University of Cape Town

STA5071

Simulation

Simulating Bee Population and Surrounding Ecosystems Under Climate Change

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Contents

1 Introduction

Wild bee populations worldwide have suffered in the last century adue to a number of factors [2]. One of the top ranked causes of wild honey bee population decline is emergent infectious diseases (EID's) [1]. This includes the *Varroa destructor* mite [4] [8]. This simulation aims to model the spread of the *verroa destructor* parasite within the context of a particular ecosystem, namely the Kootenay National Park in British Columbia, Canada.

This report is intended to be used alongside the accompanying NetLogo model.

2 Research Question and Methodology

Higher temperatures as a result of climate change have steadily increased the vulnerability of bees to the *Verra destructor* parasite, putting their colonies further at risk of collapse [8]. The simulation will aim to show the effect of the spread of the parasite under different average temperature conditions. A base case will be formulated under which there is no effect of climate change on temperature. Then, the base case will be examined against cases where the average temperature is increased.

3 Setup of Simulation World

3.1 Patches and Landscape

The patches are adapted from those in [9]. We attribute a singe day to each tick. The temperature attribute of the patches is assumed to be homogeneous across all patches. We assume our simulation world is small enough to do so. A detailed illustration of the patches setup and routine procedures can be found in Appendix 6.1.1 and Figure 4 (Appendix) respectively. The minimum, average, and maximum temperatures are crudely modelled according to monthly averages in Kootenay National Park published by the Canadian government [5]. Since our simulation operates on daily temperature, we have fit these monthly averages with a cosine function which captures the minimum and maximum average monthly temperatures with some randomness as follows.

$$
\begin{aligned}
temp_{min}(t) &= 10.45\cos\left(\frac{360}{365}t\right) - 4.65 + e_1 + \gamma \\
temp_{ave}(t) &= 11.4\cos\left(\frac{360}{365}t\right) + 4.1 + e_2 + \gamma \\
temp_{max}(t) &= 14.9\cos\left(\frac{360}{365}t\right) + 8.3 + e_3 + \gamma
\end{aligned}
$$

where,

$$
\begin{aligned}
&e_i \sim N(0,4) \forall i \in \{1,2,3\} \\
&\gamma = \text{temperature increase factor (due to climate change)}
\end{aligned}
$$

The inclusion of e_i aims to account for random fluctuations in temperature from day to day. The temperature increase factor γ is intended to be variable in the examination of different cases. The temperatures provided in [5] were used to derive this simple model (see Figure 5, Appendix). This data is recorded from 1981 to 2010, and averaged hence we assume the effect of climate change to be negligible.

3.2 Agents

The Kootenay National Park hosts a plethora of wildlife including elk, red deer, black and grizzly bears, snakes, and badgers [7]. For the purpose of our simulation goal, we will capture only those species relevant to the survival of bees. Bears (both black and grizzly) are a threat due to their fondness of feeding on honey and bee larvae found in beehives. Other smaller mammals such as moose, elk, red deer, and badgers also feed on these plants. We will capture these mammals as a single agent-set denoted `deer`. Of course, we will include an agent-set of the bees themselves, `bees`.

3.3 Agent Rules

The agent rules have been adapted by the canonical predato-prey model [9]. We have added that these rules will further be prompted by temperature conditions [5] based on known animal behaviours. The setup routines of the agents can be found in Appendix 6.1.2 and 6.1.3. Their detailed routines are shown in Figures 6, 2, and 3 (Appendix.

3.3.1 Bears

Bears hibernate when prompted by cooler weather conditions, signalling a coming scarcity of food sources. During hibernation, bears will conserve energy by remaining in their den and relying on food stores acquired during the rest of the year [6]. Bears in Canada begin hibernating at the start of autumn, and emerge from their dens in early spring. This activity is prompted by temperature conditions described in [5] in our simulation (Figure 5, Appendix).

3.3.2 Bees

Bees are immobile at temperatures below 7 degrees Celsius [3]. Our model will dictate that if bees will be active only if the temperature exceeds 7 degrees Celsius at some point in the day.

4 Experiment Results

4.1 `ChangeTemp` Experiment

The outline of this experiment can be found in the `BehaviourSpace` of our NetLogo model. Under this experiment a configuration of parameters were found that produced stable results. This was used as the base case, where temperature increase is set to 0. Using this case, we fixed all parameters aside from `temp-inc-factor` which varied from 0 to 2 degrees Celsius. At each of these values the experiment was run ten times, for 730 ticks (2 years) each. The results of this experiment are illustrated in Figures 7, 8, 10, 11, 9 (Appendix). It is clear that there is variation between runs within each temperature change, particularly for bee population (Figure 7), and consequently number of bees foraging (Figure 8). The bee population appears to be sensitive to the randomness we have included in the model. Disease incidence (Figure 10) seems to be more erratic at higher temperature increase at the beginning of the simulation, however stabilises over time. However, there is less variance between runs within temperature changes.

4.2 Sensitivity (`SensInfTemp`, `SensRecovery`, `SensMaxInv`)

The three sensitivity experiments pertain to `min-temp-for-infection`, `recovery-energy`, and `max-inv` respectively. These were chosen particularly for their impact on disease incidence and bee behaviour. For each experiment each of these parameters varied while all others were kept constant. The particulars of these experiments can be found in the `BehaviourSpace` of the NetLogo model.

As `min-temp-for-infection` increases, the peak infection shifts to the right in our simulation (Figure 12, Appendix). At lower levels of `recovery-energy`, disease incidence behaves more erratically in peak seasons (Figure 14, Appendix). Recovery and infection may occur in cycles during this time. Higher `max-inv` values seem to stabilize disease incidence between successive runs, however they also see to increase disease incidence in peak season. Perhaps the additional time spent foraging allows for more instances of bee-to-bee transmission when on the same patch.

5 Discussion and Conclusion

There are a number of weaknesses in the model. Firstly, since the growth and aging rates of plants, as well as the seasonal impact of these values are assumed, our model does not account for the role of availability of food sources for the agents. However, this is indeed relevant to the decline of bee populations, particularly as a result of deforestation.

Using the base case as a framework, there were no extreme effects on the survival of the bee colony under changing temperature conditions as is observed in nature (above the variation occurring between runs). This may be a result of parameters which were assumed in the absence of data or estimates. Overall the model does however capture the seasonal nature of disease incidence and bee populations. It would interesting to see how the model would behave if paramilitaries properly.

Ideally, we would run the simulation under different combinations of parameters many times, however this is infeasible given that under certain configurations the bee population explodes, and so too does run time per tick. The base case was used to mitigate against this problem. However, the base case itself arises from parameters which are assumed and his hence not necessarily a true reflection of occurrences in nature, as is observed by the results. This creates an inherent bias in the results reported herein. Nonetheless, we used this as a tool to examine behaviours under changing conditions in the hope that with more robust parametrisation the model will capture the desired behaviours.

References

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6 Appendix

6.1 Setup

6.1.1 Patches

to setup-patches

1. Set `plant-amount` to $p \sim U(0, 100)$.
2. Set `pollinated` to random binary.
3. Recolor the patches according to `plant-amount`.
4. Set minimum, average, and maximum temperatures where $t = 0$.

end

6.1.2 Bees

We begin our simulation in mid-summer whilst bees are foraging in simulation world.

to setup-bees

1. Create healthy bees
   (a) Set colour to yellow.
   (b) Set hive co-ordinates to $(0, 0)$.
   (c) Set position to random co-ordinates (x, y).
   (d) Set `energy` to $e \sim U(0, 100)$.
   (e) Set `inventory` to $\text{rand}[0, m]$, where $m =$ maximum inventory capacity.
   (f) Set `infected?` to `FALSE`.
   (g) Set `time-till-death` to $122 + \text{rand}[0, 30]$.
2. Create infected bees
   (a) Set colour to orange, indicating infection.
   (b) Set hive co-ordinates, position, `energy`, and `inventory` as above.
   (c) Set `infected?` to `TRUE`.
   (d) Set `time-till-death` to $\text{rand}[0, 60]$.

end

6.1.3 Deer and Bears

to setup-deer or -bears

1. Create `number-of-deer` or `-bears` deer or bears.
2. Set position to random co-ordinates (x, y).
3. Set `energy` to $e \sim U(0, 100)$.

end

6.2 Table of Figures

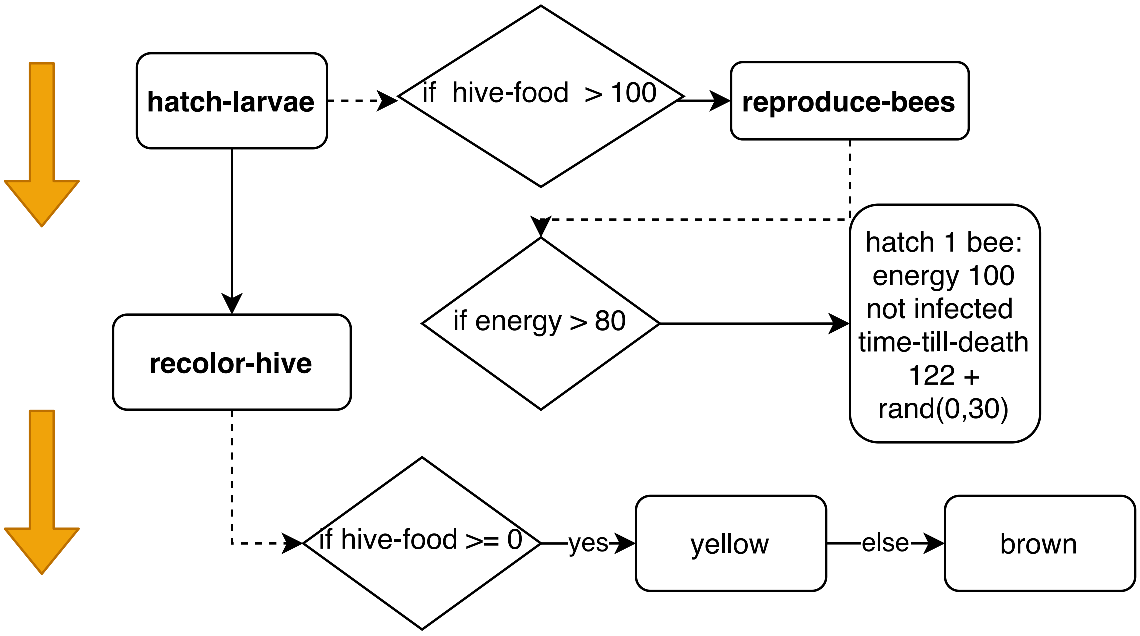

Figure 1: Hive routine

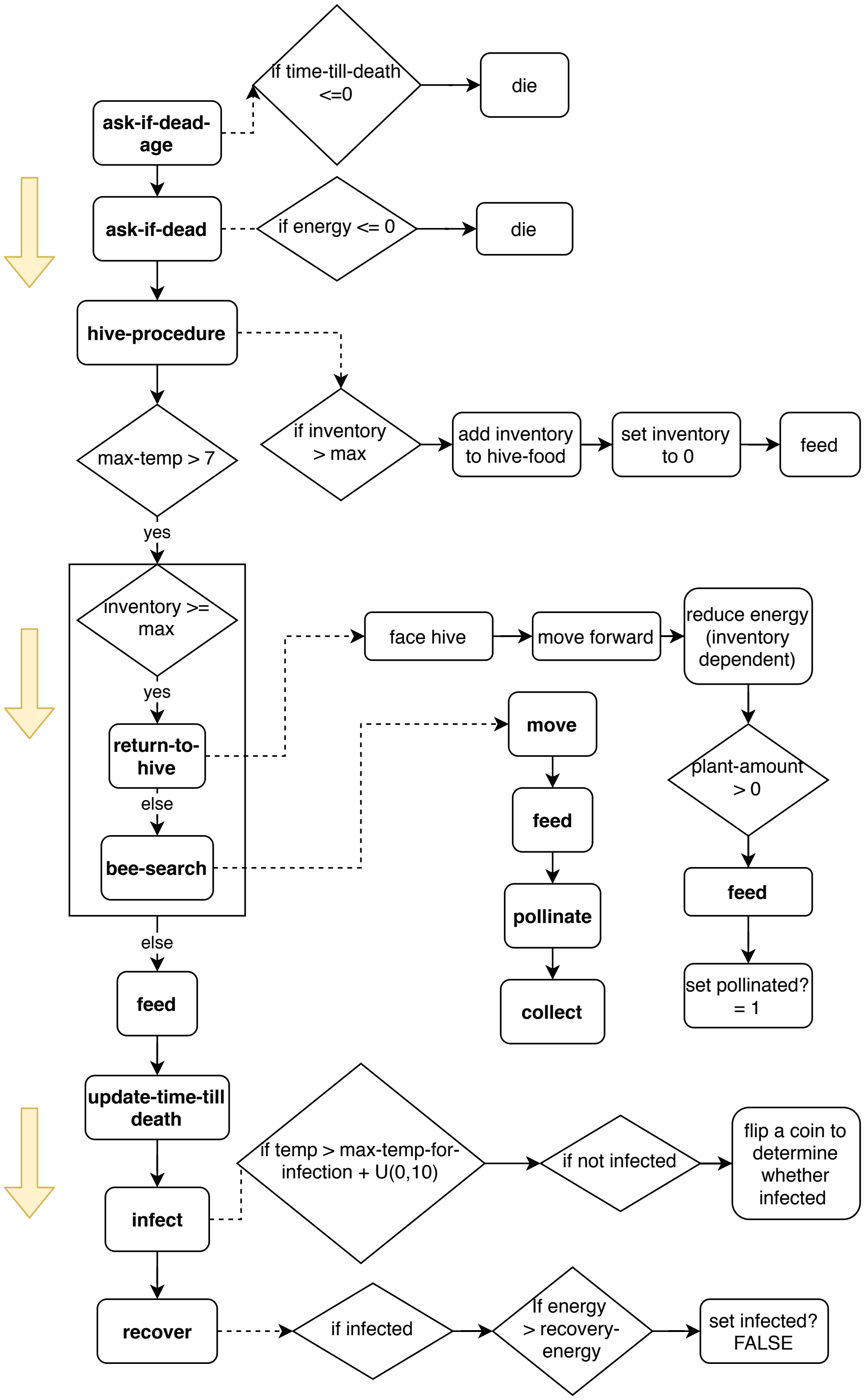

Figure 2: Bees routine

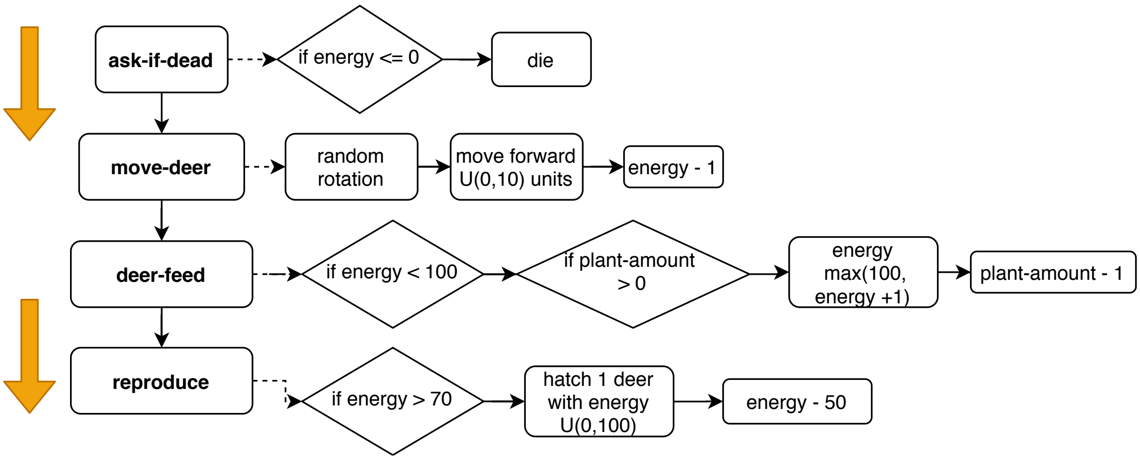

Figure 3: Deer routine

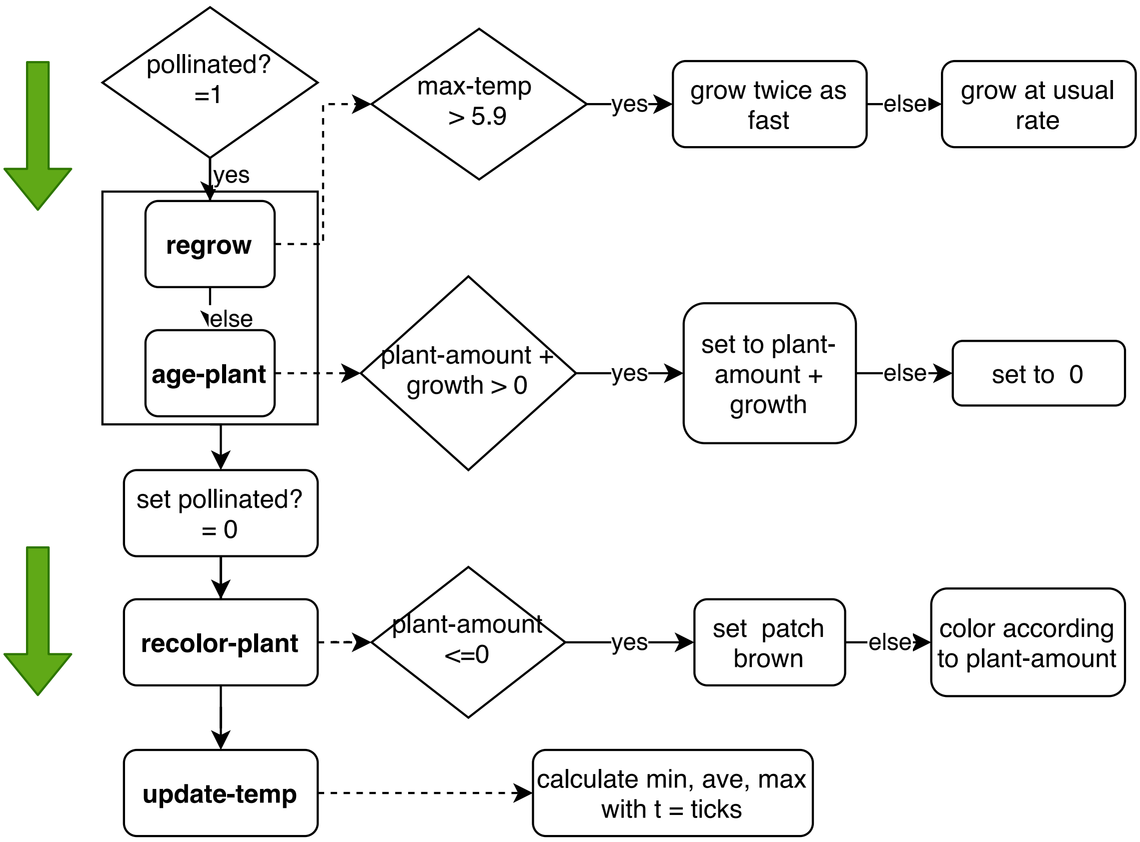

Figure 4: Patches routine

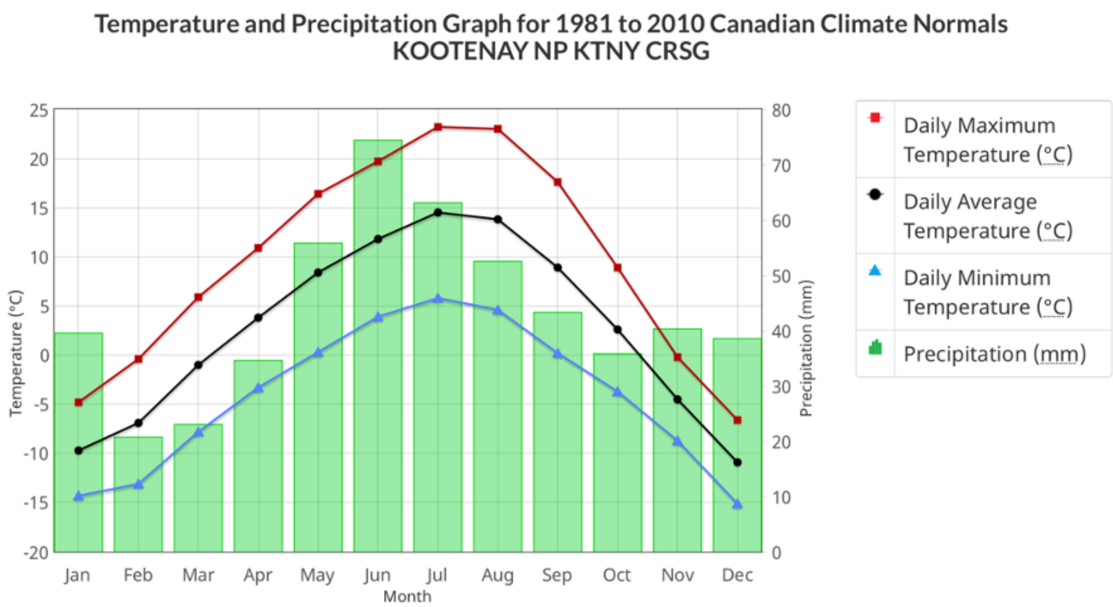

Figure 5: Monthly averages used in seasonal prompts of agents [5]

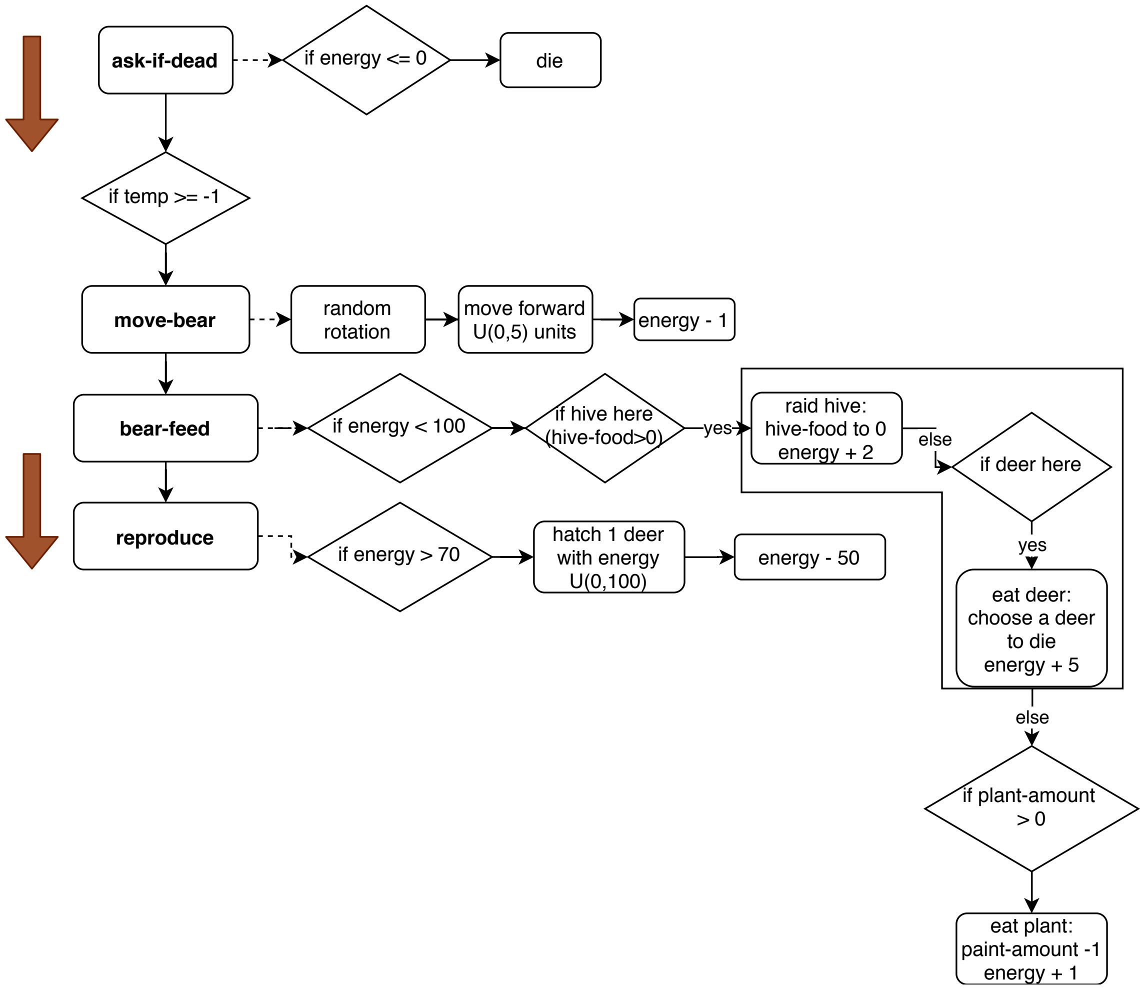

Figure 6: Bears routine

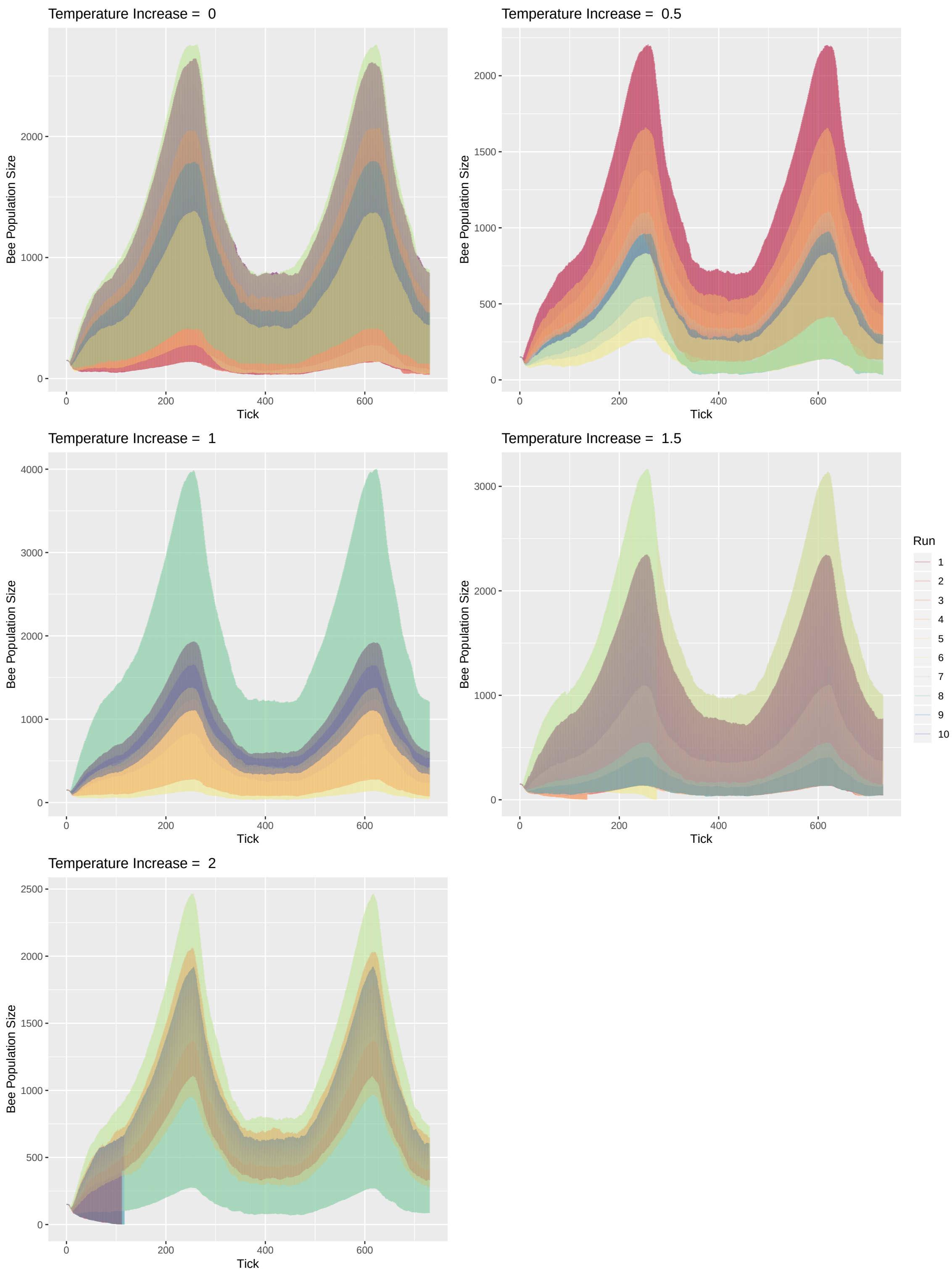

Figure 7: `ChangeTemp` experiment results

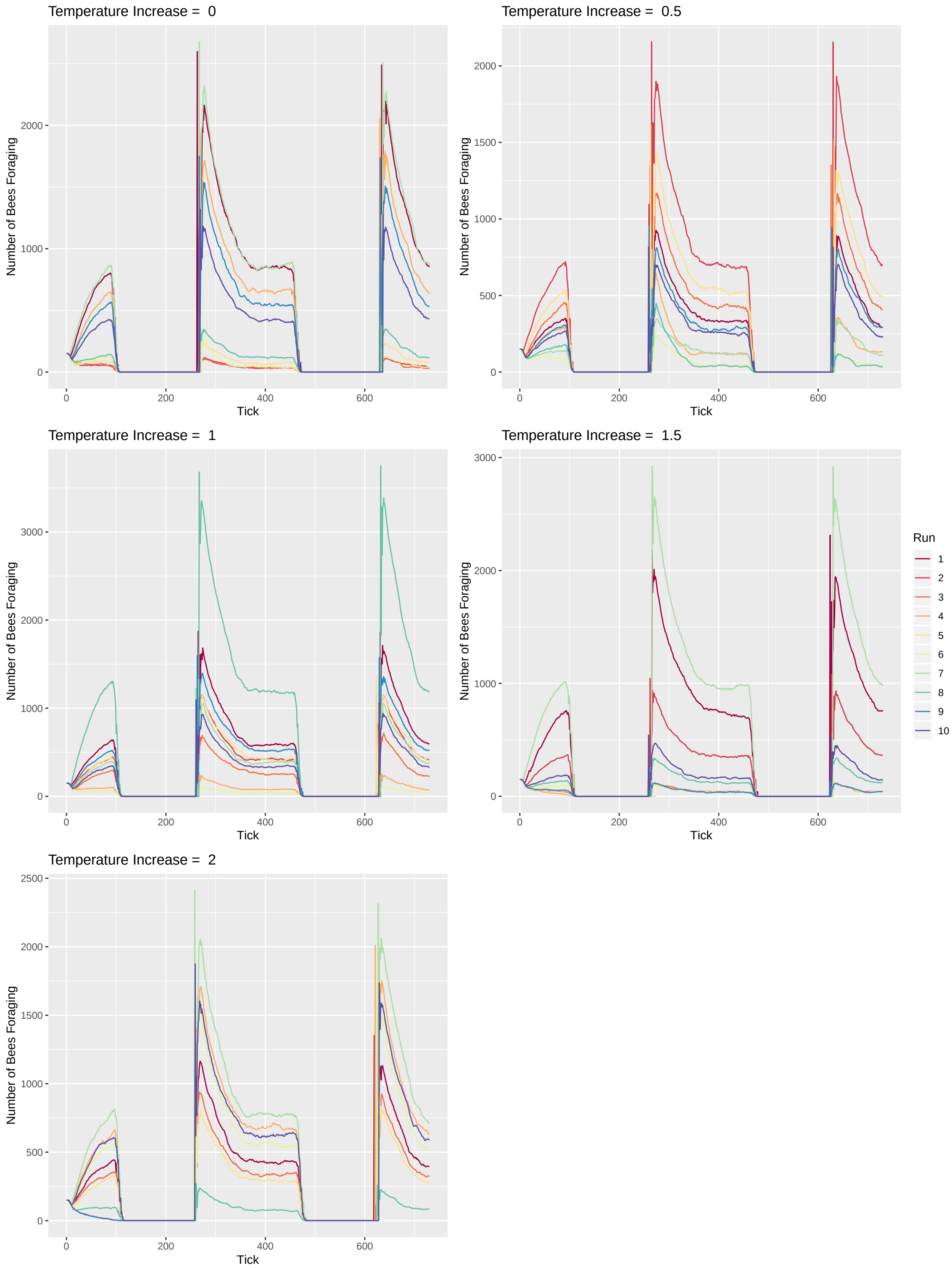

Figure 8: `ChangeTemp` experiment results

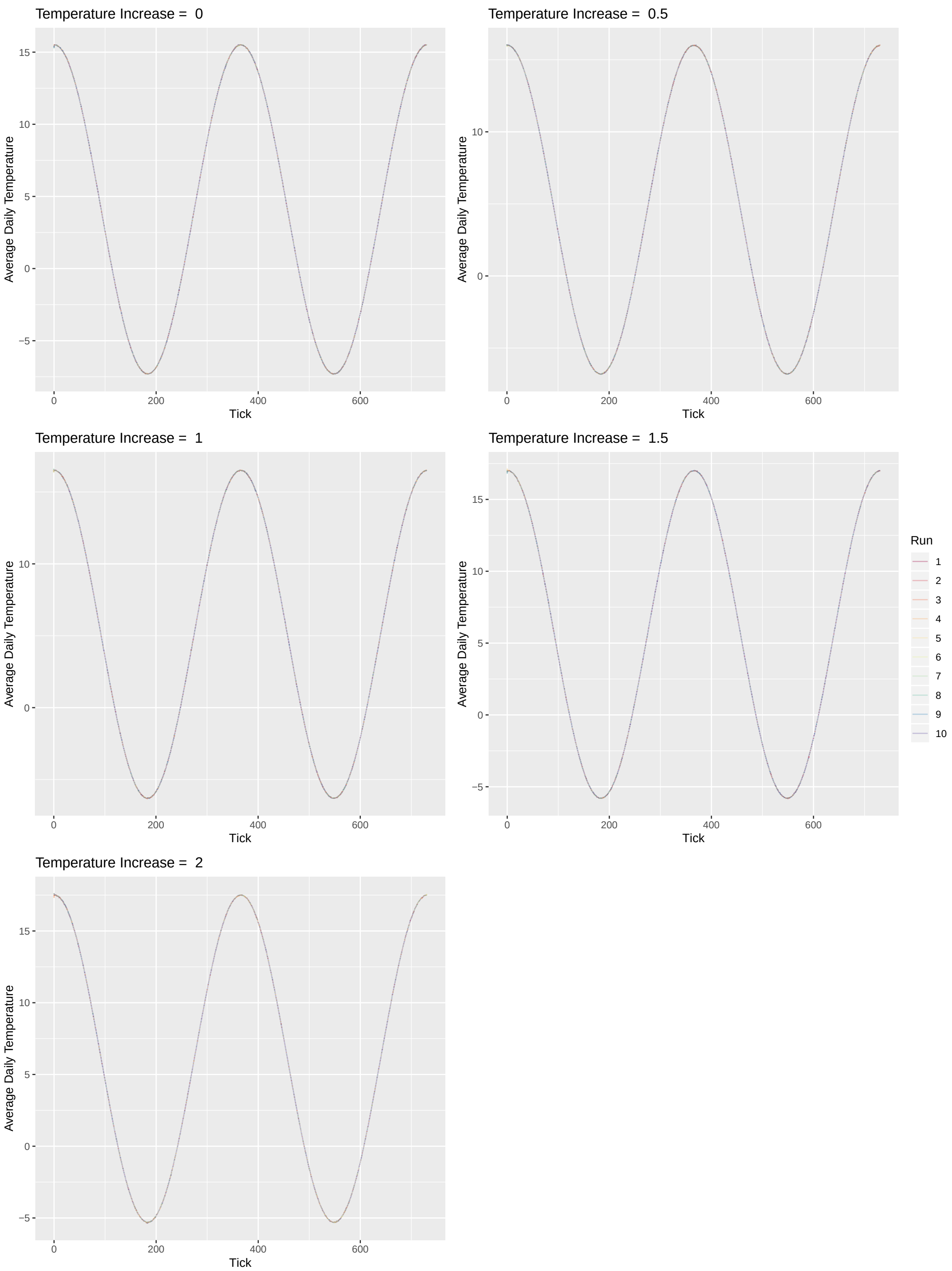

Figure 9: `ChangeTemp` experiment results

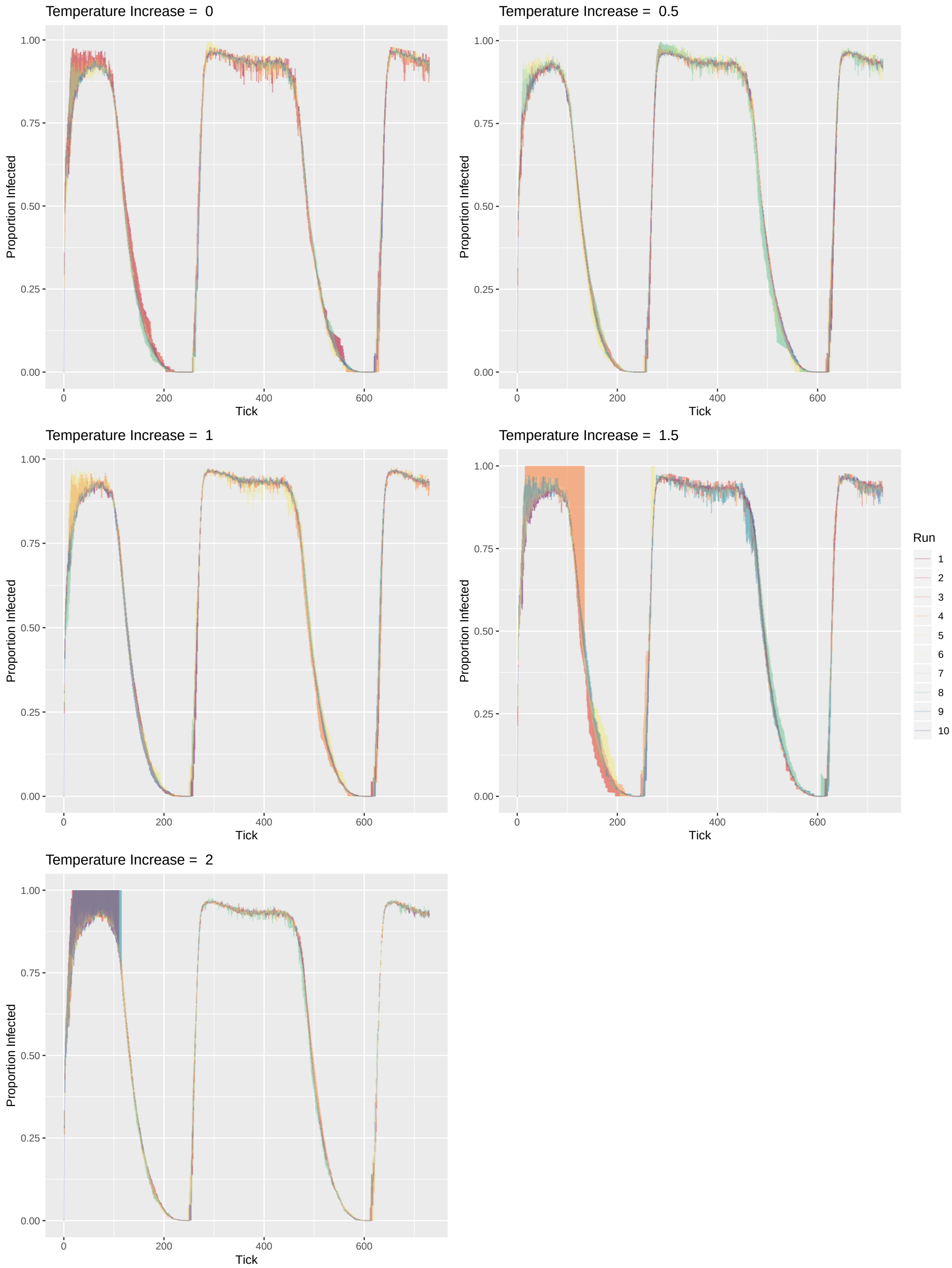

Figure 10: `ChangeTemp` experiment results

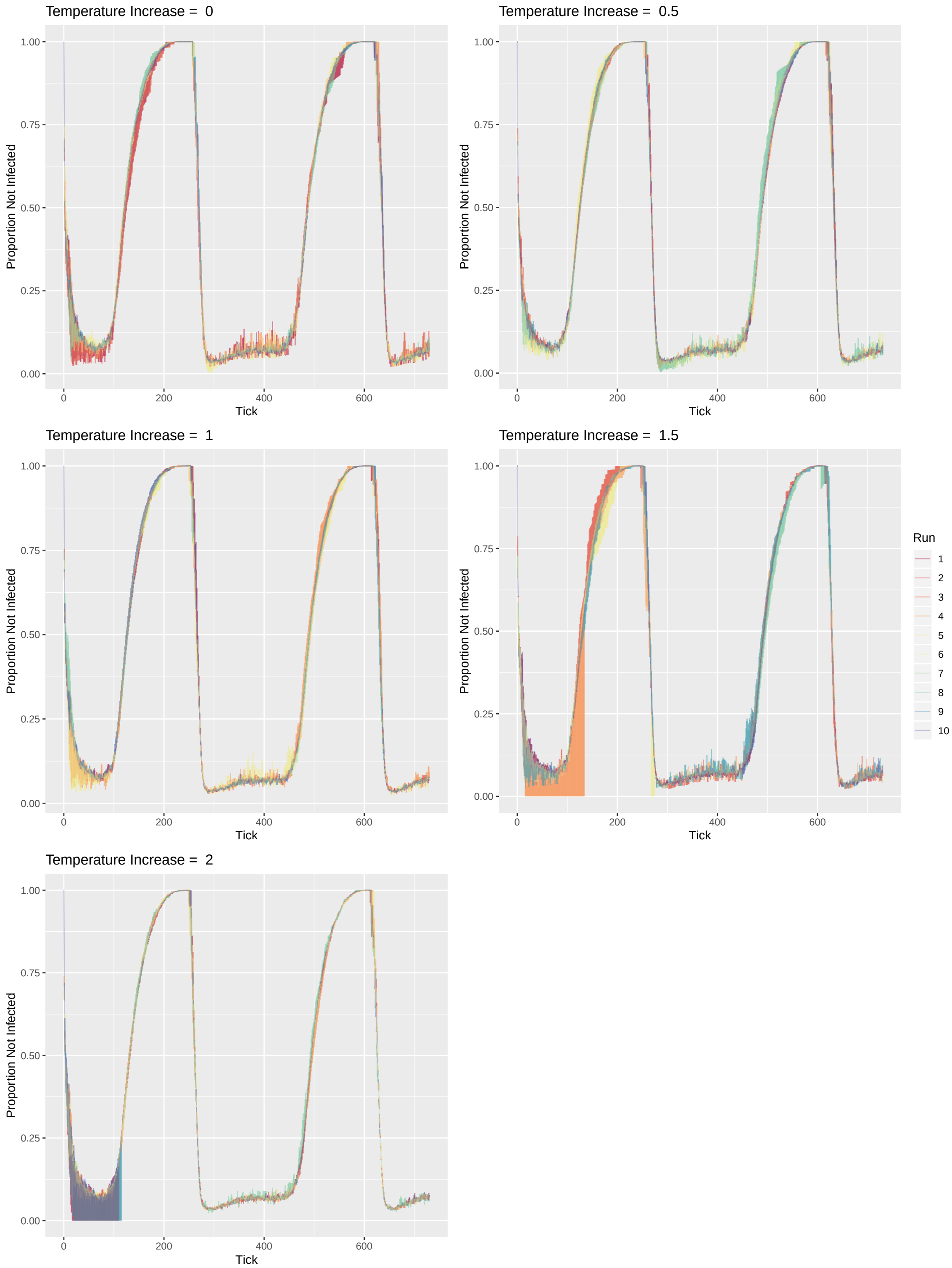

Figure 11: `ChangeTemp` experiment results

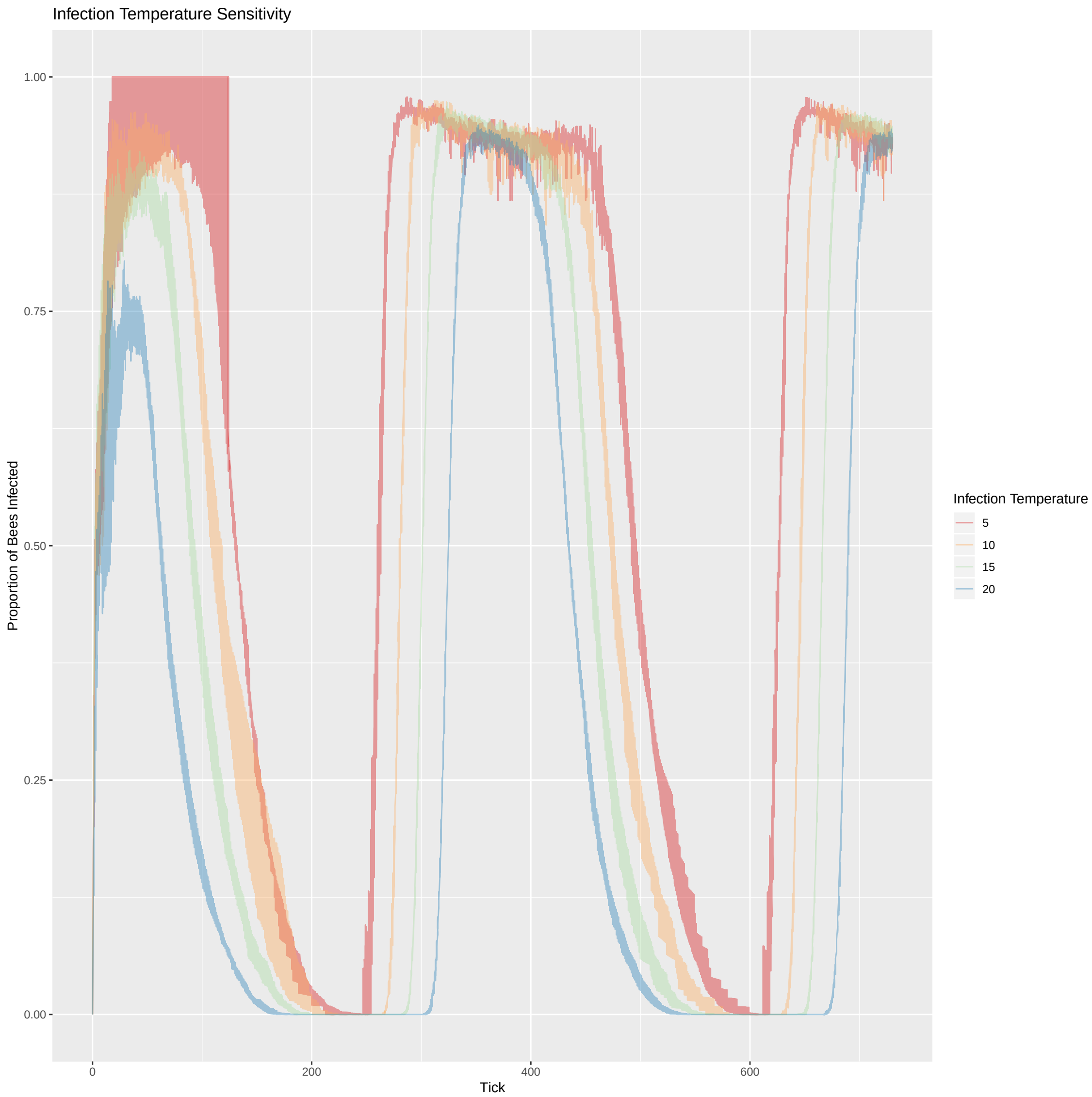

Figure 12: `min-temp-for-infection` sensitivity

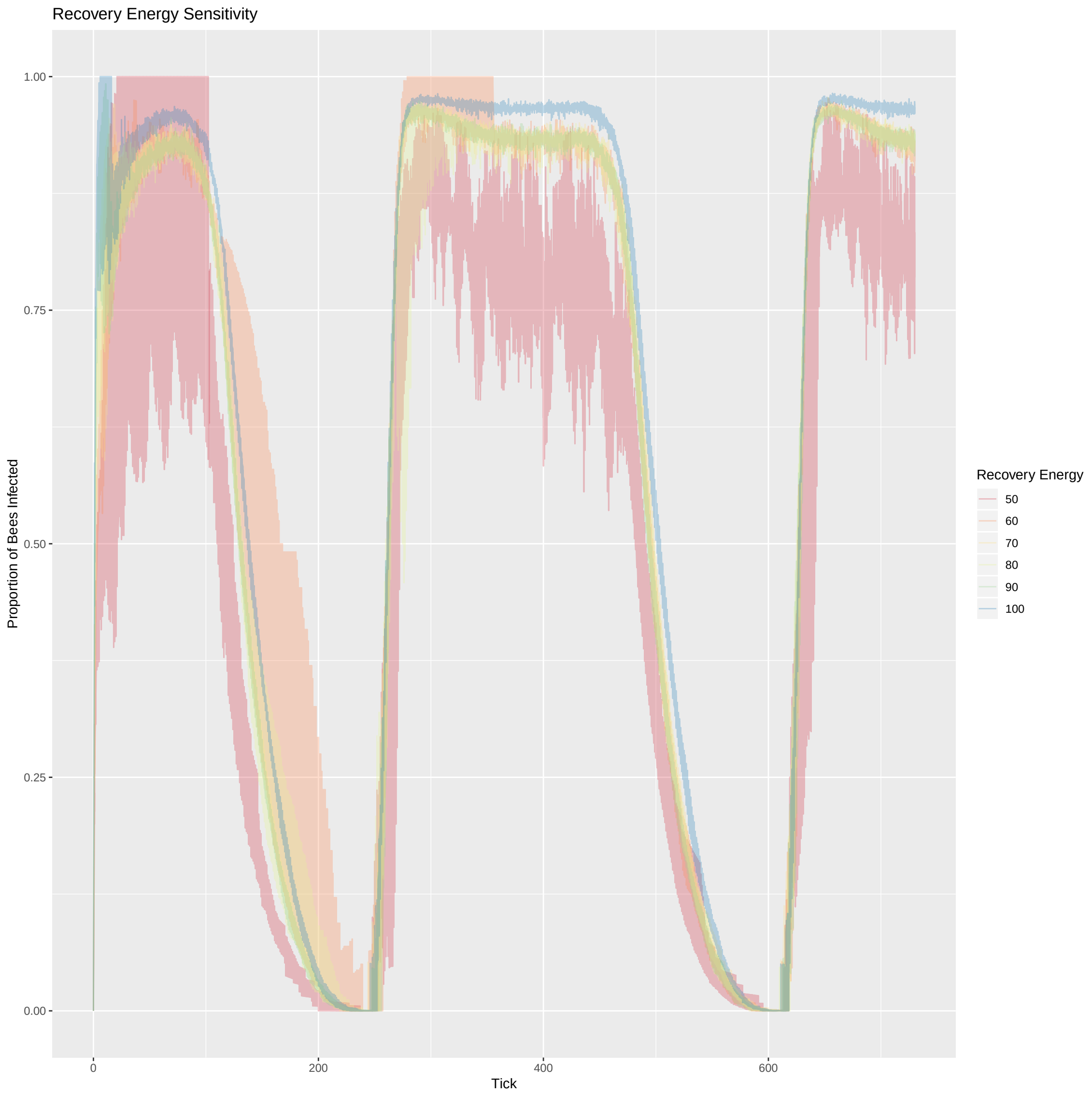

Figure 13: `recovery-energy` sensitivity

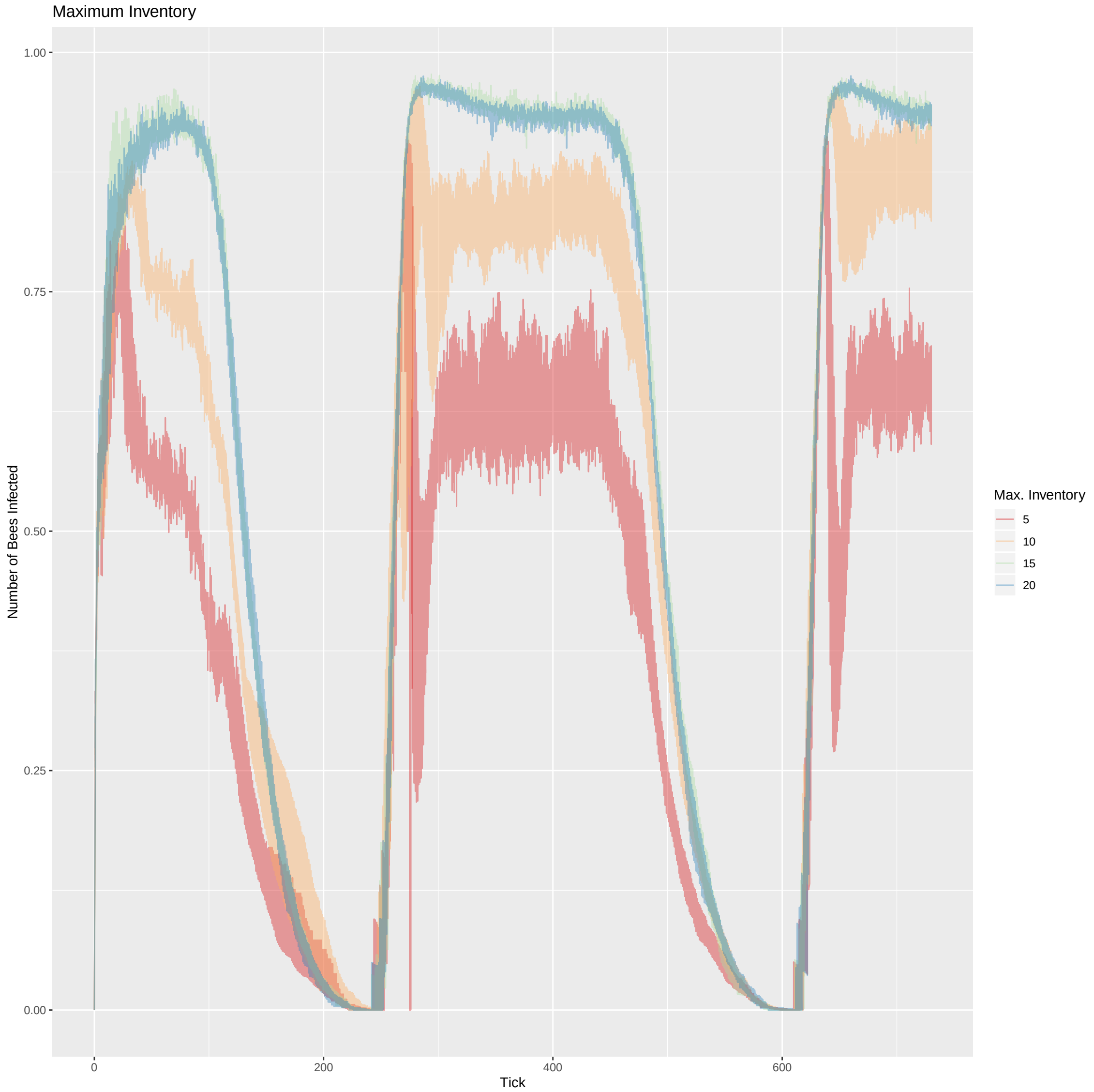

Figure 14: `max-inv` sensitivity