the source of the honey bee loss is a vital aim for beekeepers and also for human being as a whole. Many teams of researchers are currently performing hard work to find out the causes. High technologies for chemical residue analysis, disease detection or molecular markers are used for this purpose. However, low technology is being applied to monitor the dynamics of bee populations or the internal conditions of the bee colonies and their adaptation to the changes in the environmental conditions.

In this research, we have used a network for monitoring honey bee hives coupled to a design of information transmission (Gil-Lebrero et al., 2017). This task has been carried out juncture with exhaustive in situ evaluations at specific times in which we obtained accurate information about the status of the bee colonies. We have focused on the extreme conditions that climate change is generating. This information is showed on a real situation in beekeeping, and in a flowering period within a zone with template Mediterranean climate, as considered one of the most sensitive areas to the effects of climate change (Giorgi and Lionello, 2008; Amblar-Francés et al., 2017), characterized by a growing climate irregularity in recent years. Being the honey bee monitoring also an interesting tool to evaluate the environmental changes (Gordo and Sanz, 2006).

The hive weight is one of the parameters usually considered in the study of the evolution of the bee colonies (Meikle et al., 2008 and 2018; Bayir and Albayrak, 2016). Advances in apiculture of precision provide a significant potential in the frequency and high accuracy for obtaining data, as well as in its transmission and its application on research tasks or in the everyday routines of beekeepers (Meikle and Holst, 2015). The remote connection allowed us to monitor the weight of the hives, providing valuable information: i) checking that the hives were growing, which confirmed that the bees were taking advantage of the flowering. ii) Recording when the flowering ended, and therefore the time to harvest the honey; iii) or duration of the flowering period. In our research, the results showed three defined periods: the first one was characterized by adverse weather conditions with low temperatures, cloudy and rainy days, in which the hive weight decreased, probably due to these environmental conditions affecting the blooms and provoking difficulties for the bees to leave the hives and harvesting enough food. Honey bees responded quickly to the change of conditions and just after the change of weather the bee hives gained weight throughout the flowering until the high temperatures and the lack of rainfalls caused the end of the blooms themselves (see Figs. 2 and 3). In this way, the use of apiculture of precision not only proved to be useful to know the evolution of the hive weight, but also it was an easy indirect method to find out what is happening with the vegetation, which could be applied in field studies related to climate change.

Throughout our study, we observed (Fig. 2) that in 2017 rainfall was very scarce, to which is added a lasting event of high average temperatures, above 30 °C, from June 10th, which probably accelerated the wilting of blooms, highly influenced by environmental conditions (Gordo and Sanz, 2010). This environmental situation was reflected on the bee hives as they stopped continuously gaining weight up to June 18th. From this moment, the weight remained the same or even decreased, all caused by the drastic reduction of food sources in the field (Fig. 3). In contrast, in 2016 rainfalls were more frequent and the event of high temperatures was later, the hives gained weight continuously until July 11th, which caused the average increase of weight in this year of 18.92 kg compared to 7.67 kg recorded in 2017 (Table 1). On the other hand, the reduction of the time during which bees have food sources in the field (nectar and pollen) means that the bees were less likely to harvest and increase the reserves, but also implies a lengthening of the later period of scarcity, until the arrival of the rainy season in fall. During this time, the colonies have to keep up with the stored reserves, already depleted, which implies an increase of stress due to lack of food, being able to cause the death of colonies due to starvation (Switanek et al., 2017) if the beekeeper is not paying any attention, and consequently increasing beekeeping costs.

The exhaustive evaluations of the bee hives reported data about the strong influence of the environmental conditions. In 2017 the colonies started with a lower adult bee population than in 2016. Instead, they showed higher reserves of honey and pollen. The population of adult bees grew in the period between the first and the second evaluation. Moreover, while in 2016 the growth of the bee population increased progressively between the second and the third evaluation, in 2017 it slightly declined. This finding is relevant as the colonies with lower adult bee populations are less likely to survive in unfavorable conditions, as it happens in summer time (Hernando et al., 2018). Regarding the brood, the evolution was the same in both annuities. This framework depicts a typical situation, due to the drastic reduction of nectar and pollen incoming to the bee hives provoked by the fall of the queen's laying, as an adaptation to environmental conditions (see Table 2).

Pollen is the primary source of protein for the bee colony and is essential for the feeding of the brood, as well as for the maintenance and the adult bees health (Brodschneider and Crailsheim, 2010). In our trial, in 2017 initial pollen reserves in bee hives were higher than those in 2016. During the period between the first and second assessments, pollen reserves increased slightly and similarly in both annuities. This finding could be explained as it was a period in which the colonies increased the brood and probably used most of the pollen collected. By contrast, every year was different from the second to the third evaluation. While in 2016, the colonies continued increasing pollen reserves, what we could ascribe to the longer duration of the flowering period, and to the reduction in the amount of bee brood, in 2017, pollen reserves fell. This decline could be attributed to the drastic shortening of the blooms, so that in this second year, although the bee colonies started with higher pollen reserves, the availability of these reserves for the unfavorable summer period were more reduced (see Table 2). The situation could have been worsened as the lack of new pollen forced the bees to use the older stored pollen, less attractive for bees and which has lost part of its nutritional properties (Maes et al., 2016; Carroll et al., 2017). We can also think of the accumulated residues in bee wax, mainly acaricides, that can be transferred to the stored pollen, so when the bees have to use the oldest pollen, residues may return to the circulation, becoming an added threat to the survival of bees (Bernal et al., 2010; Calatayud-Vernich et al., 2018).

Honey is the primary reserve of carbohydrates for the honey bee colony (Brodschneider and Crailsheim, 2010). As it happened with pollen, in 2017, the colonies began the trial with higher reserves of honey than in 2016. During the period between the first and the second evaluation, there was an increase of the surface of honey stored. This increase was higher in 2017, what indicated that a good supply of nectar was maintained during this period. However, the early end of blooms in 2017 anticipated the end of the accumulation of honey stores and the reduction of these reserves in contrast to what had happened in 2016, when reserves continued growing during the period between the second and the third evaluation.

When considering the pollen spectrum of analyzed honey, we observed that in both years, Eucalyptus pollen predominated. However, while in 2016 honey composition contained 81% of Eucalyptus pollen grains, in 2017 this percentage descended to 66%. Instead, the pollen from Boraginaceae and Rosaceae families increased, as they respond better to drought conditions. These findings highlight the critical

Table 1
Average weight evolution of the bee hives (six colonies at 2016 and nine at 2017) during the essay. We distinguish three periods, considering together the hive weight evolution and environmental conditions: Pre-flowering, characterized by cloudy and rainy days, and without increasing of the hive weight; Flowering, with good weather conditions and increasing of the hive weight and Post-flowering, with high temperatures, without flowering and with light decreasing of the hive weight.

2016				
Parameter	Evaluation			
	Begin of the essay. May/2/2016	End of the first period. May/16/2016 Pre-flowering	End of the second period. July/11/2016 Flowering	End of the third period. July/18/2016 Post-flowering
Hive weight in Kg (mean ± s.d.)	24.80 ± 25.55	24.41 ± 26.38	44.41 ± 95.03	43.72 ± 94.10
Weight changes in each period compared with the previous[a]	N/A	−0.39	+20.00	−0.69
Average weight gained during the essay.				+18.92

2017				
Parameter	Evaluation			
	Begin of the essay. May/2/2017	End of the first period. May/16/2017 Pre-flowering	End of the second period. June/18/2017 Flowering	End of the third period. July/17/2017 Post-flowering
Hive weight in Kg (mean ± s.d.)	31.48 ± 1.75	30.61 ± 2.04	39.27 ± 7.24	39.15 ± 8.07
Weight changes in each period compared with the previous[a]	N/A	−0.87	+8.66	−0.12
Average weight gained during the essay.				+7.67

N/A: No weight change can be computed as this is the initial stage of the study.
[a] + addresses a weight increase and – addresses a weight decrease.

consequences that climate change may have on beekeepers, as in 2016 the honey could have been marketed as Eucalyptus unifloral honey. By contrast, in 2017 this was not possible, as the percentage of Eucalyptus pollen grains did not reach the minimum number what forced to market that honey as multifloral honey, selling it at a lower price.

Moreover, while in 2016 pollen grains numbered 41,500, in 2017 showed a lower value of 38,760. The reason may be related to the reduction of nectar taken from Eucalyptus, the number of pollen grains decreased as well and, considering that this specie is considered as a great producer of both, nectar and pollen (Oddo and Piro, 2004), it had an impact on the amount of pollen present in honey.

When we considered all the variables: Hive weight evolution, the evolution of adult bee population, brood, and pollen and honey stores, we could verify the importance that the change in environmental conditions had on the welfare of bee colonies and beekeeping productions.

On the other hand, as in colder areas, such as northern Europe, particular interest is given to over-wintering, since winter is a particularly unfavorable period. In the temperate Mediterranean areas, summer is an especially unfavorable period for bees, so we must also consider the resilience of the colonies during this season, in what would be called over-summering. Climate change accentuates extreme events. The forecasts for the temperate Mediterranean areas are that droughts and heat

Table 2
Evolution of the variables recorded in the bee colonies in the periods between the exhaustive evaluations and throughout test period: i) Evaluation 1, in the begin of the essay in May/2nd in 2016 and 2017; ii) Evaluation 2, at the middle of each trial period in June/2nd at 2016 and June/13th at 2017 and iii) Evaluation 3, at the end of each trial period in June/18th at 2016 and June/17th at 2017. Variables were the number of adult bees, bee brood surface, surface of stored pollen (bee bread) and surface of honey stored. All surfaces are showed as cm^2. Data are reported like the mean of the bee colonies monitored of every year (six at 2016 and nine at 2017).

	Year	Parameters	Evaluation 1	Evaluation 2	Evaluation 3
Number of adult bees	2016	Mean ± s.d.	13535.7 ± 3590.7	16296.8 ± 8141.3	17216.5 ± 4137.3
		Variations between evaluations[a]	N/A	+2761.1	+919.7
		Variations throughout the test period[a]		+3680.8	
		Mean ± s.d.	9575.7 ± 3570.3	14123.5 ± 6141.2	14064.1 ± 4658.7
	2017	Variations between evaluations[a]	N/A	+ 4547.8	−59.4
		Variations throughout the test period[a]		+4488.4	
Surface of bee brood (cm^2)	2016	Mean ± s.d.	2659.3 ± 471.2	5380.3 ± 2257.5	3194.3 ± 846.6
		Variations between evaluations[a]	N/A	+2721.0	−2186.0
		Variations throughout the test period[a]		+535.0	
		Mean ± s.d.	2040.9 ± 1012.2	3897.3 ± 1763.0	1579.8 ± 970.5
	2017	Variations between evaluations[a]	N/A	+1856.6	−2317.7
		Variations throughout the test period[a]		−461.1	
Surface of pollen stored (cm^2)	2016	Mean ± s.d.	1006.8 ± 406.5	1141.0 ± 327.1	2688.8 ± 1074.6
		Variations between evaluations[a]	N/A	+134.2	+1547.8
		Variations throughout the test period[a]		+1682.0	
		Mean ± s.d.	1776.6 ± 1120.4	1947.3 ± 349.2	1540.6 ± 840.1
	2017	Variations between evaluations[a]	N/A	+170.7	−406.7
		Variations throughout the test period[a]		−236.0	
Surface of honey stored (cm^2)	2016	Mean ± s.d.	1566.0 ± 473.9	2470.0 ± 1432.3	5871.0 ± 1307.0
		Variations between evaluations[a]	N/A	+904.0	+3401.0
		Variations throughout the test period[a]		+4305.0	
		Mean ± s.d.	3559.5 ± 1129.1	7434.3 ± 1598.4	6951.7 ± 1952.6
	2017	Variations between evaluations[a]	N/A	+3875.8	−483.6
		Variations throughout the test period[a]		+3392.2	

N/A: No weight change can be computed as this is the initial stage of the study.
[a] + addresses a weight increase and – addresses a weight decrease.

Table 3
Melissopalinological analysis of a representative honey sample of all the apiary both years.

Year 2016						
Number of pollen grain/g of honey				41,500		
Number of honeydew elements/g of honey				96		
Honeydew index (Louveaux et al., 1978)				0.02		
Classification of pollen content (Maurizio, 1979)				III		
Pollen representation (Louveaux et al., 1978).		Predominant pollen (>45%)	Secondary pollen (16–45%)	Minor importance pollen (3–15%)	Minor pollen (1–3%)	Rare pollen (<1%)
Pollen spectrums and beekeeping importance [a]	Myrtaceae (N, P) *Eucalyptus* sp.	81				
	Cistaceae (P)			4		
	Boraginaceae (N, P)			4		
	Echium plantagineum *Borago officinalis*				1	
	Leguminosae (N, P)				3	
	Labiaceae (N)					0.9
	Rosaceae (N, P)			6		
	Fagaceae (P) *Quercus rotundifolia*					<0.1
	Pinaceae (P)					<0.1
Year 2017						
Number of pollen grain/g of honey				38,760		
Number of honeydew elements/g of honey				94		
Honeydew index (Louveaux et al., 1978)				0.02		
Classification of pollen content (Maurizio, 1979)				III		
Pollen representation (Louveaux et al., 1978).		Predominant pollen (>45%)	Secondary pollen (16–45%)	Minor importance pollen (3–15%)	Minor pollen (1–3%)	Rare pollen (<1%)
Pollen spectrums and beekeeping importance [a]	Myrtaceae (N, P) *Eucalyptus* sp.	66				
	Cistaceae (P)			5		
	Boraginaceae (N, P)			12		
	Echium plantagineum				3	
	Borago officinalis Leguminosae (N, P)				2	
	Labiaceae (N)					0.5
	Rosaceae (N, P)			11		
	Fagaceae (P) *Quercus rotundifolia*					0.3
	Pinaceae (P)					0.2

[a] Beekeeping importance. N–nectariferous; P-polliniferous (Louveaux et al., 1978).

waves are becoming more frequent and extreme, and it has become a reality.

Overall, we have been able to provide quality information, verifying that the climatic conditions reached in 2017 shortened the blooms, reducing the possibilities of store reserves by bees while generating a more extended summer period. Longer summers can significantly increase risks to the survival of bee colonies and an essential cause of the CCD that year. We have also been able to measure a possible impact on the production, both for the lower reserves of honey registered at the end of the essay in 2017 and for the lower price that the beekeeper could have obtained for the harvest, because of being unable to sell it as unifloral Eucalyptus honey.

On the other hand, the electronic device also offers opportunities for beekeepers, since they can know, without moving, the evolution of the harvest, predict the production and, what is more important, when the blooms have finished and which is necessary to extract the honey or remove the hives to avoid undesirable situations. Since at the end of a flowering the bee hives remain in the crop, in the same of our essay, without alternative blooms, the bees have to feed using the reserves, and if prolonged over time they can consume a significant part of the harvest, or even worse, to suffer from the risk of hunger.

In the same way, following the evolution of the weight of the hives, the beekeeper can also know if a flowering fails and the bees is cannot make the most of it, what provides the possibility to decide whether it is desirable to remove the hives and bring them to another flowering.

The same technological approaches can be applicable to other objectives, for example, when aiming at obtaining unifloral honey (that in which the origin of a floral species predominates). In these cases, it is necessary to harvest the honey immediately after the flowering, because otherwise, the bees can later collect nectar from other plant species, which may mix with the existing one and reduce the quality of the honey so as for this honey not to be considered as unifloral.

All these applications of precision beekeeping show that they are not only useful for research, but they can also be beneficial for professional beekeepers who often own a high number of apiaries, often located at a long distance. Therefore, lowering the costs of these technologies and promoting their use among beekeepers can help beekeeping to overcome the consequences of climate change and make it more competitive.

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