Deformed Wing Virus in Honey Bee Colonies Vectored by Varroa Destructors

Report By

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ABSTRACT

This paper looks at a honey bee colony and how it is affected by the Deformed Wing Virus (DWV) which is transmitted through the *Varroa Destructor* parasite. We demonstrate the consequences of this disease by implementing it into our mathematical model at two different times of the year with altered levels of varroa infestation. This allowed us to determine the role of varroa mites in how quickly the virus spreads throughout the colony. Ultimately, we discover that DWV is deadly for any bee colony infested with varroa mites, but that with proper varroa control methods, such as acid treatments, we can reduce the number of mites and slow down the spread of DWV within a colony.

INTRODUCTION

In addition to honey production, bees play a vital pollination role and are considered the major pollinators in North America, performing over 70% of the pollination services (1). Their daily work value, according to the Agriculture and Agri-Food Canada, is estimated of more than $1-billion a year worth of apples, melons, cucumbers, berries, and many other kinds of Canadian farm produce.

There are more than 850 species of native bees in Canada - bumble bees, mason bees, sweat bees, squash bees and more, including domesticated honey bees. During the last few decades these beneficial animals have got increasingly stressed by a combination of complex factors, which has led to the near extermination of wild honey bees in Eastern Canada (1):

- Parasitic mites and bacterial diseases caused by them,
- Poor queen bee quality,
- Weak colonies,
- Weather conditions, and others.

Inadequate parasite control was the primary cause of mortality in honey bee colonies in Ontario in 2010.

HONEY BEE COLONY

Honey bees are social insects that live in colonies. Honey bee colonies consist of a single queen, hundreds of male drones and from 20,000 to 80,000 female worker bees (3). Each caste of bee performs specific tasks.

Queen Bee

Queens are the only members of a colony able to lay fertilized eggs. An egg-laying queen is important in establishing a strong honey bee colony, and can produce up to 2,000 eggs within a single day. Queens mate early in life and store up millions of sperm within their bodies. They play the most important role within their societies but they cannot establish new colonies without the help of drones and workers.

Worker Bees

Worker honey bees are the largest population within a colony. They are entirely female, but they are unable to produce fertilized eggs. If there is no queen they sometimes lay unfertilized eggs, which become male drones. Workers are essential members of honey bee colonies. They hunt for pollen and nectar, tend to queen and drones, feed larvae, ventilate the hive, defend the nest and perform other tasks to preserve the survival of the colony. The average life span of worker bees is approximately six weeks.

Drone Bees

Drones, or male honey bees, have only one task: to fertilize new queens. They mate outdoors usually in midair and die soon after mating. Drones only appear in the summer, as queens can store thousands of sperm in their bodies over the winter. In mid fall, when food for the colony becomes limited, the drones are ejected from the hive.

Bee development stages

All bees pass through the same development stages before becoming adults (4):

- the egg,
- larvae,
- and pupal.

Honey bee larvae are legless, they eat honey, nectar or pollen. Larvae shed their skin and molt several times before they enter the pupal stage. After another molt, these pupae will emerge as adult honey bees and begin to perform specialized tasks for the colony.

Seasonality of the Hive

Figure 1 shows the typical seasonal cycle for the honey bee colony. The green line of Figure 1 is the total number of bees in the colony year-round. As only worker bees are present in the winter, the blue and green line merge for those months. In the summer, the colony is composed of both worker and drone bees (5). Drone bees begin to appear in April as seen by the spike of the red line around day 100 in Figure 1. Also in the beginning of spring, the birth rate for worker bees begins to increase to prepare for the summer foraging season. The number of drones in the colony during the summer is approximately 24% of the number of worker bees (5). Come the beginning of fall, the drones are kicked out of the colony in preparation for winter as seen by the drop in the red line of Figure 1.

In the winter, the number of bees is roughly 20,000 but reaches its minimum number of bees mid-February where the total colony is composed of less than 20,000 bees. It is in the beginning of June that the colony will reach its maximum number of bees, around 80,000 bees.

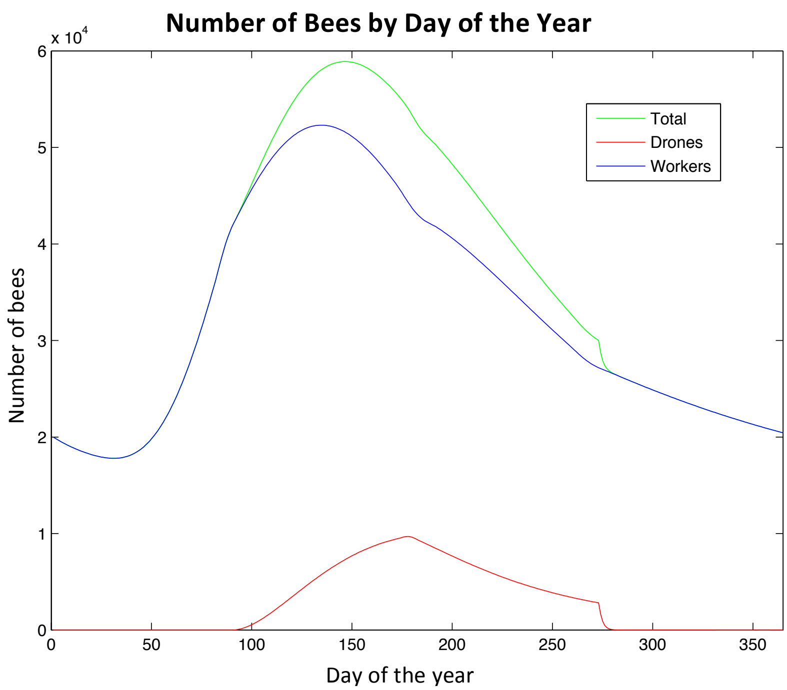


Figure 1 - Seasonality of the hive

PARASITES AND VIRUSES

Varroa Destructor

Varroa Destructor (a.k.a. varroa mite) is an external parasite that attacks both honey bees and brood (6). Varroa are completely dependent on honey bee colonies for survival and reproduction and cannot live separately from honey bees for more than a few days. They move fast from the body of a honey bee to another.

Varroa are relatively large parasites compared to their host. Without eyes, they detect honey bees by smell and movement. A female mite will enter a brood cell about a day before it is capped and lay eggs. Mites that emerge from the eggs feed and develop on the maturing bee larvae. They suck the blood from both the developing brood and adults which weakens and shortens the bee life. In most cases, varroa mites alone will not be able to kill an entire colony of bees. The true danger in varroa mites is their ability to transmit a variety of pathogens and viruses to the bees. In fact, although varroa mites do weaken the bees, the presence of un-infected varroa mites only minimally disrupts the colony wellbeing.

The typical way for a hive to become infested with varroa mites is by a single mite entering the colony on a bee. There are two possible ways this could occur; the first is from a foreign bee (i.e. a bee from a different hive) entering the un-infested hive while carrying a mite and the mite jumps onto another bee or into a brood cell. The second possibility occurs through a bee from the colony entering a foreign hive that is infested and bringing a mite back to his own hive. Starting with just one parasite, the mite population can increase very quickly due to their exponential reproduction rate.

Deformed Wing Virus (DWV)

Deformed wing virus (DWV) is one of the viral diseases associated with varroa mite infestations. DWV is a ribonucleic acid (RNA) virus which disrupts the host's mRNA translocation mechanisms and may be involved with mRNA replication and translation controlling elements. It produces 30-nm icosahedral particle which consists of "a single positive-stranded RNA genome and three major structural proteins, characteristics that are common to many insect viruses" (7).

The virus was first known as Egypt bee virus (EBV) and was discovered in 1977. Subsequently, a similar virus was found in 1982 from deformed Japanese bees, and was later renamed to deformed wing virus once it was spread worldwide. On the other hand, it is unsure whether DWV has its origins in South East Asia from the Asian Honey Bee, the original host of varroa, or whether the virus originates from the Western Honey Bee. It is suspected that DWV was spread into other regions dominated by managed beekeeping, where the virus could have appeared by trading bees and queens from infected regions.

Symptoms of an infected young bee can be often seen with distorted, misshapen, twisted, or wrinkled wings because of DWV. Unfortunately, bees born with deformed wings do not live long (8).

MODEL FORMULATION

The purpose of this project is to create a mathematical model for the inner mechanisms within a honey bee colony observing the effects that the DWV virus, vectored by the varroa infestation, make on the population of the colony. This model will include the birth and population mechanics of worker bees and drones, their respective larval stages, and varroa mite activity. This model will analyze the number of susceptible and infected bees, brood, and mites within a year of a bee keeping season.

The model assumptions are as follows. First, since the varroa mites feed on the hemolymph of both adult bees and brood, there will be a cross infection term between mites to bees and mites to brood (9). Second, bees who are infected during adulthood are unaffected by DWV, so their mortality rate will not be affected. On the other hand, when DWV is transferred to brood, their mortality is increased in larval stages and if they survive to adulthood, their longevity is reduced (10). Additionally, most research has found that varroa mites are not affected in any way by DWV. Furthermore, if a mite is infected with DWV, the virus will be passed onto their offspring. Lastly, there is no recovery class for bees or brood once they are infected. As of now, there is no cure for DWV once bees are infected, the only way to prevent a virus epidemic is for beekeepers to closely monitor their colonies and to use treatments such as chemical sprays to prevent mite populations from growing (11).

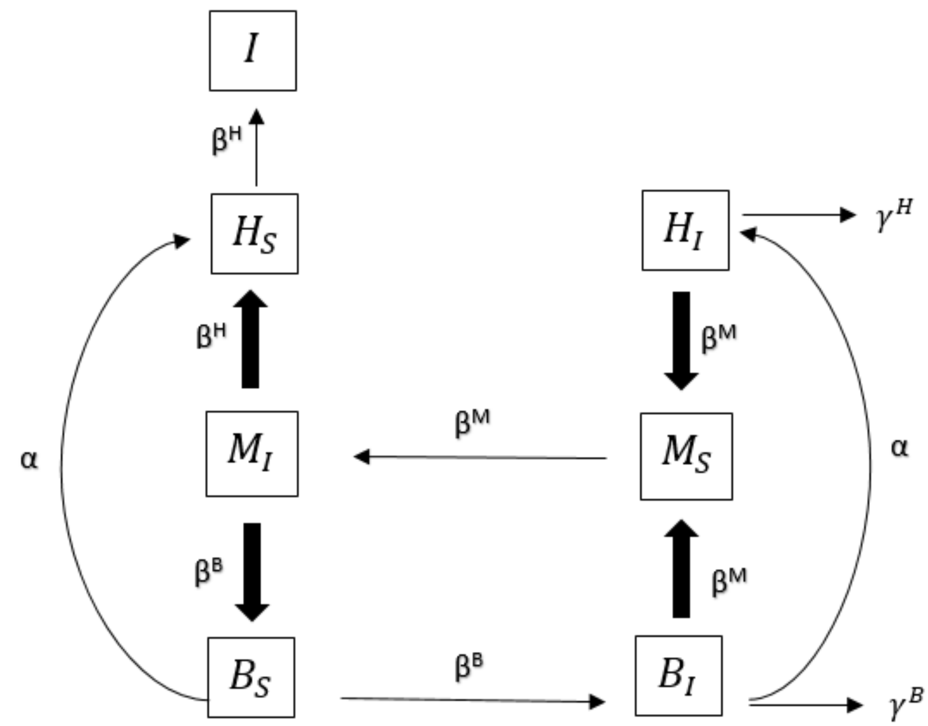


Figure 2 – Diagram describing the dynamics of the model

The model proposed is shown in the diagram of Figure 2, and detailed in the system of differential equations below:

$$\frac{dH_s}{dt} = \alpha B_S - \beta^H M_I H_S - \mu^H H_S$$

$$\frac{dH_I}{dt} = \alpha B_I - \gamma^H H_I$$

$$\frac{dI}{dt} = \beta^H M_I H_S - \mu^H I$$

$$\frac{dM_s}{dt} = \lambda^M - \beta^M (H_I M_S + B_I M_S) - \mu^M M_S$$

$$\frac{dM_I}{dt} = \beta^M (H_I M_S + B_I M_S) - \mu^M M_I$$

$$\frac{dB_s}{dt} = \lambda^B - \beta^B M_I B_S - \mu^B B_S - \alpha B_S$$

$$\frac{dB_I}{dt} = \beta^B M_I B_S - \mu^B B_I - \gamma^B B_I - \alpha B_I$$

In this proposed model,

H_S = susceptible adult honey bees
H_I= infected adult bees (infected since birth)
I = adult bees infected after development
M_S = susceptible varroa mites
M_I = infected varroa mites
B_S = susceptible brood
B_I = infected brood

For the model parameters, λ^i is the birth rate ($i = B, M$) for brood and mites respectively, β^i is the rate of infection ($i = B, M, H$) for brood, mites, and honey bees, $\mu^i$is the background death rate ($i = B, M, H$), ν^i is the death rate due to disease ($i = B, H$) for brood and honey bees, and lastly, α is the rate that brood develops into an adult bee.

Disease-Free Equilibrium

Given that $I = 0 \rightarrow \ I' = 0,\ \ H_I' = 0,\ M_I' = 0,\ B_I' = 0$ we have that:

- $M_S' = \lambda^M - \mu^M M_S = 0 \leftrightarrow M_S' = \frac{\lambda^M}{\mu^M}$
- $B_S' = \lambda^B - \mu^B B_S - \alpha B_S = 0 \leftrightarrow B_S' = \frac{\lambda^B}{\mu^B + \alpha}$
- $H_S' = \alpha B_S - \mu^H H_S = 0 \ \leftrightarrow \ H_S' = \frac{\alpha \lambda^B}{\mu^H(\mu^B + \alpha)}$

Thus, the disease-free equilibrium is $\left(\overline{Hs}, \overline{H_I}, \bar{I},\ \overline{M_S}, \overline{M_I}, \overline{B_S}, \overline{B_I}\right) = (\frac{\alpha \lambda^B}{\mu^H(\mu^B + \alpha)}, 0, 0, \frac{\lambda^M}{\mu^M}, 0, \frac{\lambda^B}{\mu^B + \alpha}, 0)$

Finding R_0 Using the Jacobian Method

We create a Jacobian matrix by differentiating every equation with respect to every variable. Since we have 7 equations, we will get the 7x7 matrix below:

$$J = \begin{bmatrix} -\beta^H M_I - \mu^H & 0 & 0 & 0 & -\beta^H H_S & \alpha & 0 \\ 0 & \gamma^H & 0 & 0 & 0 & 0 & \alpha \\ \beta^H M_I & 0 & -\mu^H & 0 & \beta^H H_S & 0 & 0 \\ 0 & -\beta^M M_S & 0 & -\beta^M H_I - \beta^M B_I - \mu^M & 0 & 0 & -\beta^M I \\ 0 & \beta^M M_S & 0 & \beta^M H_I + \beta^M B_I & -\mu^M & 0 & \beta^M M \\ 0 & 0 & 0 & 0 & -\beta^B B_S & -\beta^B M_I - \mu^B - \alpha & 0 \\ 0 & 0 & 0 & 0 & \beta^B B_S & \beta^B M_I & -\mu^B - \gamma \end{bmatrix}$$

To find the eigenvalues, we take the determinant of the Jacobian at the disease-free equilibrium:

$$\det(J - \lambda I)\,|_{\left(\frac{\alpha\lambda^B}{\mu^H(\mu^B+\alpha)},0,0,\frac{\lambda^M}{\mu^M},0,\frac{\lambda^B}{\mu^B+\alpha},0\right)}$$

$$= \lambda^3 - [\gamma^H + \mu^M + \mu^B + \gamma^B + \alpha]\lambda^2 - [\gamma^H(\gamma^B + \alpha + \mu^M + \mu^B) + \mu^M(\mu^B + \gamma^B + \alpha)]\lambda$$
$$- [\gamma^H\mu^M(\mu^B + \gamma^B + \alpha)] + \left[\alpha\beta^M\left(\frac{\lambda^M}{\mu^M}\right)\beta^B\left(\frac{\lambda^B}{\mu^B - \alpha}\right)\right] + \left[\frac{\beta^M\beta^B\lambda^M\lambda^B\gamma^H}{\mu^M(\mu^B - \alpha)}\right]$$

Which we have simplified to: $= -\lambda^3 - d\lambda^2 - e\lambda - f$, where ⍰ > 0 and $e > 0$.

By following steps outlined in Chapter 5 and Appendix F of the textbook, we can solve this cubic function to find the turning points in the following way,

$$g(\lambda) = -\lambda^3 - d\lambda^2 - e\lambda - f$$
$$g'(\lambda) = -3\lambda^2 - 2d\lambda - e = 0$$
$$\rightarrow \lambda = \frac{-2d \pm \sqrt{4d^2 - 12e}}{6}$$

We have that $4d^2 - 12e < 4d^2$ since $d > 0, e > 0$. This means that $\sqrt{4d^2 - 12e} < 2d$, so both roots are negative. This means that both turning points are in the negative region. Furthermore, since the leading term $(-\lambda^3)$ is negative, the cubic function goes to infinity for large negative values and goes to minus infinity for large positive values. Since our f>0, then by $g(\lambda)$, the intercept is negative. Also, since f>0, then the disease-free equilibrium is stable. We derive an R_0-like threshold by rearranging the formula for f above and we can write,

$$R_0^f = \frac{\alpha\beta^M\beta^B\mu^M\mu^B + \beta^M\beta^B\lambda^M\lambda^B\gamma^H}{\mu^M(\mu^B + \alpha)(\gamma^H\mu^M\mu^B + \gamma^H\gamma^B\mu^M + \alpha\gamma^H\mu^M)}$$

This threshold tells us that if $R_0^f < 1$ then the disease will die out on its own. However, if $R_0^f > 1$ then the disease will become endemic and DWV will spread throughout the bee colony.

Reproductive Ratio Using Our Parameter Values

In this section, we will substitute the seasonal parameter values we came up with into the threshold function. Note that since the birth rate of the mites is a function of how many mites are currently in the colony, and the birth rate of bees is a function of time, we will calculate R_0

starting at different initial values of mites (denoted by p) in the colony and at different intervals of time (denoted t).

For $p = 1, t = 1$: $R_0 = 21890$

For $p = 1, t = 150$: $R_0 = 129470$

Both R_0 values are significantly large, which tells us that with our given parameters, the DWV will become endemic very quickly within the colony population. Note that at $t = 150$, i.e. May 30th, is the start of summer, so the birth rates of bees and is much larger than in other seasons and the population of bees is near its maximum. This explains the much larger R_0 value for introducing and infected mite at May 30th.

RESULTS AND ANALYSIS

DWV starting on January 1st

Putting one infected mite into the colony on January 1st (Day 1), we see what becomes of the colony. The impact on the bee colony can be seen in Figure 3 and the mite reproduction can be seen in Figure 4.

Our initial conditions are: 1 infected mite, 1 infected bee (the one carrying the mite), 0 susceptible mites, 20 000 susceptible bees (this is average size of a healthy colony in January) and 100 brood.

Within a span of a few days of injecting the infected mite into the colony, all of the adult bees become infected. Initially, all of these bees will have moved into the state *'I'* where they are infected, and infectious to susceptible mites, but do not show any symptoms of the disease and their expected lifespan has not been reduced.

Also within this short span of days, the majority of the brood becomes infected. However, all of the brood that is capped, i.e. contains bee pupa, will not become infected as it is not possible for the mites to enter the cell while it is capped. The brood that is not capped, unfortunately, becomes infected very quickly. In the egg and larva stages, a "baby" bee can be visited up to 10,000 times a day by worker bees. Since the number of infected bees increased so drastically, the number of infected bees tending to the larva has also increased and the mites will jump off the bees to hide and reproduce in the larva cells thus infecting the bee before it becomes an adult.

The bees that are infected during their development have a lower probability of making it to adulthood and those that do make it to adults, but with deformed wings, die within 48 hours.

Because of this reduced lifespan of diseased adult bees and the increased death rate for diseased brood, the total amount of bees continues to decrease throughout the year. For the most part, all adult bees are infected. The only exception to that is in the beginning of spring (approximately day 100) when the birth rate begins to increase due to the season change. Here we can see a spike in healthy brood and a small increase in susceptible bees following the suit. This small spike is encouraging. However, at this point the number of infected bees is too great and the number of susceptible bees is once again reduced to approximately 0 in less than a month.

By the end of the year (December 31st) only 665 bees remain, all of which are infected. Given that a typical colony requires at least 20,000 bees going into the winter for hive temperature regulation, it is safe to assume that this colony will not last until spring.

It is important to note that it is very unlikely that a new mite would be introduced into the colony in January because bees very rarely leave the hive in winter which prevents the transfer of mites to other colonies. This scenario is therefore pretty unrealistic, however, the results are not useless: it gives a good idea of how a colony would grow in the following year if it had been infected with varroa and DWV the previous fall.

Figure 4 depicts how just one mite on Jan 1st can become 2796 mites by the end of December. The dip in the curve around day 275 is due to the drones being kicked out of the colony for the coming winter. Consequently, all of the mites that are attached to drone bees will also be eliminated from the hive. In Figure 4 we can also see that all the mites are infected. This is due to the fact that mites pass along the disease to their offspring thus, starting with only one infected mite leads to all mites being infected.

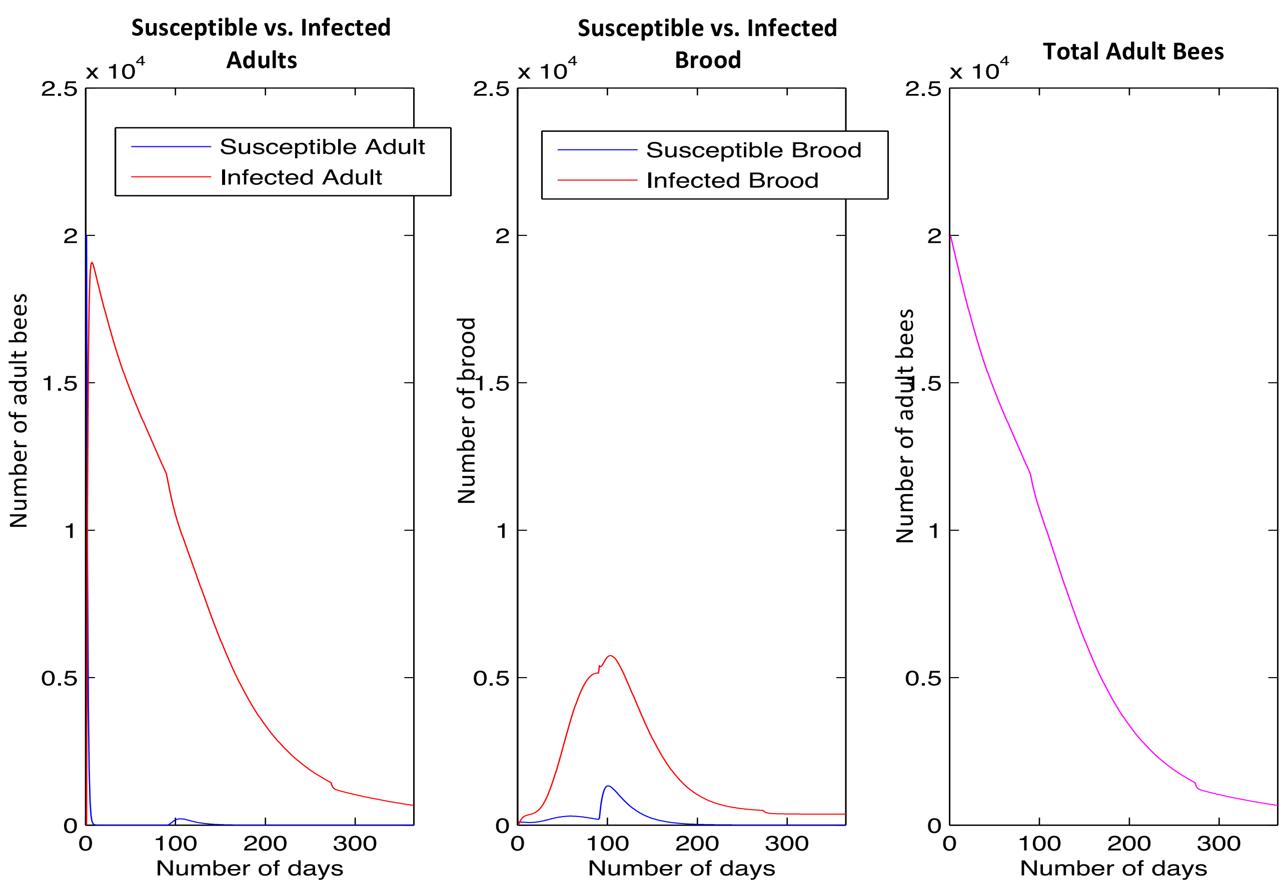


Figure 3- Effects of DWV on a bee colony starting on January 1st

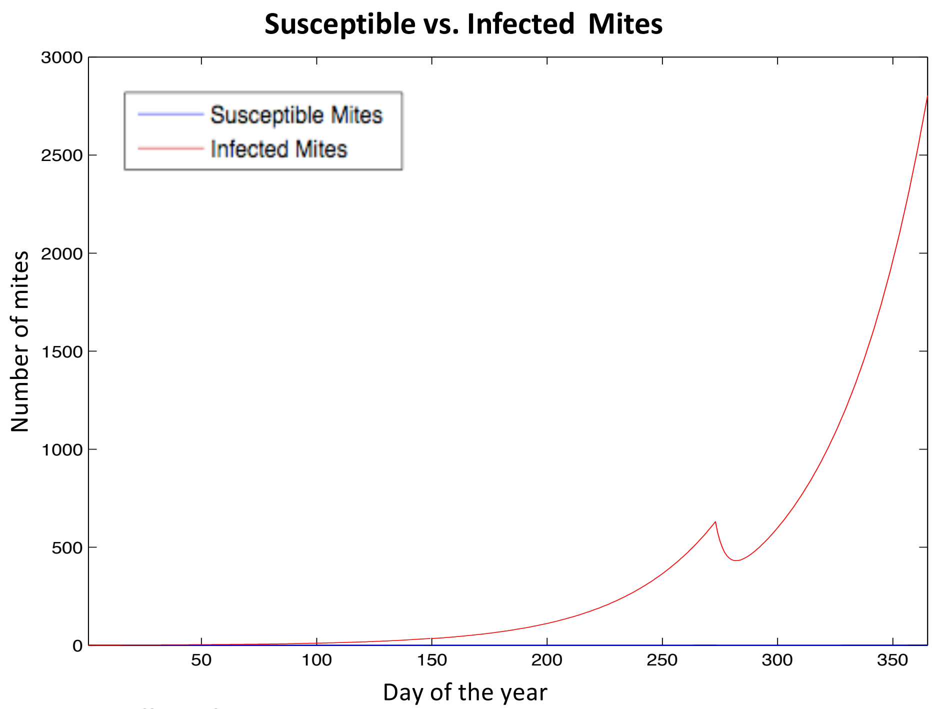


Figure 4-Effects of DWV on varroa mites starting on January 1st

DWV starting on May 30th WITH varroa already present

For this experiment, we ran the model of a bee colony starting with one uninfected varroa mite on January 1st and then we introduced an infected mite into the colony on May 30th. The initial conditions on January 1st were the following: 15 susceptible mites, 0 infected mites, 20 000 susceptible bees and 100 brood. Note that a bee is only considered infected when it has the DWV virus and not when carrying a susceptible mite.

We can see the results in Figures 5, 6 and 7. Given that in our model we assume that uninfected varroa mites do not play a role on the colony's growth, we can see the normal seasonal trends for the hive up until May 30th (day 150). Almost immediately once the mite was introduced, all of the bees become infected. This very fast infection is due to how quickly the mites become infected and spread the disease. On May 30th, before the infected mite was introduced, there were 515 susceptible varroa mites already present in the colony. These mites all became infected extremely quickly and thus infected all the bees very quickly. It appears as though the bee population numbers aren't too affected by the disease, as it looks similar to their normal cycle. However, there is a very important difference: at the end of December, only 6799 bees remain (all of which are infected) whereas in the healthy colony, there is over 20,000 bees remaining on December 31st. In fact, this infected colony does not have enough bees to make it to spring and will sadly die over the winter.

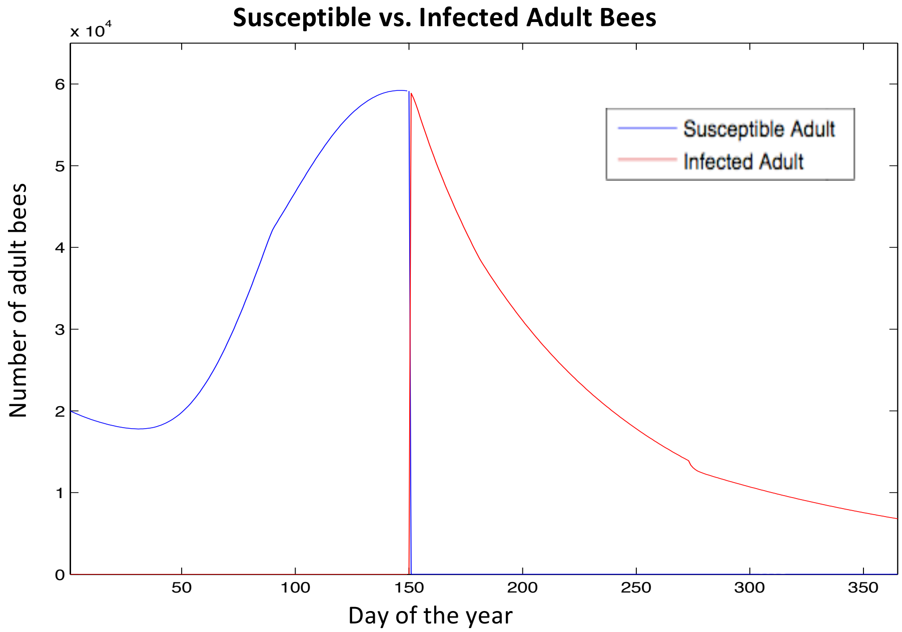
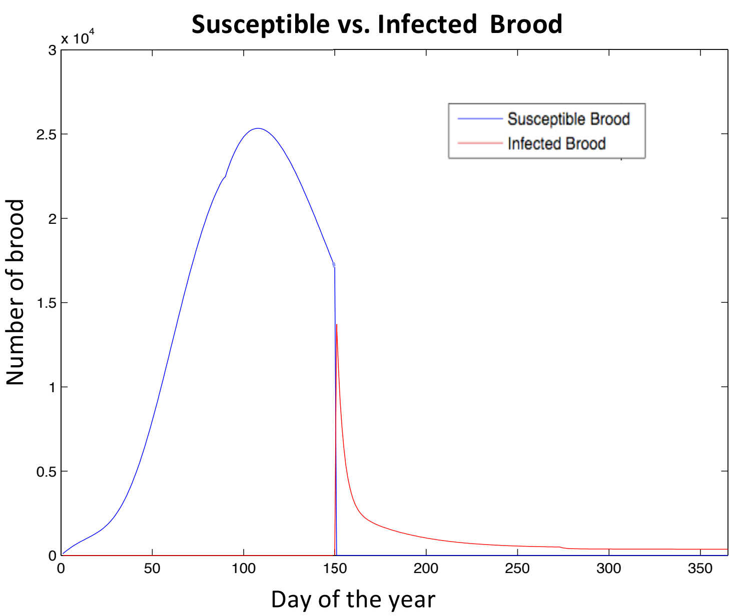


Figure 5 - Effects of DWV on adult bees starting May 30th WITH varroa mites already present



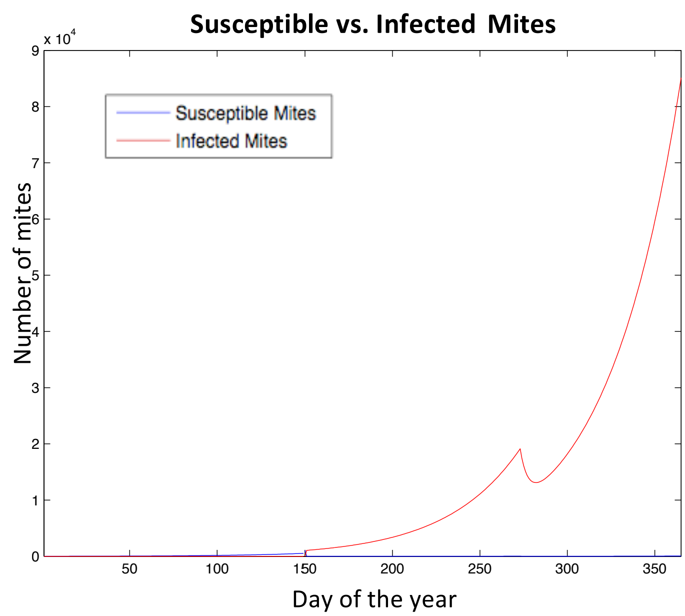


Figure 6 - Effects of DWV on brood starting on May 30th WITH varroa mites already present
Figure 7 - Effects of DWV on mites starting on May 30th WITH varroa mites already present

Furthermore, as seen in Figure 6, the brood is quickly affected by inserting one infectious mite into the colony. The healthy brood drops to approximately zero extremely quickly and the infected brood takes hold. This leads to only infected new adult bees, that is, bees with very short lifespans and deformities. Thus, the colonies "supply" of new bees is limited and of a poor quality.

DWV starting on May 30th WITHOUT varroa already present

In this case, we ran the model of a healthy, varroa free, bee colony starting on January 1st and then we introduced an infected mite into the colony on May 30th (Figure 8). The initial conditions on January 1st were the following: 0 mites, 20 000 susceptible bees and 100 brood.

Up until May 30th we see that typical colony seasonal cycle, but similar to previous models, when the infected mite is put into the colony, we see a rapid change in the number of susceptible and infected bees. It is important to note, that the disease spreads slower when there are less mites already present in the colony. Rather than the number of susceptible bees dropping to zero within just a couple of days (as seen in the colony already infected with varroa), in this case it takes over 10 days for the entire adult population to become infected. Although this is an improvement from the previous case, it is still very bad news for the bees. The remaining number of bees is 7019 by the end of December, 220 more bees left then when there was already a varroa infestation, but still not enough bees to allow the colony to survive throughout the winter.

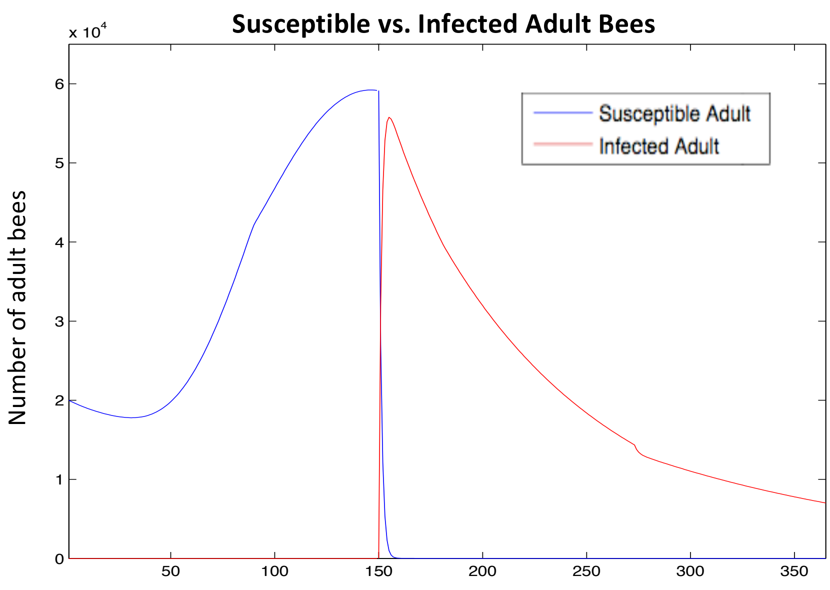
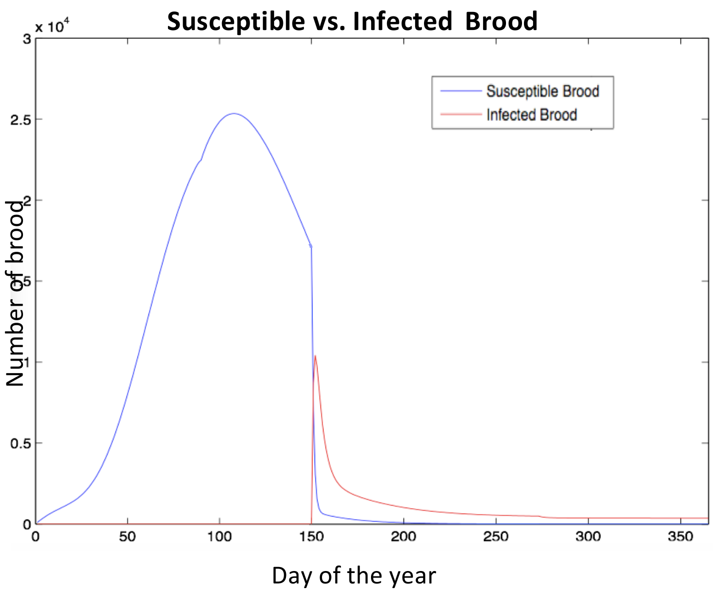


Figure 8 - Effects of DWV on adult bees starting May 30th WITHOUT varroa mites already present

There is also a significant difference in the rate of infection for the brood, as seen in Figure 9. Whereas in the previous case, all the brood was infected almost instantly, we now still see susceptible brood in the colony for 50 days following the insertion of the infected mite. Infected brood still dominates, but, because there remains uninfected brood, there will also be bees that make it to adulthood uninfected. These bees play an important role in the survival of the hive and are the main reason as to why there remains 220 more bees at the end of the year.



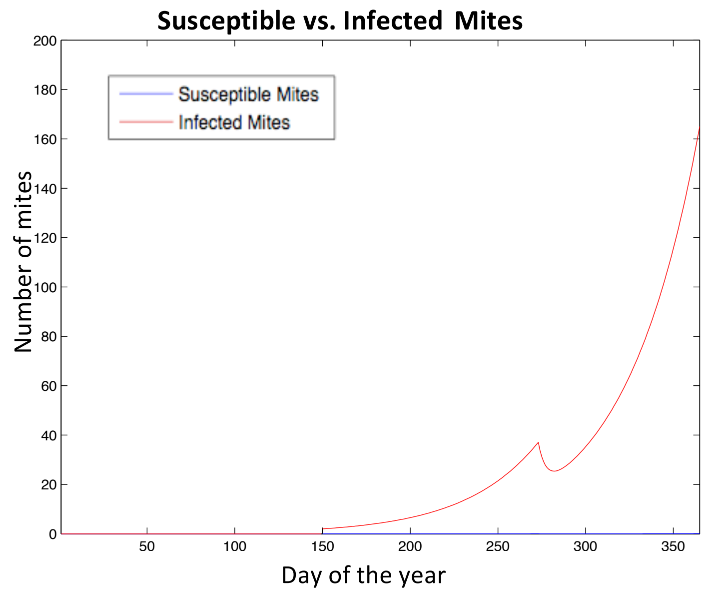


Figure 9 - Effects of DWV on brood starting on May 30th WITHOUT varroa mites already present
Figure 10 - Effects of DWV on mites starting on May 30th WITHOUT varroa mites already present

Behavioural and Chemical Treatments

Both drones and worker bees display hygienic behaviours to remove mites from themselves and from the brood cells (12). Chemical treatments can also be applied by beekeepers to eliminate mite infestations, but keep the bees unharmed (13). Adult bees perform auto-grooming and allo-grooming, which is the act of removing mites from themselves or each other respectively. Bees will use their mandibles and legs to “remove the mite and then injure or kill it” (12). Adult bees can also detect the presence of mite offspring inside the brooding cells. And to prevent mites from spreading, the worker bees will destroy and kill any infected brood cell and brood within. Acaricides (pesticides for mites and ticks) can also be used to control for mite infestations. A common Acaricide used is a combination of concentrations of oxalic acid and a sucrose solution. A study done by Gregorc and Planinc (2002) showed that there was a 39.2% efficacy of mite removal after 3 treatments when brood are present within the colony. They also found that adult Western Honey Bees were 8% efficient at mite removal (13).

For our simulations, we have chosen a 50% removal efficacy of mites. Following our simulations of introducing a single infected mite into a healthy colony half way into the beekeeping season, we chose to allow our simulation run until day 200 (mid-July) which gave us about 3 infected mites within the colony. At day 200, our beekeeper notices the mites and decides to spray the colony with an oxalic acid treatment, which reduces the infected mites to about 1. The following figures displays the effectiveness of an acid treatment.

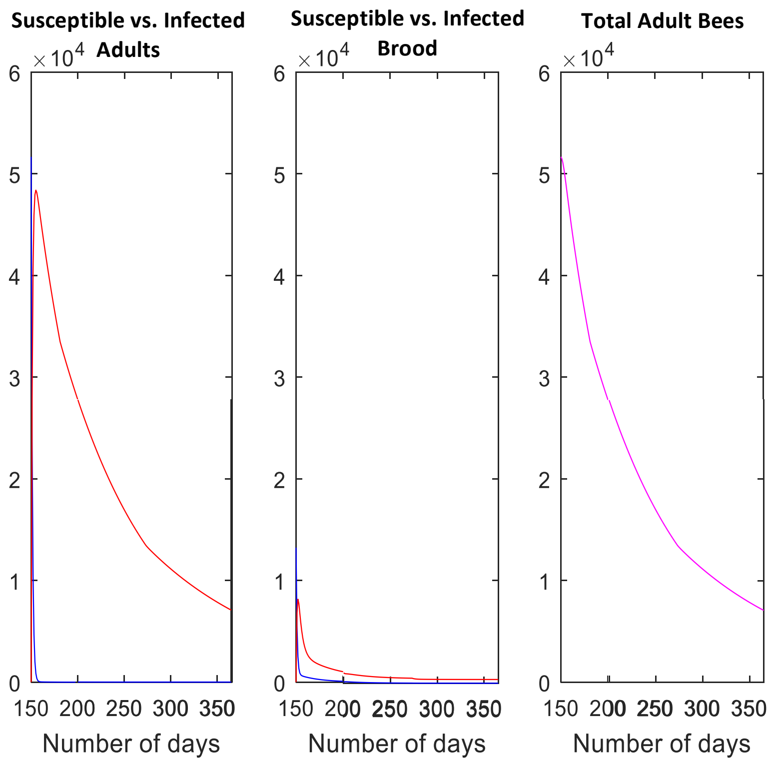


Figure 11 - The effects of acid treatment on the number of susceptible vs. infected bees

We can see that when we introduce one infected mite into the colony, almost all workers, drones, and brood become infected within a few days. Thus, spraying the colony for mites does little to nothing for the rate of infection within the colony. Since the spray is only eliminating mites, it does not stop the spread of the infection unless the spray was applied on the exact same day the infected mite entered the colony.

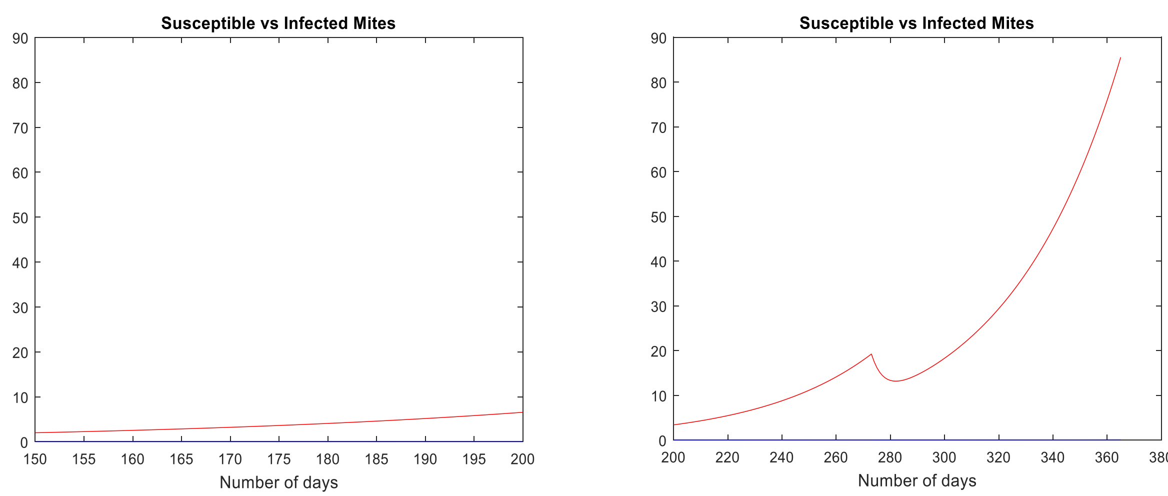


Figure 12 - The effects of acid treatment on the number of susceptible vs. infected bees

	Initial Conditions	End Conditions
Adult Bees (susceptible)	51444	0
Adult Bees (infected)	0	7078
Brood (susceptible)	12029	0
Brood (infected)	0	1
Mites (susceptible)	0	0
Mites (infected)	1	85

Table 1. Initial and ending conditions from day 150 to 365 on the number of adult bees, brood, and mites.

The above graph shows that starting with one infected mite at day 150 by day 200 there are 3 infected mites. After our beekeeper applies a treatment spray at day 200, the number of mites drops to approximately one. However, even after spraying the colony for mites, we can see that the mites will continue to grow as before for the rest of the year.

Varroa mites are always in honey bee colonies. Chemical treatments or cultural control are almost always necessary to manage infestations under damaging levels. However, even when chemical treatments are applied to reduce varroa infestations, there are always some varroa left over. They can increase their population within a colony to the point where the colony becomes severely weakened and will die. Beekeepers must take care not to delay late summer or early fall treatments for varroa mites as the winter bees that are being produced during this time must be healthy, as they will make up the winter population of bees (13).

DISCUSSION

An important remark is that our models infect adult bees and brood too quickly compared to reality. Although the mites do tend to jump from bee to bee, it is unlikely that just a few mites will infect the entire colony within a week. This of course affected our results and the disease appears to be extremely aggressive. While it's true that once DWV is found within a colony, the colony will die out within the next few seasons, our models indicate a colony collapse within the same season. From just one infected mite entering the colony on May 30th, rarely would the colony not make it through to spring of the following year. Nevertheless, our models still show some promising outcomes and some accurate qualitative results.

From the two experiments when we inserted an infected mite and a bee into the colony on May 30th (one with varroa already present and one without), we can see the time delay for the rate in which the infection spreads. It took a few weeks longer for DWV to completely take hold of all the adults and the brood when there wasn't already varroa present on May 30th versus the very quick takeover when there was varroa already present in the hive. Knowing that our models infect bees too quickly, we can conclude that having no infestation or just a small infestation of varroa, would be very beneficial to a colony that comes into contact with a mite carrying DWV.

It is thus crucial that beekeepers manage the health of their honey bees by suppressing the population of varroa in all of their colonies throughout the beekeeping season. This is not only to protect their own colonies, but to also avoid the likelihood that mites will be spread into other colonies through bee drifting. Chemical treatments and hygienic behaviour can help mitigate the growth of mites for a short time, but if there are any mites left to reproduce, they will begin their growth again. Multiple treatments throughout a beekeeping season would be essential, especially in the summer months when the growth rates of bees and mites are large, to reduce mite populations. Moreover, this will help maintain the varroa mites to low levels.

Although, getting rid of mites completely is a nearly impossible task, as it only requires one mite to reproduce, these treatments are still effective in lowering the number of mites within the colony, but the treatments do not help much in reducing the destructiveness in DWV.

CONCLUSION

Evidently, any signs DWV within a colony is bad news for the bees but we cannot lose hope quite yet. Although its destructiveness, DWV can be prevented by improving varroa control. Scientists are continuously looking for more efficient and effective tools to prevent drastic decreases in bee populations and to mitigate the spread of varroa. For now, early detection of low levels of mite infestation is the key to successful management of honey bee colonies. Beekeepers must be aware that mite infestations can occur quickly, and without proper treatment, mite populations can grow rapidly. Bees are a necessary part of our ecosystems, food supply and economic wellbeing. When bee populations are threatened, so are we. Given all of the threats bees currently face, not only from varroa mites and DWV but also from the widespread use of pesticides and climate change, we may need to rethink our daily relationship with nature to save the bees, and ultimately ourselves.

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