APPENDIX A – Proposal Content and Format

Problem Statement:

Problem:

Ever since Varroa mites were introduced to the Western world in 1987, they have been one of the biggest causes of decline in the commercial honeybee population according to the White House's Pollinator Health Task Force. If Varroa are not detected in time, this can lead to improper treatment and a continuation of the drastic decline in the honeybee population. This will cause there to be a decrease in the 90% of fruit, seed, and nut crops that they pollinate.

Significance:

What are the costs to society if the problem is not fixed?
If we neglect the problem of Varroa mites hurting the honeybee population, we are hindering our own growth. Seeing that honey bees alone pollinate one-third of all the food we eat (Colony Collapse Disorder and the Neonicotinoids Ban, 2013), if these trends continue, the world food supply will decrease. As a result, people will have less variety in their diet and food prices will increase.(Gilbert, 2016).

What are the possible causes of the problem?
Currently, the amount of crops dependent on honeybee pollination (Aizen & Harder, 2009) and the demand for these pollinators (Tirado, Simon & Johnston, 2013) are increasing at a faster rate than the honeybee population itself. There are many reasons the honeybee population is not able to continue to grow, but the biggest reason is the Varroa mite. This mite transmits many diseases to beehives, and the mite itself is difficult to kill without harsh chemicals. In addition, it is difficult to detect Varroa mites before it is too late.

How would society be improved if this problem was better addressed?
Finding a reliable method of detection of Varroa mites in commercial colonies would help to improve treatments. Usually beekeepers treat their hives assuming that Varroa is already present in the hive, leading to overtreatment (Hunt, 2010). By improving detection methods, more accurate doses of chemicals could be applied to the hive, and more bees would survive. (Tirado, Simon & Johnston, 2013). Beekeepers would also be able to pinpoint ideal treatment windows based on Varroa mite population growth and treat at optimal times. This would lead to an increase in the honeybee population, therefore helping society as a whole.

Stakeholders:

When investigating how we might assist commercial beekeepers in detecting and measuring Varroa mite infestations, there are many stakeholders whose perspectives should be explored.

The primary perspective to be investigated is that of the commercial beekeepers. It is clear that they stand to benefit the most after honeybees themselves. If the method of detection is streamlined, better treatment can be pursued therefore decreasing the number of honeybee losses. Then, the beekeepers could increase the number of hives that they currently manage. At the moment we discovered that beekeepers tend not to count mites in their hives, and just assume that all hives have Varroa at levels high enough to justify constant treatment. This is more beneficial for them not to check each hive individually because any task replicated on thousands of hives is very labor and time intensive. Furthermore, these treatments only target adult mites.

The first expert that confirmed those observations was General Jay Hendrix, a sideline University of Georgia Master Beekeeper who wants to help the honeybees return to a healthy stability in our environment. He mentioned that Colony Collapse Disorder used to be the highest concern, and that now it has shifted more towards Varroa mites because of their ability to transmit harmful diseases like the Black Queen Cell and Deformed Wing Virus. Hendrix reiterated that most beekeepers do not need to detect Varroa to know that it is in their colony, so they treat it anyway. Since Varroa is assumed to be present in nearly any beehive, beekeepers do not view accurately determining what the Varroa count is in their hives as a justifiable use of their resources. He added that if a hive is not treated in this fashion, it will tend to die in about 2 years. In addition, General Jay Hendrix added some valuable insights into our problem space that bolster the importance of determining a solution for our How Might We statement. Firstly, commercial honeybees are more susceptible to Varroa mites than feral bees because they live in closer vicinities to each other. Varroa mites tend to prefer invading the brood cells of beehives and reproducing there due to the larger incubation time. Additionally, though chemicals may be effective in killing Varroa now, mites may soon develop resistance to them. This has already occurred with treatments like coumaphos, fluvalinate, and thymol.

As a team we also consulted Cybil Preston, the Chief Apiary Inspector for the Maryland Department of Agriculture. She echoed a lot of what Jay Hendrix said, but added her own notes as well. Cybil stated that beekeepers are moving away from more “hands-on” mite treatments, and are looking for processes that are less time and labor intensive. This informed the reasoning behind our solution to develop an efficient method of detection to lead to more effective treatment processes. We also were surprised to find out that beekeepers are supposed to do monthly mite counts to inform their treatment methods, and often use devices such as bottom boards and mite shakers.

The second key perspective that must be investigated is that of farmers in the commercial agriculture business. Commercial beekeepers get paid to pollinate their crops all across america. If the amount of varroa mites in commercial bee colonies is decreased due to better detection, and subsequently better treatment, the number of commercial hives can increase as mentioned earlier. This will allow there to be more bees readily available for pollination and increase the crop yield in commercial agriculture. This will have a very beneficial effect on agriculture because as we found in our research, “commercial beekeeping adds between $15 and $20 billion in economic value to agriculture each year… Many high-value crops such as almonds and broccoli are entirely reliant on pollination services by commercial beekeepers.” Also, agriculture

and agriculture-related industries contributed $985 billion to the U.S. GDP in 2014. The overall problem that our solution could address in this problem area is the fact that the amount of crops dependent on honeybee pollination is increasing at a faster rate than the honeybee population itself. The honeybee population needs to stabilize and increase in order to mitigate this problem. This could be accomplished by first improving detection.

Looking at both of the aforementioned perspectives, if detection is improved it can lead to a better treatment and a larger honeybee population. This will lead to a greater revenue and better job security for commercial beekeepers and farmers in commercial agriculture, making them more likely to stay in and be proponents of their business.

The third integral perspective would be the everyday consumer. If the problem of detecting Varroa mites is not properly addressed, certain crops will be nearly eradicated because they will not be pollinated by bees, although a smaller percentage of pollination is conducted by other organisms and the wind. This drop in supply will cause prices to increase, potentially having a detrimental effect on food security. Dr. Stavros, a math professor and hobby beekeeper that we interviewed highlighted the importance of commercial bees moving around to pollinate crops. He also mentioned that as awareness increases in the United States about the honeybee population decline, beekeeping in the U.S. will most likely be on the rise as people do not want there to be a decrease in the 90% of fruit, seed, and nut crops that they pollinate.

Finally, one of the most important perspectives that has not been voiced as thoroughly is that of the honeybee itself. When a hive is overtreated, the honey and wax is altered negatively by the chemicals. Many times, also, honeybees can enter a foreign hive and contract Varroa mites there if they did not currently exist. This weakens colony health, but is not usually discovered until it is too late, because honeybee population health is only currently measured in a national voluntary survey that does not have perfect participation. Additionally, mite counts are not being used as a way to report apiary health. It is important to recognize that Varroa mites exploded in the Western honeybee population, but not the East, because they are resistant. This is why we should focus on the Western Honeybees in our problem area.

Context and Existing Solutions:

Many beekeepers have already attempted solutions to this problem of detection, but have not been very successful. Some decide to switch out the bottom boards of the hive for screen boards. This causes the mites on the adult bees to drop to the ground on a sticky board. This allows the beekeeper to count the amount of Varroa mites supposedly in the hive after 2 days.

Another method of detection that is employed is the drone brood removal. This is when an artificial frame of drone cells is inserted into the hive for the drone brood to develop, knowing that the Varroa mites will be attracted to these cells. When the pupae are developed, the entire frame is removed, freezed, and the mites inside of the cell are counted by destroying the pupae.

Varroa mites are, in fact, large enough to observe with the naked eye. Our team was fortunate enough to observe this ourselves on top of the Clough Undergraduate Learning Commons while observing the beehives of the Dr. Leavey's Urban Honeybee Project. Some beekeepers take advantage of Varroa mites' visibility and use the sugar roll test, alcohol wash test, or ether roll test. These processes consist of removing a bee sample from a hive in a jar or container of sorts and shaking approximately 300 bees around. If at least 15 are found, the whole hive is treated. However, this disturbs the colony and can only be conducted limited times.

As one can see, these existing methods are simplistic, not highly accurate, and are usually only detecting the Varroa mites on adult Varroa.

Why is this still a problem?:

The issue of Varroa mites can be broken down into two problem segments: detection and treatment. Both are incredibly hard issues to tackle. According to many beekeepers with whom we spoke, the count of Varroa in any beehive is always assumed to be high enough to warrant treatment. Beekeepers treat for Varroa anywhere from one to four times a year as a result. Nearly all solutions focused on controlling Varroa mite populations are focused on treatment using harsh chemicals like oxalic acid, formic acid, and thymol. These chemicals are effective in killing large numbers of Varroa at a time, but large doses of these chemicals can cause a buildup in hive wax, thus harming bees and the honey they produce. Because these treatment based solutions are effective in killing Varroa, many beekeepers have not chosen to look for a better alternative. Furthermore, most solutions that exist to detect/count Varroa in hives are very simplistic and not highly accurate. An example would be placing a grid-style board at the bottom of the hive and counting the number of adult Varroa that land on it. This only accounts for adult Varroa near the end of their life cycle, and does not consider the Varroa that are reproducing and developing alongside honeybee larvae and pupae in the brood cells of the hive. By the time the presence of Varroa is detected, the only course of action is to use high doses of these harsh chemicals.

Ideally, if Varroa were detected in their early stages of reproduction, smaller doses of existing treatments would be the best solution to manage Varroa. The biggest challenge for us will be finding a more accurate detection method that is cost effective. The detection method must be cheaper than current methods beekeepers use to deal with the issue of Varroa currently.

Proposed Work:

Goal:

Our team's solution-goal is to investigate and discover the most reliable method to detect Varroa mites in a honeybee hive in order to accurately inform beekeepers about the immediate health of their hives and therefore provide treatment assistance to combat Varroa mite infestations.

Because many treatment already exist to prevent Varroa mites and preserve the health of hives, the focal point of our problem space is around the detection of Varroa mites. With a method detection, not only will beekeepers better understand how they should treat their hives, but also treatment methods will be directly verifiable to deduce which treatment methods are most successful and at which times. Aspiring to provide accurate and continuous beehive information through a low-maintenance, cost-effective device, our team's ultimate endeavor is to establish a safe, growing, and healthy American honeybee population now and for the future.

Objectives:

1) *To accurately count the Varroa mites in a honeybee hive with less than a 5% margin of error.*
2) *To develop an automatic, low-maintenance, and cost-effective treatment plan for beekeepers.*

- *Background:*
    - *Objective 1:*
    - This objective is important because by having an accurate and precise count of how many mites are present in a beehive, beekeepers can utilize the proper amount of treatment. Currently, excess chemicals damage the hive by building up in the hive wax and seeping into the honey in the hive (Honeybee Parasites, Hive Pests, and Diseases, 2017). Not enough chemicals leaves excess Varroa in the hive, and this is problematic for obvious reasons.
    - If accurate detection methods are not developed, beekeepers will continue to treat for Varroa haphazardly. As long as a beekeeper cannot gauge exactly how much Varroa is present in a hive, Varroa cannot be eradicated from the hive completely. Furthermore, conditions of the hive will continue to deteriorate until the colony eventually collapses. Elevated populations of Varroa mites are known to damage colonies and may play a role in colony collapse (vanEngelsdorp et al., 2009) If beekeepers know exactly how much Varroa is present in a hive, they can decide exactly when to treat and how much to treat.
    - *Objective 2:*
    - As some experts mentioned, there is currently no centralized and reliable

method of measuring honeybee hive health in large commercial colonies. This is because oftentimes treatment itself is so time consuming and labor intensive that beekeepers are not willing to expend more time on detection and precise measurements. An automated detection device would make it easier to record this information and know the exact health of the hive, using factors like Varroa mite count as well.

- Through the invention of an automatic, low-maintenance, and cost-effective detection plan, beekeepers will be able to more effectively and efficiently observe the health of their hives. As previously noted with conversations with Cybil Preston, nearly all Western hives contain Varroa mites, signifying that beekeepers already understand that mites exist in their hives. The problem is that no effective solution exists to detect the intensity of mite infestation in hives. This is concerning because Varroa mites are one of the main causes of colony collapse. If this device is not made in time, the Varroa mite population could become uncontrollable due to lack of knowledge and chemical resistance, and the honeybee population would decrease drastically.

- *Methods:*
  - *Objective 1:*
  - In order to count the number of mites inside a hive, first we need to determine a way to detect mites. We are currently looking at three different technologies: acoustic measuring devices, thermal/infrared imaging or sensing, and ultrasound imaging. The viability of each of these technologies will have to be tested to see if they can be utilized.
  - For acoustic detection we would need to see if a noticeable frequency produced by the bees could be correlated with mite infestation and or mite levels. This method relies on interpreting communication among the bees, and researchers in Australia have had success with some research into this solution space (Qandour et al., 2014) If a correlation could be determined this may be a viable option.
  - For infrared imaging we need to determine if adult or baby mites have noticeable temperature difference from bees or brood. Currently, reliable data on the body temperature of honeybees and Varroa mites does not exist. As a result, we will have to conduct experimentation to obtain data about the temperature of bees and Varroa. This experimentation will also help us help us determine detection limits of infrared imaging. The hive is thermoregulated by the bees to maintain a constant brood temperature, so this may be a challenge if the mites maintain themselves at the same temperature as the hive.
  - With ultrasound imaging we will plan to target mite reproduction in brood cells. Medical ultrasound imaging kits are relatively inexpensive but tend to be bulky. Therefore the unit would probably have to be positioned outside of the hive. We would need to see if ultrasound could be used to scan the brood comb, and if it

could be focused on different frames within the hive.

- Once we determine a method to detect the mites we need to determine how the sensor samples the hive. Varroa mites will be concentrated where the brood is located. Therefore the brood pattern of the colony should be taken into consideration when a sampling pattern is created.

- *Objective 2:*
- Once a reliable method of automatically sampling counting and estimating mite levels inside each colony is created, the data needs to be analyzed to optimize Varroa mite treatment. We need to determine a way for the data to be transmitted from the sensor to a computer where the data can be stored and analyzed. Deciding when to treat and with what chemical is already dependent on temperature, nectar flows, and transportation of colonies so these factors should be taken into account when the treatment plan is created. Test will have to be conducted to determine at what time is best to treat based on Varroa levels. The mite detection sensor will also report how effective various treatment options are at killing Varroa. Continually monitoring the effectiveness of different treatments and when they are applied in comparison to mite and bee growth rates the system should work to improve treatment plans.

- *Outcomes:*
  - *Objective 1:*
  - The measurable outcome from this objective would be determined numerically by calculating the average Varroa count between at least twenty trials. If the experimental number of counted Varroa mites is within 5% of the number of mites given by existing algorithms, we would know our method worked. From past conversations with Cybil Preston, the Maryland Department of Agriculture Chief Apiary Inspector, any Western commercial honeybee hive will always contain Varroa mites. In other words, the dependent variable from Varroa treatment is not the presence of Varroa mites, but rather the quantity of Varroa mites. Furthermore, many commercial beehives include at least 11,000 bees (Dennis 2016), which at any time may either be infested with a handful of mites, or swarmed with thousands of mites. To create an effective, reliable, and long-lasting solution, our group has determined 5% as the margin of error and standard for mite-counting accuracy as this detail will allow any beekeeper to know the exact content and intensity of treatment needed to best protect the health of the hive. In conclusion, if the resulting margin of error for the Varroa detection method is greater than 5%, we will deem the method a failure and explore future method improvements, but if the margin of error is less than 5%, then the method will be deemed a success.

- *Objective 2:*
- The measurable success of this objective will be determined on how much time and money is required each day, per hive to fully maintain the health of the beekeeper's honeybees. In creating a device that automatically processes and provides accurate feedback, we hope to streamline communication between the counting device and the beekeeper, reduce the time that a beekeeper must tend to their hives, and reduce the overall financial burden for beekeepers. Additionally, the objective's success will be determined based on the price of the device and the device's demand from the beekeeper market. If the initial cost of the device is too expensive and outweighs the potential gains of attaining accurate, updated hive information, then the objective is a failure as the device will not be desirable.

- *Anticipated Problems:*
  - *Objective 1:*
  - The anticipated problem with this objective is that existing algorithms and methods for counting Varroa mites are not precise or accurate. Many algorithms include sampling methods which do not guarantee the presence of an exact number of mites in a hive. Additionally, creating a technology that detects the simple presence of Varroa mites in a small area seems feasible, however detecting the near-to-exact number of 1-2mm Varroa mites across several cubic feet creates many challenges.
  - Other Problems: If the sensor had to fit inside the hive, potential problems could arise if the honeybees coat the sensor with propolis and beeswax. Furthermore, the sensor would have to be designed in a way that is not perceived as a threat by the bees in the hive. If the sensor has to move between multiple hives and go into them, transmission of viral and bacterial diseases should be consider to not create additional problems. Commercial beekeepers often have their hives in remote areas where it may be hard to transmit data and power sensors in the hive.

  - *Objective 2:*
  - The most anticipated issue from this objective is to determine a method that will benefit various types of commercial beekeepers. If a method proves successful and saves many resources for some beekeepers, it might also be a tremendous burden to others. For example, as previously stated, the methods must be applicable to beekeepers with the greatest number of hives and smallest number of hives. Additionally, technology must be properly advanced, but still easily accessible to most beekeepers. All in all, in assisting to the broad range of personal beekeeper requirements and inefficiencies, inventing a broad, universal, and applicable device is a major obstacle.

Project Team:

Some people in our group will need to be in charge of managing all the data we collect from conducted experiments. This would probably be one of our industrial engineers. This person could also be in charge of managing some other aspect of our project, like our finances. In the event we need to request funding from different organizations or be reimbursed by Grand Challenges, we will need a treasurer to appropriate this money. This will be Nishant and Ollie.

Our group will need a project manager. The project manager will be responsible for making sure the group stays on schedule and has a strong sense of communication, so that all group members are on the same page. The project manager will also have the responsibility to document the progress of the group. Nicole will be our project manager in the upcoming year.

Our group will need people with coding experience in order to develop programs that will transmit data from the sensor in the hive to some sort of database or app that beekeepers can use to track Varroa mites. The coders will be responsible for creating code that will optimize treatment plans and provide useful data to beekeepers. Ruchi and Chris will be the software engineers for the group.

Our group will need a person with background experience in working with honeybees. The beekeeping expert will be responsible for managing any hives needed for data collection, installing sensors into hives, and taking mite samples needed for preliminary research and networking with local and commercial beekeepers. This will be Patrick.

Our group will need a person who excels at communications and has experience in the field of marketing and public relations. This person will keep track of any societal trends or current events that correspond with our research. Using this information, this person will look for potential sponsors. Additionally, this member will give valuable insight into how the team should present and brand our final product. Bethany will fill this role.

Finally, we plan to have at least three individuals to consistently contact throughout the future of our project for useful advice. The three people we currently plan to communicate with are Kevin Omolo (our Grand Challenges Advisor), Dr. Leavey (Director of the Georgia Tech Urban Honeybee Project), and Dr. Tovey (Georgia Tech ISyE professor and honeybee enthusiast).

Timeline:

Spring/Summer 2017

- Undergo preliminary investigation into the Georgia Tech Heat Lab and infrared technology.
- Preliminary experiment in the Heat Lab with infrared technology.
- Contact David Anderson in the ECE department in regards to acoustic signal detection.
- Contact Amro Qandour, lead author of "Remote Beehive Monitoring Using Acoustic Signals." See: http://ro.ecu.edu.au/cgi/viewcontent.cgi?article=1505&context=ecuworkspost2013
- Contact Dr. Stanislav Emelianov, a Georgia Tech Bioengineering Professor and an ultrasound expert.
- Discern most promising solution pathway

Fall 2017

- While weather permits, conduct thermal imaging experiments within hives of the GT Urban Honeybee Project.
- If promising, continue to pursue our thermal imaging solution. If not promising, pursue other potential solutions such as ultrasound solutions.
- Continue to consult experts, updating them on our progress and asking for opinions.
- Decide solution pathway
- Build a fundamental, successful prototype that counts mites.

Spring 2018

- Contact commercial beekeepers and evaluate feasibility of solution and how it can be implemented. Get feedback on initial mite counting prototype.
- Improve and debug prototype.

Budget:

- *Materials and Supplies:*

	A	B	C	D	E
1	Material	Cost in Dollars	Borrow	If yes, from who?	Buy
2	Hive /w bees	$339	yes	Dr. Leavey	
3	Hive /wo bees	$229	yes	Dr. Leavey	
4	Protective gear	$125	yes	Dr. Leavey	
5	Infrared imaging	$995	yes	GA Tech Lab	
6	Acoustic signaling	null - still being developed			
7	Varroa mites	null - are on the bees			
8	Bees	$110	yes	Dr. Leavey	
9	Sugar	$6			yes
10	Oxalic acid	$45			yes
11	Oxalic acid vaporizer	$76	yes	Dr. Leavey	
12	Jar	$20			yes
13	Ultrasound machine	$900	probably	Ga Tech Sports Medicine	

- *Equipment (over $1,000):*

In terms of equipment, our group does not have a piece of equipment that is more expensive than $1,000. We will be borrowing equipment that is more expensive from third parties. However, the $1,000 dollar mark might be encountered if our infrared and ultrasound machine-partnerships fall through.

- *Services:*

There are no services that we are expecting to need from others except for borrowing equipment. If we use some of the campus equipment instead of buying them the owners of the equipment may expect compensation. However, Georgia Tech professors have been willing to collaborate with our team and thus have volunteered to help us.

- *Travel:*

Our group does not currently expect a large transportation cost, but we may later need transportation to visit local beekeeping companies. Many commercial beekeeping companies are within a 3.5 hour drive from campus. We also have many native Georgians in our group that have cars and can drive. Our group will need, for example, reimbursements for trips to commercial beekeepers like Blue Ridge Honey Farms, which is 108 miles away in south Georgia.

Expected Outcomes and Future Directions:

At the end of our project, our goal is to develop, prototype, and distribute a cost-effective tool that can reliably, accurately, and precisely count Varroa mites in a given beehive. This product would be either able to be rotated among a beekeepers' many hives or be cheap enough to allow each beehive to have a dedicated Varroa detector. The tool would collect real time data about the Varroa mite levels in the beehive and would transmit this data to a web and mobile application that alerts a beekeeper when the Varroa population exceeds a certain critical value using IOT (internet of things technology). This tool and its corresponding application would automatically continue to learn as more data points are obtained. By extrapolating data points in each hive to form growth curves, the application would more accurately learn about Varroa mite reproduction. This would continue to optimize the application's performance in determining when the ideal time is to treat for Varroa.

At the end of year two of our project, our goal is to have tested and experimented with each of our current three solution ideas (as well as any new ideas that we discover). We hope to be able to specifically target one solution direction and have a general idea for what a prototype might look like. At the end of year two, we do not anticipate to be finished with the application that will accompany our finished product. In year two and beyond, we hope to be able to conduct research on acoustic signal detection, infrared imaging, and ultrasound imaging at various research labs on campus and experiment with Varroa and bees in these labs. We hope to continue to develop or form relationships with the urban honeybee project on campus, various research labs, the UGA Honey Bee Program, commercial beekeepers, and honey bee interest groups around Georgia. These individuals could provide us with guidance and direction. For funding, we would rely on Grand Challenges and grants from honey bee interest groups. There are many honey bee interest groups around Georgia that offer research grants to individuals or groups with purposes similar to ours. With these two sources of funding, we hope to be able to conduct the necessary research to develop a prototype at the end of year two.

Sources:

1. (2013 July). Colony Collapse Disorder and the Neonicotinoids Ban. *Newsletter FWAG Southwest* (4). Retrieved from https://issuu.com/fwagsouthwest/docs/newsletter_julyl_2013-_flipbook_cop
2. Aizen, M. A., & Harder, L. D. (2009). The Global Stock of Domesticated Honey Bees Is Growing Slower Than Agricultural Demand for Pollination. Current Biology, 19(11), 915-918. doi:10.1016/j.cub.2009.03.071
3. Dennis, B., & Kemp, W. P. (2016, February 24). How Hives Collapse: Allee Effects, Ecological Resilience, and the Honey Bee. Retrieved March 26, 2017, from http://journals.plos.org/plosone/article?id=10.1371%2Fjournal.pone.0150055
4. Gilbert, N. (2016). Global biodiversity report warns pollinators are under threat. Nature. doi:10.1038/nature.2016.19456
5. Hunt, G. (2010). Beekeeping (Tech.). West Lafayette, IN: Purdue University Cooperative Extension Service.
6. Qandour, A., Ahmad, I., Habibi, D., & Leppard, M. (2014). Remote Beehive Monitoring Using Acoustic Signals. *Acoustics Australia*, 42(3), 204-209. Retrieved April 11, 2017.
7. Tirado, R., Simon, G., & Johnston, P. (2013). A Review of Factors that Put Pollinators and Agriculture in Europe at Risk (Tech.). Amsterdam: Greenpeace.
8. U. (n.d.). Honeybee Parasites, Hive Pests, and Diseases. Retrieved April 13, 2017, from https://uaex.edu/farm-ranch/special-programs/beekeeping/hive-pests-diseases.aspx
9. vanEngelsdorp D, Evans JD, Saegerman C, Mullin C, Haubruge E, Nguyen BK, et al. (2009) Colony Collapse Disorder: A Descriptive Study. PLoS ONE 4(8): e6481. https://doi.org/10.1371/journal.pone.0006481