Investigating the Effect of Memory Loss on Pollinator-Plant Interactions Through Agent-Based Modeling

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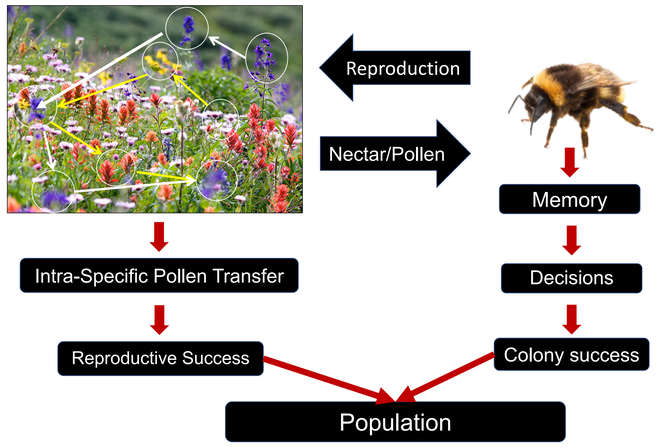
Abstract

Over the past decade, pollinators populations have significantly declined in abundance and diversity worldwide. The decline of pollinators has significant impact on crop pollination, biodiversity, and ecosystem stability due to the crucial role they play in plant reproduction. However, the causes and consequences of pollinator decline remain poorly understood. The present work uses an agent-based modelling approach to investigate how pesticide-induced reductions in memory affect bumblebee populations and the floral diversity that they support. Agent-based modeling (ABM) is a style of modeling that mixes experimental and mathematical approaches. The simulations mimic real-world experiments with the assumption that we can accurately represent a subject's behavior with rules. The goal is to discover emergent properties of the system that help us make predictions and explanations.

We show that memory affects both a bumblebee's ability to compete and impacts the diversity of the flowers they feed on. In a varying floral environment, bees with highly-impaired memory perform worse than their unimpaired counter-parts and gather fewer resources. Interestingly, memory impairment increases floral diversity. When we allow bees and flowers to change over time, the effects of memory impairment on populations and flower diversity are amplified. We see these effects even when only a portion of the population is affected.

Background



Foraging Behavior of Bumblebees:

- Bumblebees rely on memory to make efficient foraging decisions.
- Decisions determine how much nectar is collected.
- Nectar results in more reproductives (males and queens) for the colony.
- Reproductive cost to plants when bees switch between floral species.

Effects of Pesticide

- Numerous pesticides are present in nectar and pollen.
- Sub-lethal effects impair learning and memory.
- **The effect of pesticides on populations of bumblebees is unknown**

Hypothesis

We hypothesize that impaired memory affects a bumblebee's ability to adapt its behavior, resulting in a loss of bumblebee diversity and consequences for plants in a varying environment. We set up scenarios with our model to test this idea.

Bumblebee Agent Design

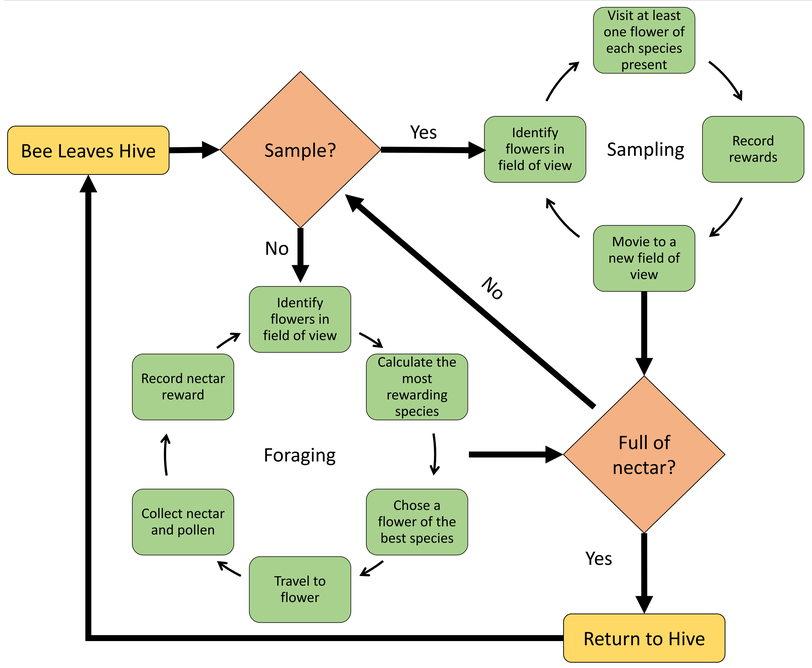
The Bee:

- Start with two populations of 100 bumblebees
- Bees sample all floral species, then forage on most rewarding species in their field of view
- Bees determine most rewarding flowers to visit based on memory
- Bees pick up pollen from each flower visited; pollen is lost from a bee at an exponential rate.
- All bees die at the end of the season, and next generation of bees is determined based on overall nectar collected

Memory:

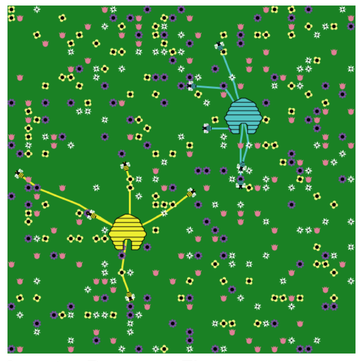
- Memory in our model is a simple list of flower species and reward
- We simulate memory impairment by changing the maximum length of the list
- Bee agents use their entire memory to generate a likelihood of visiting each species of flower

Bumblebee Agent Behavior



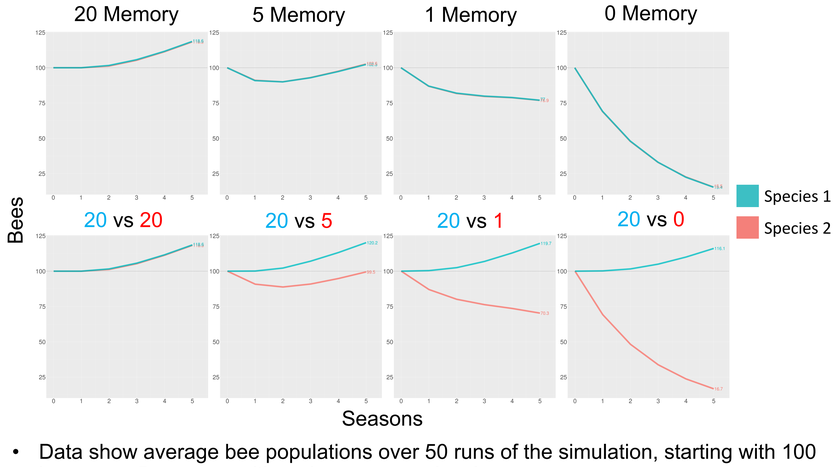
Plant Agent Design

- Start with 1,620 for each of four species
- Flowers instantly refill nectar from a uniform random distribution for each visit.
- Each species has a different mean nectar content and the same variation from the mean
- Flowers are perennials – 20% of current population dies off each year.
- Next generation of flowers is determined as a percentage of successful pollinations.
- All flowers have 50 female gametes and produce pollen.
- Pollen from the same species produces a seed. Pollen from different species blocks a seed.



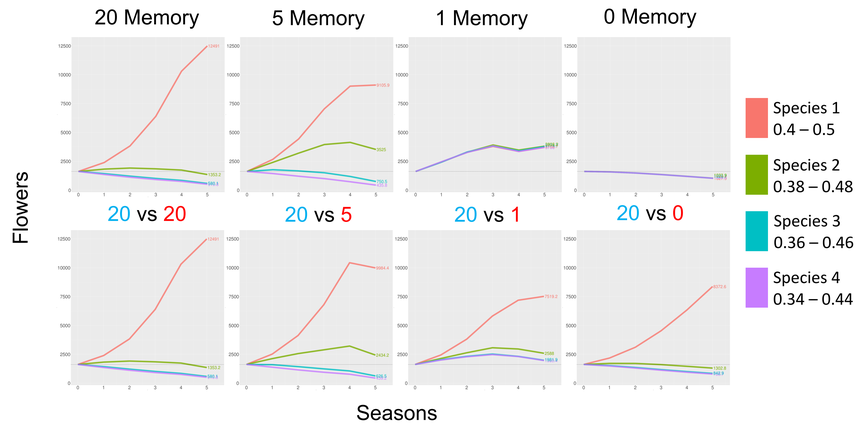
Agents: Bees and Flowers
Environment: 160 x 160 field

Impaired Memory Affects a Bumblebee's Ability to Adapt to a Varying Environment



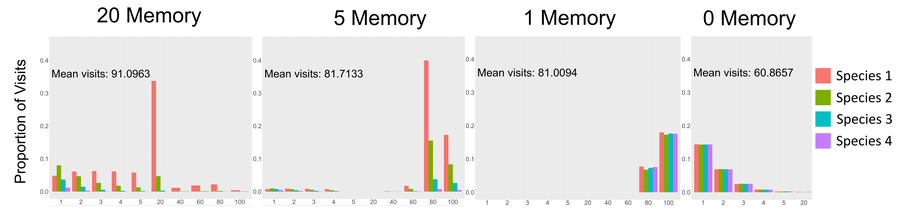
- Data show average bee populations over 50 runs of the simulation, starting with 100 bees over 5 seasons with various memory levels.
- Memory confers an adaptive advantage. Over several generations, hives with impaired foragers will shrink as bees from unimpaired hives out-compete them.
- Since resources are not limiting, the behavior of one species has little effect on the behavior of the other.
- Populations that initially start decreasing can recover later on – likely due to interaction with plant populations.

Consequences of Impaired Memory on a Varying Floral Environment



- Plant diversity suffers the most when bees are able to adapt most effectively to the environment. The bees all compete for the most rewarding flowers, and as a result the most rewarding flower is pollinated the most.
- When the bumblebees suffer from high levels of memory impairment, they tend to choose a species of flower to visit without remembering which species is most rewarding. This results in greater plant diversity but lower average rewards to the bees.
- The loss of bee populations coincides with a loss of plant populations.

Pollinator Behavior Changes with Memory Impairment

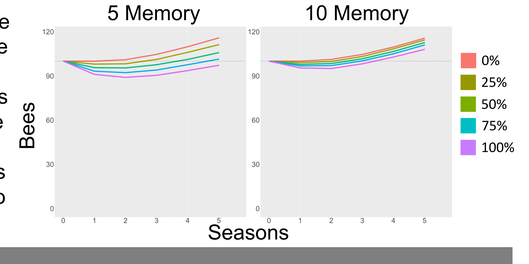


Behavior of a Bumblebee During an Uninterrupted Foraging Period:

- A bee with zero memory spends 57% of its time foraging in runs of length one; that is, it switches from one flower species to another after 57% of its visits.
- A bee with one memory spends 100% of its time in runs of lengths greater than 60
- As memory increases from 1 to 20, the average length of runs decreases.
- Bees with 20 memory demonstrate increased behavioral flexibility

Memory Impairment of a Portion of Bees Affects Overall Population Numbers

- We impaired a percentage of the bees in a population to see if the population dynamics change.
- When only a percentage of bees in a population are impaired, we still see population-level effects
- The percent impairment impacts how long it takes a population to recover.



Future Steps

Bumblebees:

- Species-specific flower preferences
- Switch cost
- Alternative memory structures
- Physical resource partitioning

Flowers:

- Blooms
- Physical attributes
- Plant life-cycle

Acknowledgements

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