Honey Bee Colony Collapse Disorder Model (CCD)

1 Introduction

The Agent Based Model I have implemented simulates the population and cross pollination of Honey Bees and flowers when affected by various detrimental factors relating to Colony Collapse Disorder (CCD). The goal of this model is to find out how these different factors work together to cause CCD, a major issue currently affecting bee colonies all over the United States.

The pollination of crops is vital for agriculture in the U.S.. Agriculture in the U.S. is responsible for the growth of many common plants and foods that include things such as Almonds, Peaches, and Soybeans. In order for farmers to grow these crops, they require the help of various little creatures, winds, and insects to cross pollinate plants by carrying pollen from one crop to another to aide in the growth of new crops. The most important of whom, happen to be Honey Bees. An article on Mother Nature Network describes the importance of bees as such:

> *…According to the U.S. Department of Agriculture, these under-appreciated workers pollinate 80 percent of our flowering crops, which constitute one-third of everything we eat. Losing them could affect not only dietary staples such as apples, broccoli, strawberries, nuts, asparagus, blueberries and cucumbers, but may threaten our beef and dairy industries if alfalfa is not available for feed. One Cornell University study estimated that honeybees annually pollinate $14 billion worth of seeds and crops in the U.S.*

> *Essentially, if honeybees disappear, they could take most of our insect pollinated plants with them… ("*The Importance of Honeybees" 1)

However something is killing the bees in the U.S.. In 2006 beekeepers and farmers started to notice significant losses in bees, and over time, those losses only got worse. Back in early May the Empire State Tribune reported that in Colorado the percentage of honey bee colonies that died between April 2014 and April 2015 was 42 percent, which is 11 percent more when compared to only a year ago (2). This phenomenon isn't specific to Colorado either, bee colonies all around the U.S. disappearing at an alarming rate. The cause for such a shocking increase in the loss of bee colonies is what scientists call Bee Colony Collapse Disorder (CCD).

1.1 Explaining Bee Colony Collapse Disorder (CCD)

Simply put, Colony Collapse Disorder has scientists baffled. It is not that they are unable to find a cause for CCD, but rather there are so many being thrown around yet not one is significant towards CCD on its own. Reasons ranging from genetically modified organisms (GMOs) to cellular phone towers were all speculated to cause CCD, though none of those have been proven to be true. Still over the years many causes towards CCD have been found. The model will explore four of these factors.

1.1.1 Pesticides

According to the US Department of Agriculture (USDA), high levels of pesticides have been found in bee hives affected by CCD. In many cases, these pesticides are used to kill off any insects that harm the various crops that are grown, but inadvertently cause harm to the honey bees come to pollinate those crops. These pesticides include a varying degree of chemicals, some relatively harmless to bees and others highly toxic. While most pesticides do not have a huge effect on bees, the few that do including Neonicotinoids and Coumaphos, especially combined, can cause considerable damage to the nervous system of honey bees, specifically aiding in a bee's loss of function (4).

1.1.2 Varroa Mites

The Varroa Mite of Varroa destructor is a parasitic arachnid that attaches itself to an unsuspecting bee and sucks its blood. While this causes harm to the bee, it also leaves wounds that can easily become infected with various bacteria, fungi, and viruses such as Deformed Wing Virus that have the potential to harm the bees even more. On top of that, treating bees with Varroa Mites often requires the use of a miticide that contains Coumaphos, one of the pesticides that have been shown to be highly toxic to bees (5).

1.1.3 High Fructose Corn Syrup

A typical bee diet consists of honey and bee-bread, a food source derived from the pollen collected by bees. These food sources contain the enzyme p-coumaric, which turns on certain detoxification genes that strengthens a bee's immune system. However because honey is taken by beekeepers to be sold, and less and less wild flowers are found around the U.S., beekeepers and farmers have begun to feed their bees High Fructose Corn Syrup instead. This practice fails to expose the bees to p-coumaric and other important nutrients, and as a result, leads to bees having a weaker immune system making them more vulnerable to detrimental factors such as pesticides and Varroa Mites (6).

1.1.4 Deforestation

Bees are lastly affected by the construction of roads and building that limit their natural resources. With less space to find wild flowers to collect pollen, bees become limited in how many resources they have to make honey and bee bread.

2 Motivation for the Model

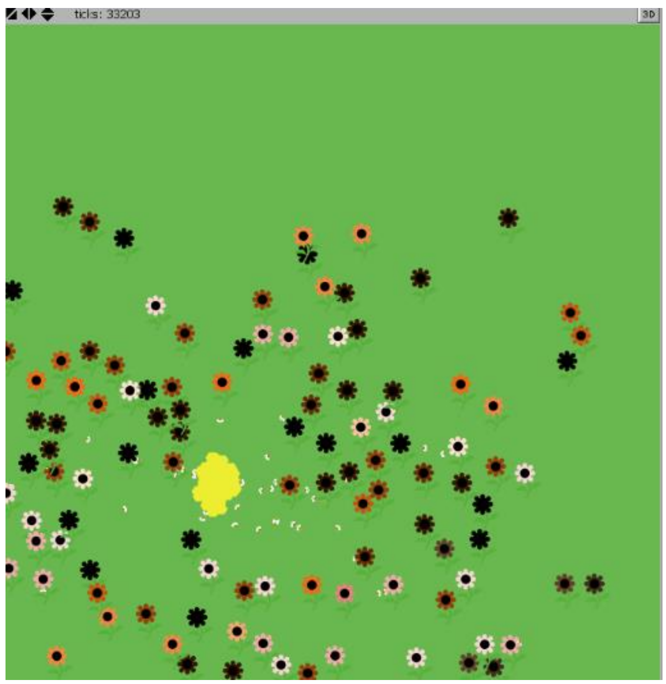


Figure 1: The Honey Bee Colony Collapse Model Visualization

With Colony Collapse Disorder being the cause of various factors working together, the main motivation for simulating this phenomenon in Agent Based Modeling is to find out how the four factors outlined above might independently and cooperatively cause CCD.

2.1 WHAT CAN BE LEARNED

The intention of this model is to find out the effects the different factors will have on bee and flower populations, the key question being, exactly how do these factors work together to cause CCD? And perhaps, in extension, the model might be able to foster discussion on what actions we as a nation should take to ensure the decline of CCD.

In terms of specifics, there are a few important pieces of information that should be able to be taken from this model.

2.1.1 The Potency of Pesticides

A big question among researchers right now is the apparent effect of pesticides on bee populations. Some swear by pesticides as the main reason for declining bee populations and push banning various chemicals, while others believe that other factors in conjunction with pesticide use are the main causes of CCD. On top of that, the potency of a specific pesticide is important to understand in both situations and complicates the discussion even more. This model will attempt to simulate both situations with an adjustable relative potency in pesticides in order to get a better understanding of which theory is more believable.

2.1.2 High Fructose Corn Syrup a Real Problem?

Another controversial issue is concerning the use of high fructose corn syrup as a main food source for Honey Bees. Namely, how big of an issue is it for a bee to have a weakened immune system? This model aims to find out, in conjunction with the other factors, when High Fructose Corn Syrup can be an issue that ultimately factors towards CCD.

2.1.3 When All Four Factors Appear

While researches cannot agree on which factor is the most significant contributor to CCD, it is universally agreed that in bee colonies the suffered from CCD, there was evidence of all four factors mentioned previously. As a result, the question that begs to be answered is in a healthy hive environment, what happens when all four factors of CCD are introduced into the system? Does it collapse immediately? Is it gradual? Does it collapse at all?

2.2 Rationale

The rationale for modeling CCD with agent based modelling comes from the desire to test multiple unique scenarios among various different kinds of bee populations to get a better understanding of the underlying causes of CCD. There is a bit of randomness involved with bee movements and the growth of various flowers which greatly affects bee and flower populations, and being able to visualize these while under the influence of various factors such as pesticides might lead to a greater understanding of CCD.

With the causes CCD being such a debated issue, The Honey Bee CCD Model should be able to be used as a tool to realistically demonstrate these causes in various situations and settings. Users will be able to customize a variety of settings to fit their own perceptions of CCD. Even if two users had contrasting beliefs on the severity of the influence of pesticides on bee colonies, then they should be able to set their own factors to present their own individual arguments.

Another benefit to using agent based modeling is the ability to observe a system as well as an individual agent. With ABM users will be able to observe trends that affect the system as a whole, but also monitor specific agents to see how the different factors of CCD might affect their behavior. The variables of these individual agents can also be tracked and monitored to see any trends that might appear.

3 Implementation of the Model

Implementation of the Honey Bee CCD Model can be split into two parts, the bee flower population model, and the implementation of the four factors that contribute to CCD. For the bee flower populations the agents in the system follow a set of rules to ensure thriving populations.

3.1 The Agents

The agents of the Honey Bee CCD model consist of different breeds of turtles and the patches. These different breeds of turtles include bees, flowers, and hives.

3.1.1 Bees

The bees are concerned with only two things, collecting pollen for the hive and staying alive. To do this they will seek out flowers and collect pollen from them.

Rules:

1. I am born in the hive with random energy and age
2. I move around randomly at a speed of .25 per tick
3. If I see a flower in my cone of vision, I will turn towards it and fly at a speed of .5 per tick

4. If I touch a flower and it has pollen, I will collect one pollen from it and look for another flower
5. If I have five or more pollen, I will turn towards my hive and fly there at .5 per tick
6. Once I reach my hive I will deposit five pollen
7. If my energy gets too low, I will consume a pollen
8. If I fly over pesticide sprayed lands (pink, light pink, light green) lose energy of value pesticide-potency
9. If Mites are on, lose energy every 5 ticks or so
10. If High Fructose Corn Syrup is on, add energy every 10 ticks or so but take twice the damage from pesticides and mites
11. Each tick I lose energy and I age
12. If my energy or age reaches zero, I die

3.1.2 Flowers

The flowers are concerned with producing pollen and planting the seeds for new flowers to grow. In order to do this, they need the assistance of bees to cross pollinate.

Rules:

1. I am born with a random age on top of grass or pesticide sprayed grass
2. Every tick I have a chance of increasing my pollen count by one
3. If a bee lands on me and I have pollen, I lose one pollen
4. If a bee lands on me and it is carrying pollen, I become pollinated

5. If pollinated, I have a chance every ten ticks to release to spawn a new flower up to fifteen patches away from me.
6. If my offspring is to spawn on roads, don’t let it spawn
7. Every tick my age goes down by one
8. If my age reaches zero, I die

3.1.3 Hive(s)

The main hive is a yellow rectangle which acts as the spawn point of every bee. Its purpose is to store nectar created from every five pollen that is returned by bees, and to grow in size.

Rules:

1. I am spawned randomly in the world
2. Every time a bee deposits 5 pollen into me, I increase in nectar by one
3. For every hundred nectar I receive, add on another yellow rectangle adjacent to me

3.1.4 Patches

The patches represent the ground of the system. In most cases its grass but in certain cases it can be pesticide treated land or roads

Rules:

1. I spawn green 55.5

2. If sprayed pesticides, turn pink

3. If pink for 1000 ticks, turn light pink

4. If light pink for 1000 ticks, turn light green

5. If light green for 1000 ticks, turn green

6. If set to road, turn dark gray

3.2 Interface of the Model

The interface of the model is composed of the setup and go buttons, the display, sliders for the variables, switches and choosers for the CCD factors, and different monitors and plots for data analysis. Each can be interacted with and affects the model in various ways.

3.2.1 Setup and Go

When pressed, the setup button will reset the model and randomly place a hive or hives, and flowers around the display. Go will start the model ticking and release bees from the hive to create the population model.

3.2.2 Display

The display will show the actual model at work. While the model is running small bees should be seen interacting with the hive and various flowers. Depending on the settings, a user may also interact with the display by clicking patches with the mouse which can spray pesticides, make roads, or revert patches back into grass. It is located on the right side of the UI.

3.2.3 Variable Sliders

On the left side of the UI should be a column of various variable sliders that control the variable of the bees, flowers, hive, and CCD factors. These can be altered to change the conditions and outcomes of the model. Their values of the sliders upon first opening the model are the default values, and will be used in the analysis portion of this report.

3.2.4 CCD Factor Switches

On the right side of the sliders near the top is a chooser and a couple of switches that allow for the various CCD factors. The chooser decides what mouse interaction does upon clicking a patch (pesticides, roads, grass). The two switches can be used to turn on corn syrup feeding and mite infections among the bees.

3.2.5 Monitors and Plots

Below the CCD Factor Switches are a few monitors and plots that can be used to analyze the data output by the model. The monitors include the number of bees, flowers, hive size, and total pollen among flowers. Similarly the plots have graphs of all these values over ticks in the model.

3.3 Implementation of the CCD Factors

The four different factors toward CCD implemented are all unique and affect the population model in various ways.

3.3.1 Applying Pesticides

Pesticides can be selected using the chooser and applied using mouse clicks. Clicking on a patch will turn that patch and its neighbors a pink color. In 1000 ticks the pink color will become light pink, then light green in another 1000 ticks, then return to green grass after a final 1000 ticks. While the pesticide sprayed grass is not green, a bee will suffer damage equal to the pesticide-potency per tick while flying about the sprayed patch.

3.3.2 Switching on Varroa Mites

The Varroa Mites can be switched on using the Mites? Switch on the UI. This will cause new bees to have a chance equal to the mite-infection-rate of being born with the Varroa Mite which will remove energy from that bee every 5 ticks or so based on the mite-damage slider. This is to simulate the mites sucking blood from the bees and causing infections.

3.3.3 Switching on High Fructose Corn Syrup

Feeding the bees High Fructose Corn Syrup can be switched on using the Corn-Syrup? Switch. When it is on bees will gain energy at a rate of the corn-syrup-value every 10 ticks or so. However they will also take twice as much damage from pesticides and Varroa Mites.

3.3.4 Building Roads (Deforestation)

Roads can be built on the grassy patches by selecting roads on the chooser and clicking on the patches. The clicked patch and its neighbors will turn dark gray and act as roads which do not allow for the growth of flowers. This can have considerable change to the behavior of bees and flowers in the population model.

4 Model Analysis

A bee colony is incredibly delicate yet versatile at the same time. The population can withstand many forces, yet when the factors that lead to CCD work together, honey bees stand no chance. Their populations are quick to decline which causes flower populations to decline as well. Eventually the hive dies out when there are no more bees to keep it up.

When not affected by CCD factors, the system will exhibit a health population where both bees and flowers reach a certain capacity and stay at a generally similar population. The BehaviorSpace chart below shows the population of bees and flowers over 10000 ticks with default initial values. It can be inferred from the chart that the bee and flower populations, which start off small, quickly grow until reaching a maximum at around 250 to 300 where they start to plateau. In almost every instance of running the model, this trend can be observed. The bees and flowers share a healthy relationship and consistent population.

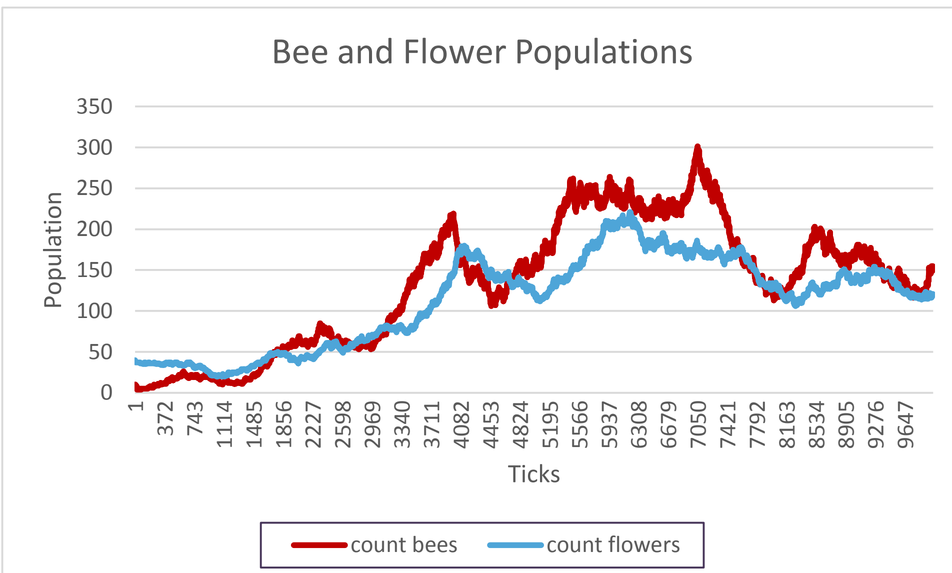


Figure 2: Bee and flower populations with default values

Although this model is meant to be used as a tool with customizable settings, this analysis will explore how the different CCD factors, alone and working together, affect this healthy population model with its default settings to cause its collapse. Default settings can also be found on this model's Info tab.

4.1 Pesticides and Varroa Mites

Pesticides and the Varroa Mites are the first relevant factors that contribute to CCD since they do observable physical harm to bees, and as such, often get the most media attention. To analyze the effects of pesticides on my model's bees, I edited my model's code to have pesticides applied to every flower's patch.

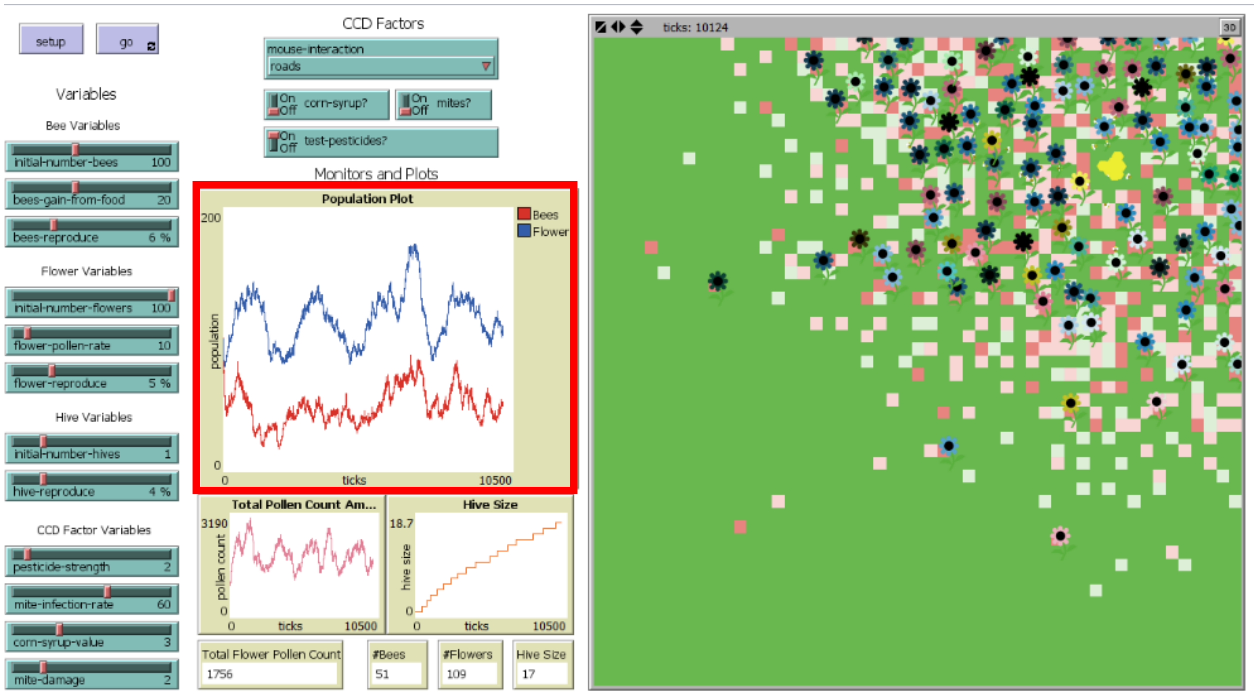
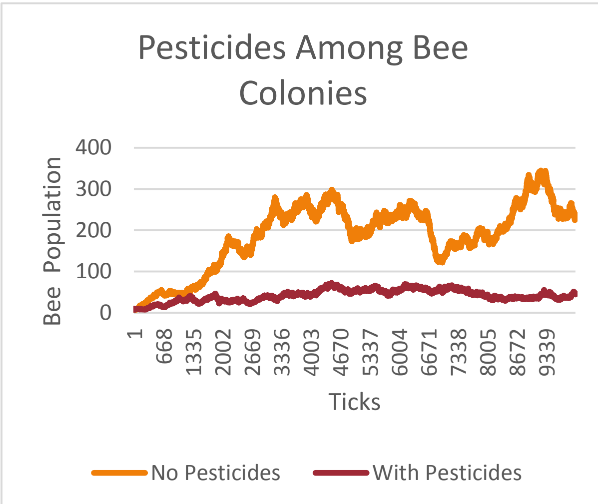
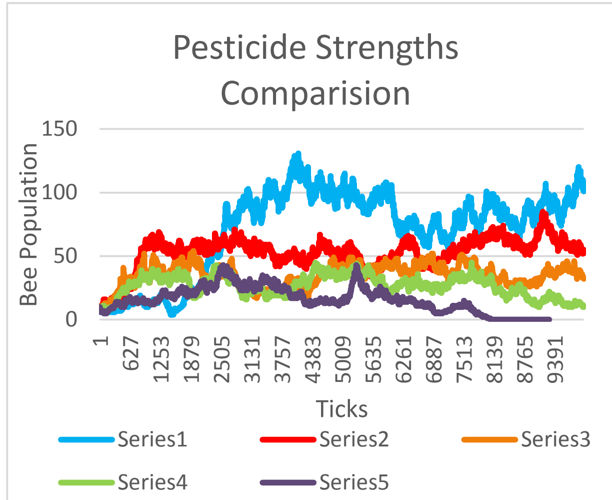


Figure 3: The user interface of the model with pesticides turned on. Notice the plot outlined in red.

As you can see from the UI (figure 3), the pesticide-strength is set to only 2 but it already has had considerable effects on the population of bees. As noted by the population plot to the right of the display (outlined in red), the graph of bees outlines in red follows the same trend as the flowers in blue, but is at a much lower amplitude, so while flowers are being pollinated and reproduced, the amount of bees have been cut significantly. This is especially noticeable in the

BehaviorSpace graph displayed below. When pesticides are in effect the population stays steady but does so at a much smaller population.

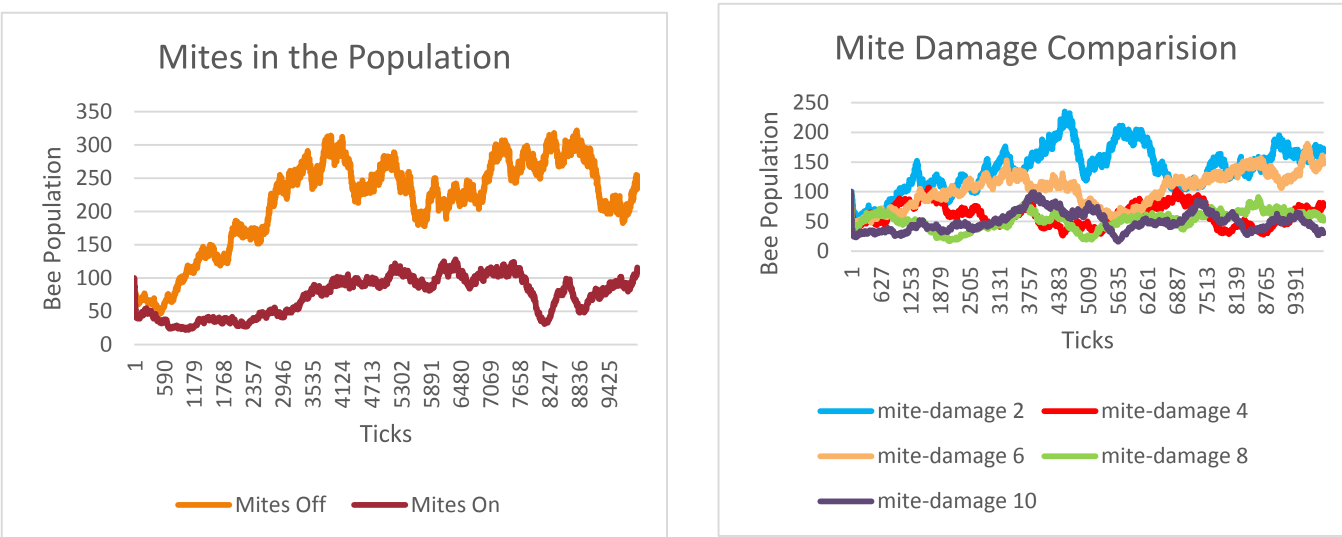




Figures 4 & 5: Plot of bee population differences (pesticides) and different pesticide strengths

The chart to the right (figure 5) shows the changes in bee populations over time when different pesticide-strength values (where the series is the value) are initialized. It's clear that stronger pesticide strengths can lead to a bee population completely disappearing, so highly toxic pesticides can be a pressing danger to bee colonies, but more realistically pesticides do little damage to bees so the first two values are a bit more realistic, which show that while pesticides still do damage, the bee populations are still stable enough to survive as the chart on the left (figure 4). Perhaps if they are paired with other factors collapse of the bee colony is more probable.

The Varroa Mites have a very similar trend when introduced into the population model. They are turned on via a switch and infect bees based on a set mite-infection-rate variable slide. In a healthy initial model set with 100 bees and flowers, having mites on and off, similar to the pesticides, will curb the mean bee population but not be able to actually cause colony collapse. In fact, even its two plots (figures 6 & 7) look oddly similar to those of the pesticides.



Figures 6 & 7: Plot of bee population differences (mites) and of mite-damage differences

Even when the pesticides and mites work together, in their default values they still cannot cause a colony collapse, but instead just leave the bee population at a very low average. In the UI presented below (figure 8), the population plot has the bees sitting around 30 bees on average but still shows stability. In order to completely rid the population of bees the two factors would need to cause a lot of physical damage which isn't typical in the real world since it would be easily observed if that were the case. That means that more factors are causing a drastic change to the system.

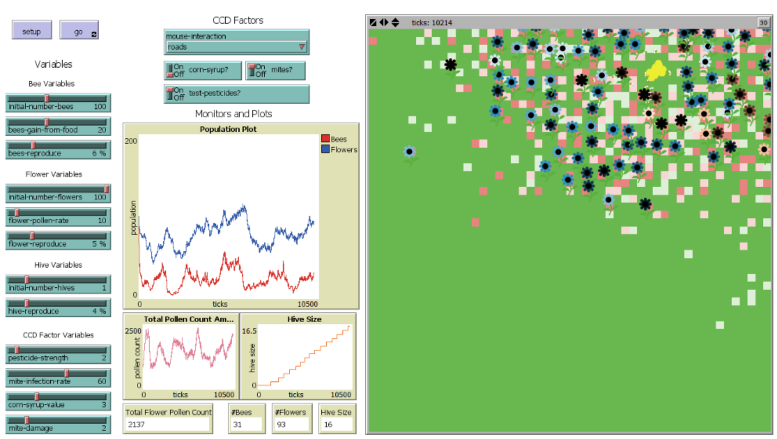
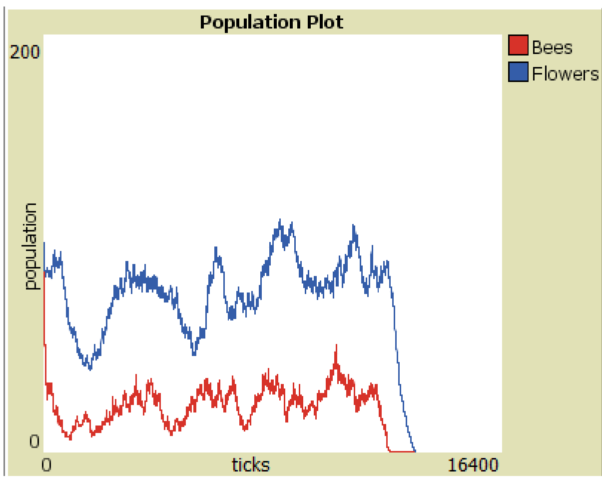
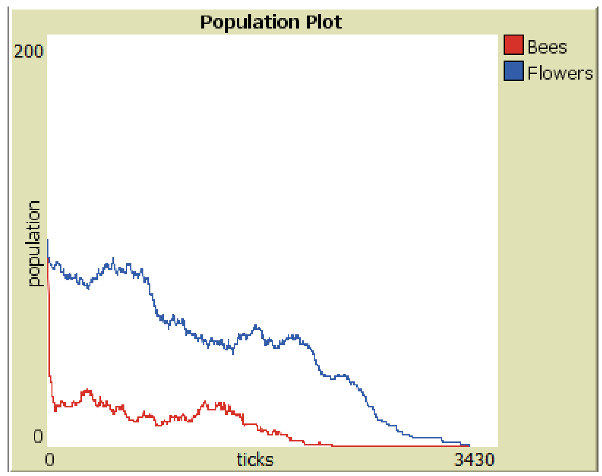


Figure 8: The UI when both pesticides and mites are on

4.2 Immunity Deficiency through High Fructose Corn Syrup

High Fructose Corn Syrup cannot cause any damage to the bees by itself. In fact, in the CCD model High Fructose Corn Syrup actually increases a bee's energy. Its detrimental effects come from it being paired with other factors since it does not supply a bee with the nutrients it needs to build up a strong immune system. As a result, adding this factor to pesticides and mites very easily cause CCD.





Figures 9 &10: Population plot of bees once corn-syrup? Is turned on, plot when starting with corn-syrup? on

On the left (figure 9) is the exact same population plot from the last model (with pesticides and mites on) after being run a few hundred more ticks with the corn syrup factor turned on. Almost immediately the bee colony completely collapsed, taking the flower population soon with them. On the right (figure 10) is a run through with the same settings with corn syrup turned on from the very beginning. There is an immediate drastic drop at the beginning and then a gradual decline until there is a complete colony collapse.

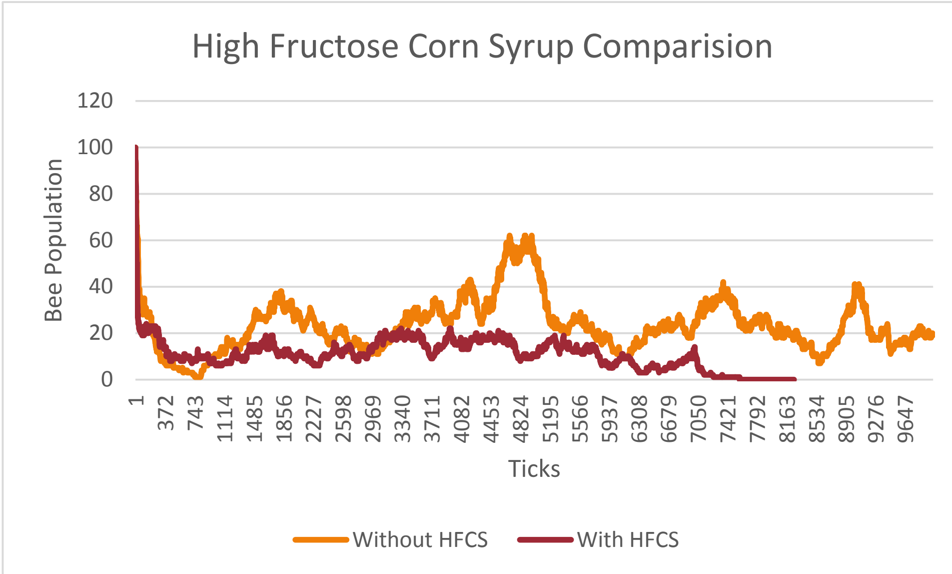
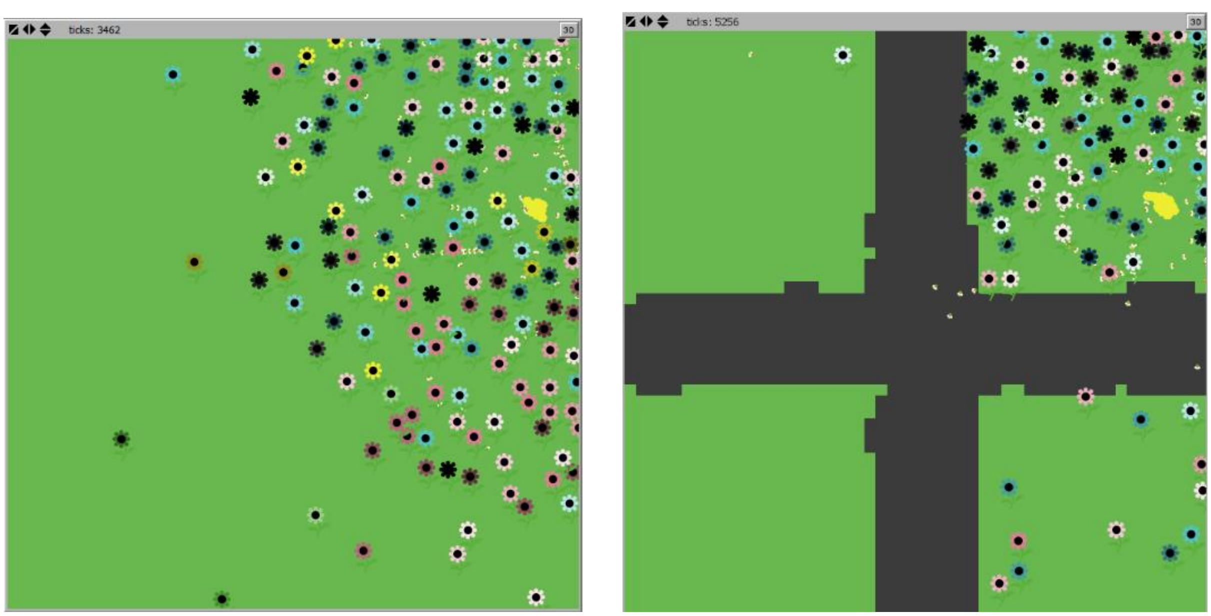


Figure 11: BehaviorSpace comparison of HFCS vs no HFCS

Here is a run through comparison using BehaviorSpace comparing the same settings with and without High Fructose Corn Syrup turned on (figure 11). The graph shows colony collapse coming in around 8000 ticks on the run through with High Fructose Corn Syrup turned on while the other run through appears to stay stable.

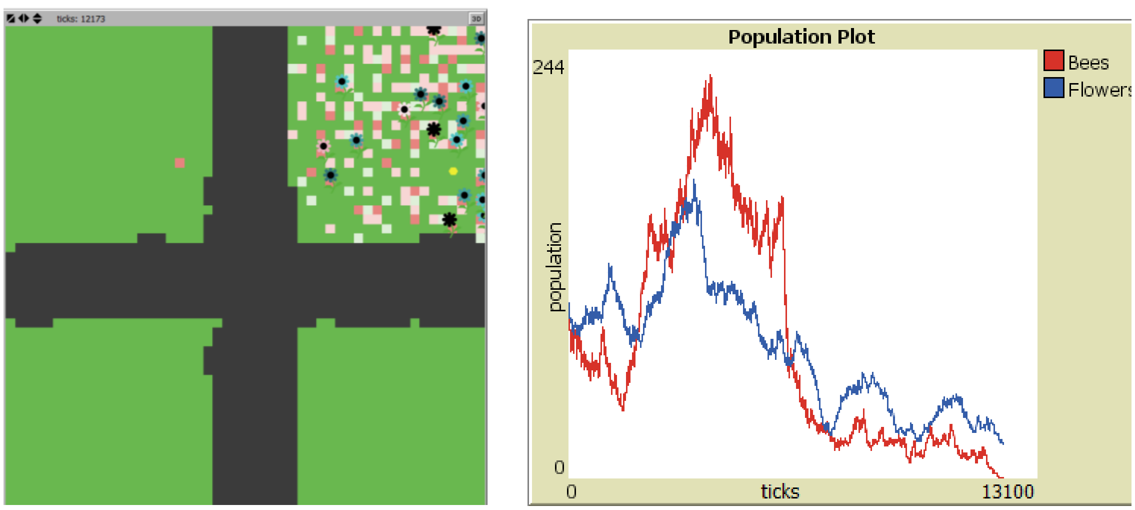
4.3 Changing the Behavior of Bees Using Roads

Along with High Fructose Corn Syrup the last CCD factor, deforestation, can help push pesticides and mites into cause colony collapse disorder.



Figures 12 & 13: Initial model without roads and model with roads implemented

On the left (figure 12) is the initial model (without pesticides or mites) after 3462 ticks. The flowers are close to the hive but still scattered about, and the spread of the flowers are growing to cover the entire display. On the right (figure 13) is the same model with roads put in to split the display into four quadrants and run for 2000 more ticks. The behavior of the bees and flowers have changed significantly. With flowers being unable to grow on roads, bees are less incline to cross them and instead stay within the quadrant containing the hive. As a result, only flowers close to the hive are pollinated so most flowers only grow in that same quadrant. This causes bees to be clusted into the same space. With the limited space, the amount of flowers also goes down which in turn causes the bees to decline a bit.



Figures 14 & 15: Display of model with roads after pesticides, and population plot of said model

Here is the display (figure 14) and the population plot (figure 15) of the same run when the pesticides are turned on. On the display because of the clustering of flowers in the top right quadrant near the hive, more pesticides are applied there thus affecting more bees for a longer time since the bees also spend more time in that quadrant. The population plot on the left shows a dip one the pesticides are applied (halfway down the ticks axis) that gradually kills off all the bees and causes a colony collapse. It can be concluded that deforestation that blocks hives into a smaller area combined with pesticides can easily cause CCD. The mites on the other hand do not cause CCD when coupled with deforestation since the mites are not affected by changes in space.

5 Conclusions and Possible Extensions

With the use of ABM the Honey Bee Colony Collapse Disorder Model aims to be a valuable tool in visualizing the causes and effects of Colony Collapse Disorder. Through Analyses such as the one performed in the previous section, I hope the this model will help explore the various factors of CCD that include pesticides, Varroa Mites, High Fructose Corn Syrup, and deforestation, as well as their relationship with each other.

There are many possible extensions however that can be added to this model to improve it. The first being increased communication among bees. While this model has each bee acting separately, I would love to be able to use links to simulate communication which would lead bees to share information about were certain flowers were. This might have even lead to a different result in my deforestation analysis if it was implemented. Another additional feature that would have been good to have would be more accurate cross breeding between flowers. A newly born flower should share and combine traits from both its parents, not just one. In the current model a new flower will have a variant color depending on the flower that hatched it, but I would like to also have its color affected by the color of the flower that had its pollen used to pollinate the parent flower. It would have at least made for a more colorful board. Lastly I would have loved to flesh out the Varroa Mite factor in this model. In reality, the effects they have on bees is far more complex than what is programmed already. There is a risk for infections and various different viruses and diseases a bee can receive just from having been infected by a mite. Unfortunately the implementation of it here can be considered primitive, but hopefully it's something to think about in the future.

Still, even with many untapped territory I hope that this model goes to good use and might help educate users on the causes and consequences of Colony Collapse Disorder. It truly is a pressing issue that needs more exposure so I'm very grateful to have been able to model this phenomenon.

6 References

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