Simulating Pollinators to Find How Habitat Loss Affects Biodiversity

Grant Proposal

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Abstract

Nearly one third of all agriculture relies on pollination from bees. Native pollinators are very important to both native ecosystems as a keystone species and to farms because they provide pollination without needing to be constantly taken care of like the domesticated honeybees that commercial farms oftentimes use to pollinate their crops. Habitat fragmentation is causing decreased numbers of these native pollinators by removing their sources of food and places to make nests. To mitigate their falling populations due to habitat fragmentation, different flower types and positions that most effectively mitigate these problems are needed. This experiment evaluates the effectiveness of possible solutions when trying to increase the survival of native bees using software to simulate their behavior. To test these animal's approximate behavior an agent-based model with varying bee agents that interact with a population of flowers was created. Then, various levels of habitat fragmentation were created to test the effects of habitat fragmentation on bees with different flower preferences and different patterns of solutions were tested. This research could be applied to different empty green spaces around towns and farms to help promote native pollinators in that area and help reverse the decline of native bees.

Keywords: Agent-based modeling, habitat fragmentation, native pollinators, agriculture, bees

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General Context

Pollinators are made up of different types of animals, but the most significant pollinators are the various bees (Rong & Sadhukhan, 2021). Bees are keystone species, about ⅓ of our agriculture relies on them as pollinators (Rong & Sadhukhan, 2021). However, they have been in decline due to various problems such as pesticides, diseases and parasites, climate change, fragmentation and loss of habitat (Rong & Sadhukhan, 2021). The most known bee is the western honeybee (*Apis mellifera*); however, there are many other types of bees that are extremely important in the pollination of plants, like the various types of bumblebees that are native to North America. Native bees are important as they are well adapted to the plants of the area and can provide pollination without the need of being kept by beekeepers (Kremen et al., 2002; Beecology Project, n.d.). They are also often better than honeybees at pollinating the type of flower that they specialize in (Sapir et al., 2017). Much of our pollination comes from native bees, even though the continued decline. Oftentimes, these important native species of bees do not receive the same conservation as honeybees (Beecology Project, n.d.).

Habitat Fragmentation

One of the major factors that is contributing to the decline of bees and other pollinators is the fragmentation and the loss of habitat. Habitat fragmentation, the breaking up of habitat into smaller, separated pieces, can have various negative effects on pollinators like bees because of reduced living space and places to find flowers. Still, fragmentation can also have other more subtle impacts. One of these is that habitat fragmentation can cause the flowering periods of plants to shift times, changing when the pollinators are able to visit the flowers. This shift in bloom times leads to the phenological patterns between pollinators and plants to become misaligned, leading to a greater risk for local pollinators to die out (Xiao et al., 2016). Habitat fragmentation can affect what flowers bees can access, causing bees to have less flowers that they can access, impacting their ability to survive. Native bees need to be close to flowers as they are more likely to access flowers when they are close to the edge of forest (Huais et al., 2020). Also, different types of bees act differently in the types and number of flowers they will collect food from. Some bees are more generalist, meaning that they pollinate many different types of flowers, while others are more specialist, meaning that they pollinate only a couple of types of flowers. This difference leads to differing consequences of habitat loss on them (Figure 1). Generalist bees, in general, do better in the face of habitat fragmentation

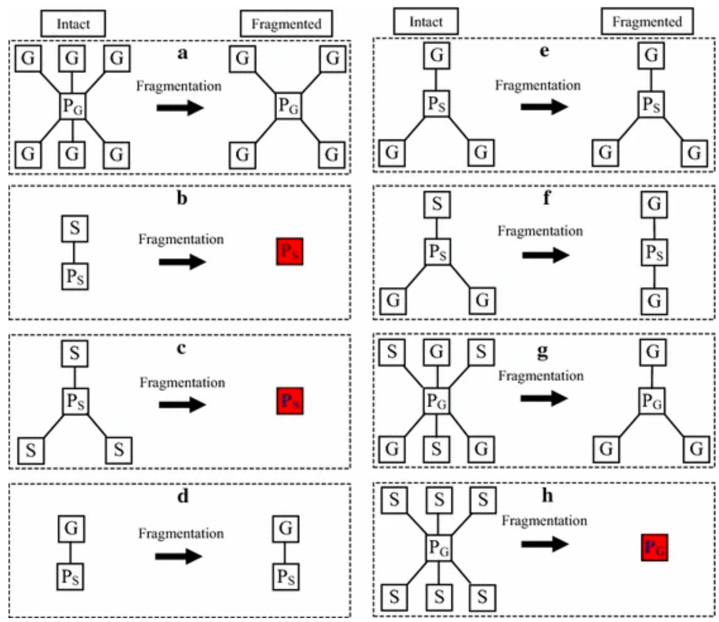

Figure 1. This chart shows a general model of the how well a generalist and a specialist bee would survive in response to habitat fragmentation, with fragmentation taking away several of the pollinators' flowers that they can access. P_S represents a specialist pollinator. P_G represents a generalist pollinator. S represents a specialist plant and G represents a generalist plant. The line connecting elements represents that they have plant-pollinator relations (Xiao et al., 2016).

when compared to specialist bees due to having a wider range of food sources. Therefore, when habitat fragmentation leads to the loss of some populations of flowers, generalists can more easily switch to another source of food. In contrast, specialist pollinators are more likely to lose their only source of food. As a result, habitat loss selects for more generalist pollinators and a decreased biodiversity of the pollinators, but specialist pollinators are more beneficial to the plants (Beecology Project, n.d.).

Research Question

Is there a way to limit the effects of habitat loss on bee populations using the varied placement of flowers and usable habitat? I hypothesize that if I have flowers that native bees are naturally attracted to in more concentrated smaller patches spread throughout, I will be able to mitigate the effects of habitat loss. My approach to this problem is using Agent-based Modeling to simulate the bee's behavior and apply the bee's behavior with different patterns of habitat loss and different populations affected to find ways to mitigate effects. Agent-based simulations have been able to model many factors that go into the health of a hive, making it a useful tool to be able to predict behavior of bees (Rivière et al., 2018). I will specifically look at different flower distributions and how different bees may prefer to land on some types of flowers more than others.

Agent-based Modeling

Agent-based models are simulations with different coded entities called agents that interact with each other, which allows for the behaviors to be coded and various organisms to interact with each other. These biological systems can be approximated with enough accuracy that different variables can be studied, provided useful information (Introduction to Simulation, n.d.).

Section II: Specific Aims

This proposal's objective is to study where the placement of flower patches will help provide access to nectar and pollen lost from habitat fragmentation for the different native pollinators of different areas. Solutions will be found by studying varying nectar collecting patterns and different flower preferences using a simulation coded in an agent-based modeling programming software called Netlogo.

Our long-term goal is to help mitigate the effects of habitat fragmentation on native bees by planting patches of specific flowers.[1] These flowers could be strategically placed in areas that are currently only being used as empty grass areas. The rationale behind using an agent-based model for this problem is that by simulating the flower preferences and other behaviors of native bees, the most optimal placement of wildflowers to aid in mitigating habitat fragmentation will be determined. This simulation can consider different behaviors of various species. This could help stop native bees from dying out due to the loss of habitat.

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[1] Much of the habitat that native bees rely on to live in is being used for agricultural or other purposes. Olivia Kline and Neelendra Joshi claim that to help to remedy this problem, patches of flowers or "floral strips" can be planted in agricultural or other regions to help provide habitat to native bees. (Kline & Joshi, 2020).

Specific Aim 1: The objective is to create a simulation that models the behavior of multiple bee species with different flower preferences on a scale that can handle many flower patches.

Specific Aim 2: The objective is to create a simulation that models the different behaviors of generalist and specialist bees.

Specific Aim 3: The objective is to apply the simulation to different levels of habitat fragmentation and different possible solutions.

The expected outcome of this work is that flower patches spread throughout the areas of habitat fragmentation will be able to help mitigate the effects of habitat fragmentation on bees that are both specialist and generalist.

Section III: Project Goals and Methodology

Relevance/Significance

In a world with an ever-growing population, agriculture is of utmost importance, which makes the pollinators that help these plants grow even more important. However, the population of the most common pollinator, the bee, has been declining. While the honeybee isn’t likely to go extinct due to its commonality, native bees, which are more apt to pollinate the local plants of an area and do not need the constant care of a honeybee hive, are in danger (Borst, 2015; Kremen et al., 2002). They both provide pollination to crops in the area without needing to be kept and transported to pollinate the flowers. They are also keystone species as many organisms directly or indirectly depend on them (Kremen et al., 2002).

Innovation

Agent-based models have individual agents that interact with each other to simulate organisms in an ecosystem. The agents in this model were bees, hives, and flowers. Each of the three species had one starting hive with a set number of bees, these bees would then be released in seasons to collect nectar. The flowers which the bee agents would collect nectar from was determined by their preference for certain flowers. This allowed for some species to be generalist and visit any flower, while some were specialist and would avoid certain species of flower. This nectar collected would then go on to determine how many new bees could be produced as well as how many new hives could be produced. Every passing of time, or tick, any flower or hive agent on a white area would be removed to be able to model how habitat fragmentation limits the area which these bees and plants can be.

Methodology

The model would be run with a different background that represented different levels of habitat fragmentation. This simulation would be run for a total of 10 seasons for each run. Then resulting data of the population levels throughout the 10 seasons would then be used to determine the effects of that habitat fragmentation.

Specific Aim #1:

The objective is to create a simulation that models the behavior of multiple bee species with different flower preferences on a large scale. The approach is to take a previous model created as a framework. The previous model provides a model to have different preferences for different flowers and the mechanisms for pollination. The proposed models can then be expanded to a larger scale with bees interacting with flower patches containing various proportions of flowers and amounts of available nectar instead of having the bees interact with individual flowers. The rationale for this approach is that habitat occurs on greater scales than singular patches of flowers. Therefore, to create a model that simulates habitat fragmentation, there needs to be a way to scale up to groups of many flowers. The scaled-up model will allow more hives to be shown, and it will allow for the simulation to be less computationally taxing.

Justification and Feasibility. This model will help address the specific aim in that it will allow for different types of bees to be tested within the model. The starting code was provided by Ryder et al. (n.d.), which already shows the effects of different flower preferences on two different bees (Figure 2).

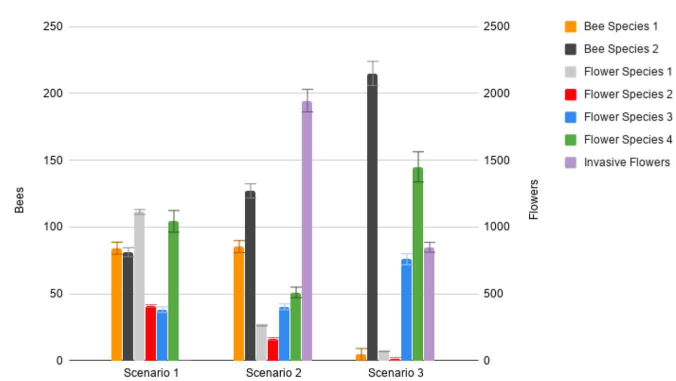

Figure 2. The simulation that generated this data considers 2 bee species as well as 5 different flowers, four native and one invasive. The model measures the flower and bee population for three different scenarios with the two different flowers preferring different flowers (Beecology Project, n.d.).

Summary of Preliminary Data. Preliminary data has shown that the model is working well.

Expected Outcomes. The expected outcomes are that it will produce a working model that can be applied to the next steps of the project.

Potential Pitfalls and Alternative Strategies. A possible pitfall is that the computer would not be able to handle the level of computing needed for the bee and flower agents and to generate their behavior. An alternative solution to the problem would be by simplifying the simulation. Simplifying the simulation would be done by having beehives collecting nectar based on how many flowers are near and then telling the flowers to pollinate themselves based on just a random probability instead of the chance of the bee running into the patch, essentially removing a step in the process of the bee agent moving around.

Specific Aim #2:

The objective is to create a simulation that models the different behaviors of generalist and specialist bees. The approach to creating this model is to have several different types of bee agents in the agent-based model that all have different preferences for different flowers. To model generalist and specialist pollinators, some bees will be programmed to prefer many different types of flowers. In contrast, others will be programmed to prefer just two or three types of flowers, requiring many different species of flowers and bees to model accurately. Individual generalist bees tend to focus on one kind of flower when collecting pollen, possibly being included in the simulation by raising the probability of a bee landing on a flower if the bee had just landed there (Pollination, n.d.).

Justification and Feasibility. As a result of modeling both generalist and specialist bees accurately, many different types of bees will be able to be modeled, giving greater depth into the different species that can be studied because of the varied behavior shown by the study.

Summary of Preliminary Data. Different bees have been shown to be more reliant on their respective types of flowers. When a certain species has a higher population its respective flower populations it relies on tend to be higher as well (Figure 3).

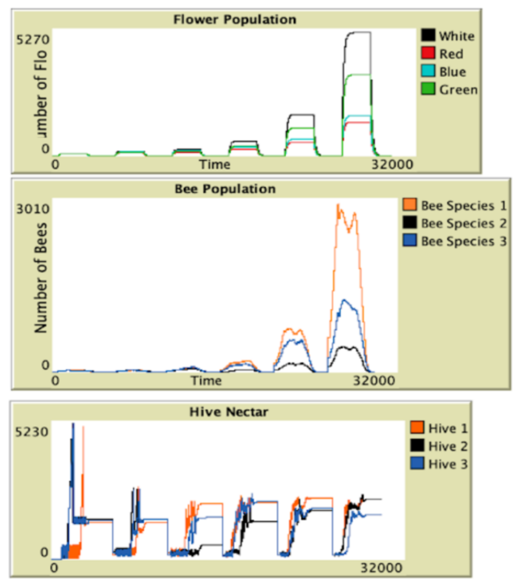

Figure 3. The simulation shows one generalist species, species 3, in blue and two different specialist species, 1 and 2, in orange and black. Species 1 is preferential towards black and green flowers. Species 2 is preferential towards red and blue flowers.

Expected Outcomes. The expected outcomes of simulating both generalist and specialist bees included that generalist bees will have higher populations when there is less land available for flowers to grow.

Potential Pitfalls and Alternative Strategies. Potential problems with the model respecting generalist and specialist populations of bees include irregularities or improper generation of flowers that favor certain species over others. An alternative strategy to solve this problem is making sure that the flower generation is truly random, and that all flowers are equivalent in characteristics.

Specific Aim #3:

The objective is to apply the simulation to different levels of habitat fragmentation and different possible solutions. Once the model can be applied for the behavior of different bee species and the scale that would be able to model habitat loss, the model can be applied to different examples with varying levels of habitat loss. When different placements of flowers are paired with varying levels of habitat loss the most optimal solutions will be found for different bee species.

Justification and Feasibility. In the past, agent-based models have already been used to study the impacts of habitat fragmentation, confirming that this idea is plausible (Newton et al., 2018). The technology of Netlogo is very versatile in its uses with there being a tool to use background to influence the agents. This mechanism allows for this use of the agent-based modeling software.

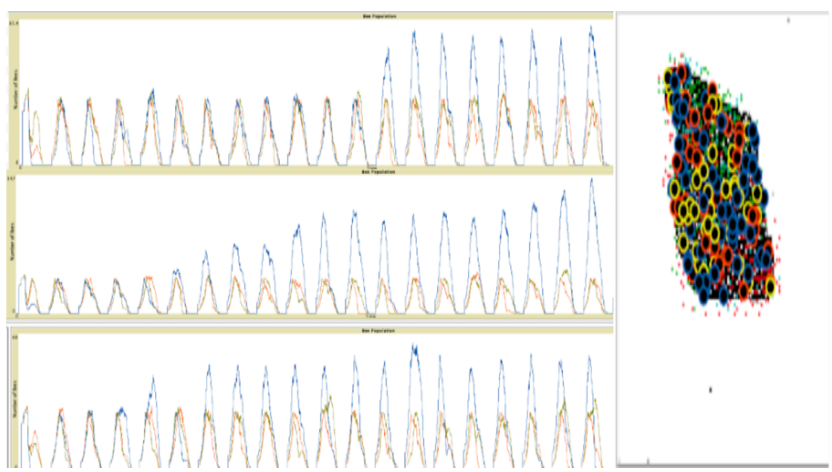

Figure 4: This figure shows the results gathered from running the model with land area pattern of habitat fragmentation shown to the right. To the left the graphs generated from the three tests are shown. The blue marker represents the singular generalist bee while the orange and yellow lines represent two different specialist bees with opposing flower preferences.

Summary of Preliminary Data. The preliminary data for this field shows that the predictions for when there is more habitat fragmentation, that there will be a higher level of generalist species population, seems to be true (Figure 4).

Expected Outcomes. The expected outcomes of simulating different solutions with the habitat fragmentation is that small and well distributed pieces of habitat will mitigate the effects of habitat fragmentation most efficiently.

Potential Pitfalls and Alternative Strategies. A potential problem with the modeling of different solutions is that it may be computationally taxing for the simulation to run with more habitat available. This may cause the program efficiency to decrease. A possible solution to this problem would be decreasing the scale to where it is still large enough to model what is needed but doesn't cause the simulation to be unusable.

Section III: Resources/Equipment

To complete this project, agent-based modeling software will be used to simulate the behavior of different bees with Netlogo 6.3. This will be done on a 2022 MacBook pro.

Section IV: References

Beecology Project. (n.d.). *Native Pollinator Decline and Conservation*. WPI. https://beecology.wpi.edu/website/home

Borst, P. (2015). The Fall and Rise of the Honey Bee. *American Bee Journal*, 315-319.

Huais, P. Y., Grilli, G., Amarilla, L. D., Torres, C., Fernández, L., & Galetto, L. (2020). Forest fragments influence pollination and yield of soybean crops in Chaco landscapes. *Basic and Applied Ecology*, *48*, 61–72. https://doi.org/10.1016/j.baae.2020.09.003

Introduction to Simulation. Chapter 1: Introduction to Simulation. (n.d.). https://intro.bio.umb.edu/SLNbook/introduction.html

Kline, O., & Joshi, N. K. (2020). Mitigating the effects of habitat loss on solitary bees in agricultural ecosystems. *Agriculture*, *10*(4), 115. https://doi.org/10.3390/agriculture10040115

Kremen, C., Williams, N. M., & Thorp, R. W. (2002). Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences*, *99*(26), 16812–16816. https://doi.org/10.1073/pnas.262413599

Newton, A. C., Boscolo, D., Ferreira, P. A., Lopes, L. E., & Evans, P. (2018). Impacts of deforestation on plant-pollinator networks assessed using an agent based model. *PLOS ONE*, *13*(12), e0209406. https://doi.org/10.1371/journal.pone.0209406

Pollination. (n.d.). Native Plants and Ecosystem Services. Retrieved November 23, 2023, from https://www.canr.msu.edu/nativeplants/pollination.

Rivière, J., Alaux, C., Le Conte, Y., Layec, Y., Lozac'h, A., Rodin, V., & Singhoff, F. (2018). Toward a Complete Agent-Based Model of a Honeybee Colony. In J. Bajo, J. M. Corchado, E. M. Navarro Martínez, E. Osaba Icedo, P. Mathieu, P. Hoffa-Dąbrowska, E. del Val, S. Giroux, A. J. M. Castro, N. Sánchez-Pi, V. Julián, R. A. Silveira, A. Fernández, R. Unland, & R. Fuentes-Fernández (Eds.), *Highlights of Practical Applications of Agents, Multi-Agent Systems, and Complexity: The PAAMS Collection* (pp. 493–505). Springer International Publishing. https://doi.org/10.1007/978-3-319-94779-2_42

Rong, C., & Sadhukhan, S. (2021). *Decline of Bees, a Major Pollinator – A Review*. BKGC Scholars, *2*(2), 9. https://bkgc.in/ejournal/paper_list/35-43.pdf

Ryder, E., Corace, M., Heath, K., & McDonough, D. (n.d.). *Blooms* (Version 5) [NetLogo].

Sapir, G., Baras, Z., Azmon, G., Goldway, M., Shafir, S., Allouche, A., Stern, E., & Stern, R. A. (2017). Synergistic effects between bumblebees and honey bees in apple orchards increase cross pollination, seed number and fruit size. *Scientia Horticulturae*, *219*, 107–117. https://doi.org/10.1016/j.scienta.2017.03.010

Xiao, Y., Li, X., Cao, Y., & Dong, M. (2016). The diverse effects of habitat fragmentation on plant–pollinator interactions. *Plant Ecology*, *217*(7), 857–868. https://doi.org/10.1007/s11258-016-0608-7