Analysis of Flock Sensitivity Profiles

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CSCI 4314: Dynamic Models in Biology

Abstract

The act of flocking can have great benefits in terms of predator evasion. Some researchers have shown a heterogeneity in the sensitivity of an agent's response to a predator when being part of a flock. This paper aims to address this heterogeneity to understand if the variation in response is adaptive, or if there is an "ideal" response to predation. An agent-based model was created, simulating a flock with heterogeneous responses to predators in terms of their sensitivity in predator detection and the magnitude of their response. Birds with high-sensitivity predator responses incurred an energy penalty proportional to their sensitivity that reduced their probability of reproduction. Convergence towards an ideal, desensitized profile was seen in the magnitude of the change in heading after detecting a predator, sensitivity to neighboring birds' responses, and detection radius. In contrast, predator detection angle of vision and acceleration during an evasive response failed to converge, suggesting that variability within a flock in these dimensions aids flock survival. These results suggest that local information and a largely uniform, desensitized predator evasion profile are sufficient for flock survival under a significant energy penalty and energy-based reproduction.

1.0 Introduction

Flocking is the action of many individual agents coming together to form a large mass, moving in unison instead of acting solely on individual behavior. There are many proposed theories as to why animals initiate a flocking behavior. Some of those theories include a better ability to fight off predators, easier to hunt by working together to find food, and as a way to evade predators. This paper will focus on the last theory. While flocks as a whole can determine a certain formation pattern to evade a predator, this paper examines the response on an individual level. Agents within a flock can show unique evasion behavior from its neighbors. Some agents may focus on its neighbors' activity, some choose to increase their velocity when evading, and some change their angle to avoid the predators. This individual behavior can be tracked to determine if certain characteristics are used more than others in order to successfully evade a predator's attack.

This paper will look into the different characteristics that make up a sensitivity profile of a flock and track said characteristics over time. This will be simulated in an agent-based model using NetLogo by calculating predator and prey behavioral components. This will be further analyzed to assess if the agents converge to a certain sensitivity profile over time.

2.0 Background and Related Work

Many studies have been conducted to determine the purpose and effectiveness of flocking. Some studies have shown that flocking could weaken defense as it creates a much larger body of prey that could attract fiercer predators that would have normally ignored a single agent (3). Others have shown that, given the correct response time, the escape time within a flock is much quicker than the time it takes for a predator to attack, thus proving to be quite advantageous to the individuals in the flock (1). Researchers have shown that flocking can create faster reaction times because the group-led behavioral transitions stem from minor changes in individual-level interactions (2), meaning that one agent could spot the predator before others in the flock, thus being able to alert the others which helps the flock escape when some have not even seen the danger.

There have been studies specifically conducted that analyze flock response sensitivity to predators as we are trying to accomplish in this project. These studies have used methodologies such as observing the response sensitivity of the prey flock across risk ranges at different noise levels on the attacking course of the predator (4). Our approach to the problem will differ because their solution varies the level of predation risk while our model will work by introducing agents that replicate the "winning" response from previous generations, where the predation risk is kept constant. While we are building on similar constructs for the model, the results will hopefully give insight to new factors within the evolution of a species that could influence the response sensitivity of a flock.

3.0 Problem Description

Researchers have long sought to identify the purpose of aggregation behavior in animals, and one popular possibility is that such behavior, particularly flocking, provides a flock with increased ability to detect and evade predators (7). In a variety of animals, this idea has been supported (6). However, some researchers have noted that there is heterogeneity in the sensitivity of individuals' responses to a predator within a flock (5). This prompts the question of whether variance in response to predators is adaptive, or whether there is an "ideal" response to a predator. We aim to examine whether sensitivity of agents within a flock converge over multiple generations under constant predation. This examination is significant because the deeper understanding of flock response to the presence of a predator can help us gain a new level of comprehension as to why certain species survive longer than others. We can study whether this type of behavior is adaptive, and thus learned by the surviving members of a flock. If this is the case, then we can study these flocks knowing that there is an informed individual that creates a response for the entire flock in order to preserve that species. We can also look at the behavior to see if the response is created to be the ideal response in a specific situation, showing differing flocking patterns over time without converging to the sensitivity of one individual.

4.0 Model Setup

This model was modified from the Flocking model provided by NetLogo created by Uri Wilensky. The flocking functions provided in this model and the flocking parameters (i.e. vision, minimum-separation,max-align-turn, max-cohere-turn, max-separate-turn) were not changed from their default settings.

Agents: Two breeds of agents were created in this model - predators (large and white/blue) and birds (small and yellow/green/red).

Attributes: Each of these agents had several attributes that dictated their behavior. Predators were given an agentset of targets within a cone of vision defined by kill-radius (set to 4 patches) and kill-angle (set to 140 degrees), a velocity that varied based on attack-mode, an attack-mode that determined whether predators were able to remove members of the flock, and a closest-bird that determined the heading for that predator. Predators were initialized at random *x* and *y* coordinates in with attack-mode set to false.

Each bird had a set of flockmates and a nearest-neighbor bird that determined its flocking behavior. Birds' predator sensitivity was determined by five attributes: detection-radius and detection-angle, which specified a cone of vision within which they can detect predators or frightened neighbors, escape-angle which determined the turning angle after a predator evasion response has been initiated, escape-velocity-scale, which determined the acceleration of a bird during predator evasion, and neighbor-sensitivity, which determined how many of a bird's neighbors must mount a predator response before that bird begins evasion (in the absence of spotting a predator). In addition, each bird had an attribute designating whether they are currently being pursued to allow its neighbors to mount a predator response and an energy level to punish high-sensitivity predator evasion behavior. Birds were initialized at random x and y coordinates with 100 energy units. Predator evasion profiles were initialized as follows: detection-radius as a random integer between 0 and 9 patches, detection-angle as a random integer between 0 and 359, escape-angle as a random integer between 0 and 179, escape-velocity-scale as a random number between 1 and 3, and neighbor-sensitivity as a random integer between 1 and 5.

Behaviors

Each time step consisted of the following procedures: bird flocking behavior, predator chasing the closest bird, bird evasion, a check of whether to switch the predators' attack mode, predators killing birds in vision, and birds mating.

Predation Behavior: Bird chasing mode was only activated if the predators were in attack mode. In this case, all birds in their cone of vision would be identified and the predators heading would be set to the coordinates of the closest in-vision bird.

Evasion Behavior: In the evasion procedure, birds would randomly turn either left or right by their escape angle and increase their velocity by a factor of escape-velocity-scale if a predator was detected in their visual cone or the number of pursued birds in their visual cone exceeded their neighbor-sensitivity threshold. An amount of energy equal to *escape-velocity-scale * escape-angle * 0.3* was deducted from their energy stores. It should be noted that this penalty is fairly severe: assuming a normal distribution in both sensitivity components, 34% of profiles have an energy penalty of greater than 100 per timestep, meaning that a full-energy bird would be killed evading a predator (fig. 0). Birds with negative energy were removed from the simulation. A bird's energy was restored at 0.025 units per timestep in the absence of predation.

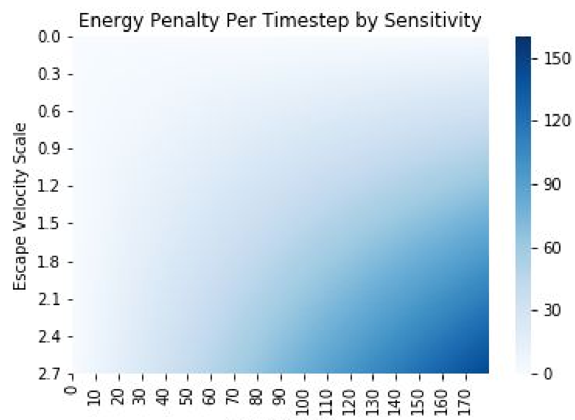

Figure 0: Energy penalty per time step by sensitivity

Attack Mode Update: Every 200 timesteps,the attack mode would be reversed, and the velocity of the predators would be either returned to 0.2 if attack mode was false else it was increased to 0.3.

Predator Killing Behavior: If the predators are in attack-mode, b birds in the attack cones of the predators were killed where b is a Binomial random variable with n as the number of birds visible to predators and p the probability of a predator killing a bird within its visual cone (maintained at 0.3).

Bird Mating Behavior: every 200 timesteps, the birds would reproduce. Two mating schemes were employed - one based on energy level and one random. *Energy based:* the probability of a bird reproducing was defined by the function $p(Reproducing) = 0.25/(1 + e^{-0.17 *(energy-80)})$.

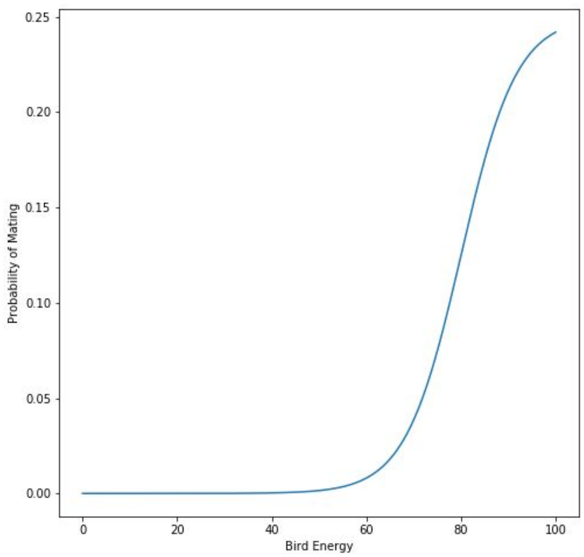

Figure 1) Probability of reproduction based on energy levels of an agent

Then, the outcome of a Bernoulli trial with $p = p(Reproducing)$ determined whether that bird would produce a bird with jittered x and y coordinates but identical predator sensitivity as its parent. *Random:* The probability of reproduction for each bird was fixed at $p = 0.005$.

5.0 Methodology

After establishing the behaviors described in section 4.0, experimentation could begin. For the process of determining sensitivity profiles, there were many constants. The total number of birds was set to 400 and the total number of predators was set to 12. There were 77 trials conducted with the probabilistic reproduction method, each trial lasting 15,000 timesteps. 100 random reproduction trials lasting 15,000 timesteps were also conducted.

In order to determine the sensitivity profile, the attributes were broken into two different categories: sensitivity of detection and magnitude. Radius of detection, angle of detection, and neighbor sensitivity characterized the detection sensitivity, while escape velocity scale and turning angle were classified under magnitude. The value of each of these attributes for all living birds were tracked at each time step to understand if certain profiles were being reproduced more than others. This analysis was conducted for both methods of reproduction to examine the effects of an energy penalty.

6.0 Results

Population

Charting population over time (fig. 2.a, 2.b) revealed a distinct difference between the energy- and random-based mating approaches. Both flocks initially experience a sharp decline in population. The randomly mating flock in Fig. 2.a, however, never regains population, indicating that the flock does not adopt behaviors that successfully avoid predation. Figure 2.b shows a decrease in population in the beginning until a minimum “optimal” profile is reached, and then the population begins to increase, indicating that the flock has begun to successfully evade the predators. This result indicates that a fitness-based mating approach using energy as a fitness metric improves flock survival at the cost of individual birds’ energy.

Detection Sensitivity While both groups decreased in average sensitivity to neighboring birds’ predation responses (fig. 3.a, 3.b), as shown by an increase in the number of predated neighbors needed to induce an evasion response, the energy-based mating group had a larger decrease than did the random mating group. Both groups also converged to a single, low-sensitivity response (fig. 8.a, b), with the energy group having a greater proportion in the low sensitivity group than the random mating group.

A greater dichotomy in detection angle trajectories was found between the two groups (fig. 4.a, 4.b) . As expected, the random mating group had a large increase in detection angle, approaching the maximally sensitive profile. The energy mating group had little increase in mean detection angle from the initialization. Interestingly, while the random mating group converged to a high-sensitivity profile (fig. 9.a), the energy mating group failed to converge to a single profile, forming a roughly trimodal distribution with peaks at 0, 130, and 350 degrees (fig. 9.b).

Once again, the random mating group's mean detection radius approached the maximum allowed value (fig. 5.a), while the energy group was significantly desensitized over the course of the simulations (fig. 5.b). Both the energy and random mating groups strongly converged to a single profile (fig. 10.a, 10.b). Interestingly, the modal detection radius for the energy mating group was 0 patches, so birds could still sense predators and other birds that shared the same patch.

Together, these results show that a very low-sensitivity (low neighbor sensitivity, small visual cone) predator detection profile are sufficient for formation of a successful flock that can evade predation under a high energy penalty for predator evasion.

Response Magnitude Both groups had a substantial increase in escape velocity scale, with the random mating group again exceeding the energy mating group (fig. 6.a 6.b). While the escape velocity scale of the random mating group converged to a high value, however the energy mating group had two common values (1.6 and 2.6).

Again, the escape angle diverged between the two groups (fig. 7.a, 7.b). The random mating group increased moderately, while the energy mating group decreased dramatically. The random mating group did not strongly converge to a single value, but the energy mating group consisted almost exclusively of a 0 degree turning angle.

With a trend toward higher increases in velocity during evasion and a minimal escape angle, at a high energy penalty changes in velocity are more important in successful predator evasion than changes in heading. While a single escape angle profile appears adaptive, escape velocity scale has a higher variability.

7.0 Future Work

Current efforts were focused on answering the question: "is variance in response to predators is adaptive, or whether there is an 'ideal' response to a predator?" While the methodology used in this paper was sufficient to answer this question, there were avenues left unexplored. One way to expand upon this project is to conduct the experiment with varying predation behaviors. The predation behavior used in this project was to have the predator attack the nearest bird in its cone of vision when in attacking mode. Other behaviors such as attacking the center of the entire flock or attacking dense regions of the flock could also be studied in greater depth. Along with changes in predation behavior, one could examine variations in flock responses. It has been shown that certain flocks will respond to predators by initiating their own attack response. Other studies have shown that the way flocks evade the predators can change through reformation of flock into different escape patterns. Migration season is also a very important factor in flock movement. It could be pertinent to model the flock's response to predators throughout the year to see if there are any variations during a time of great migration. Further empirical research could also help fine tune the parameters dictating the predator and prey behavior.

8.0 Conclusion

Due to the lack of penalty for hyper-sensitive responses, the random mating group moved on the average towards a highly sensitive predator evasion behavioral profile. Notably, there was still significant variance in response sensitivity, particularly in neighbor sensitivity, escape angle, escape velocity scale, and detection radius. The random mating group also failed to adopt evasion features that promoted flock survival, and the flock was eventually eliminated by the predators.

With the addition of an energy penalty, we expected the energy mating group to exhibit a desensitized predator evasion strategy versus the random mating group, and for this group to outperform the random mating group due to a fitness-based mating strategy. This assertion was backed by a desensitized profile in both the response sensitivity and magnitude of response. This desensitization was especially noticeable with regards to the escape angle, detection radius, and detection angle.

Interestingly, neither group increased in sensitivity to their neighbors, suggesting that the benefit of a flock to its members does not come from responding to “informed individuals” that directly detect the predators.

Neither group strongly converged in escape velocity scale or neighbor sensitivity, suggesting that while acceleration during escape is advantageous, a variety of responses does not hinder flock survival. Escape angle strongly converged to a minimal change in heading during evasion, suggesting that changes in speed and sensitivity are more important for successful predator evasion than changes in heading. Variation in detection angle seemed adaptive, as the energy mating group failed to converge on a single value, while the random mating group converged on a near-360 degree detection angle. Detection radius strongly converged to a detection radius of 0 patches in the energy mating group, indicating that very local information is sufficient to promote flock survival under a high energy penalty.

Together, these results indicate that local information combined with a desensitized predator response in terms of detection sensitivity and the magnitude of the evasion response are sufficient for flock survival under constant predation. Further, convergence towards a single, optimal profile is adaptive for detection radius, escape angle, and neighbor sensitivity, whereas a variability in responses was associated with improved flock survival for detection angle and escape velocity scale.

Project Contributions

The research work done for this project was shared by both members. The code for the simulation was originally built off of an existing NetLogo model. As such, more research was needed to determine how to create realistic predator behavior and reproduction methods. After researching, the team members discussed their findings and what should be implemented as changes to the model. Benjamin was responsible for creating the code that was utilized during the trials of the experiment. Benjamin also produced the graphs after running the experiments that are seen in this paper. Both team members performed analysis on the results produced from the experiments.

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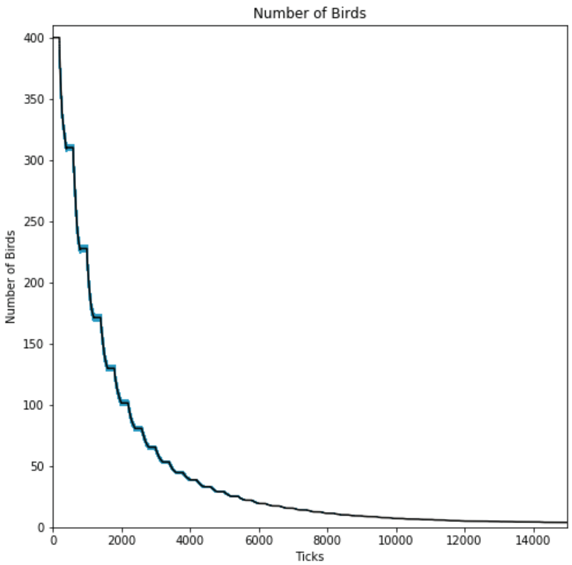
2.a



2.b

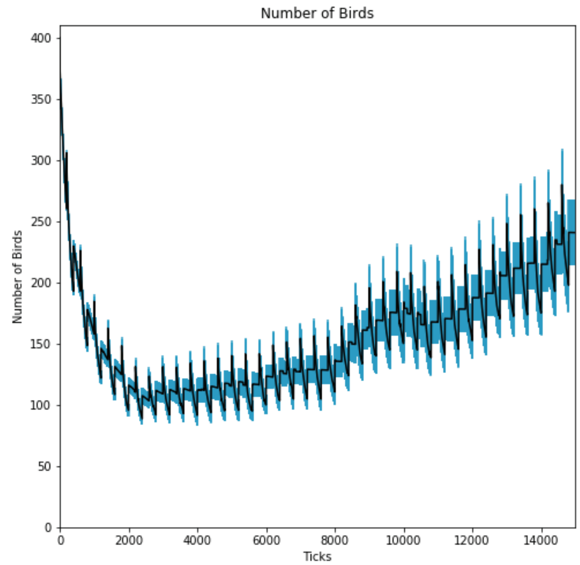
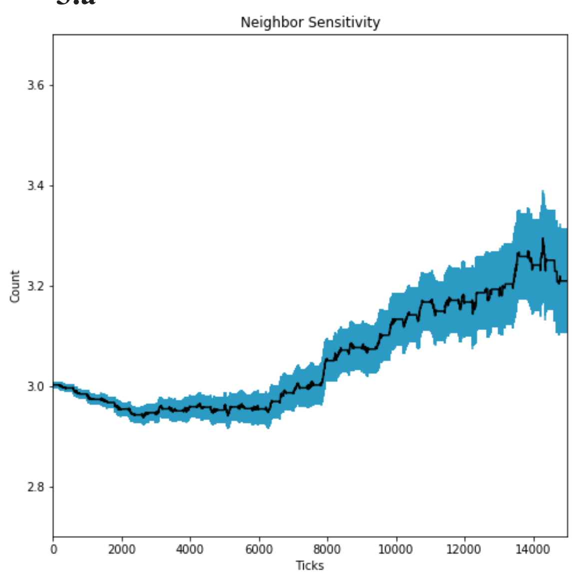


Figure 2: Change in mean population ± SEM over time with a) random mating and b) energy-based mating

3.a



3.b

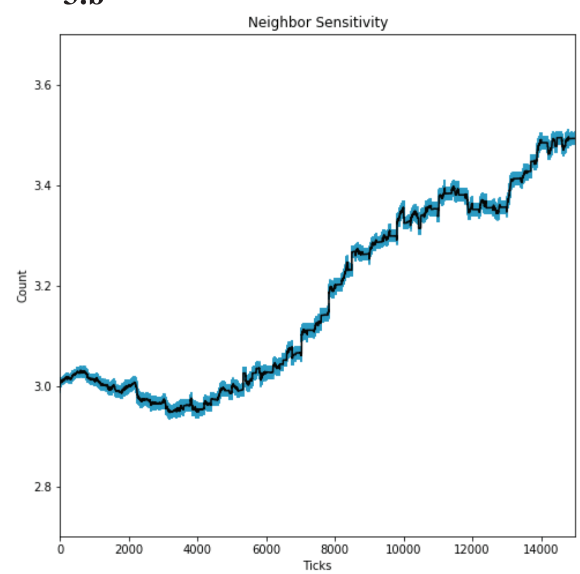
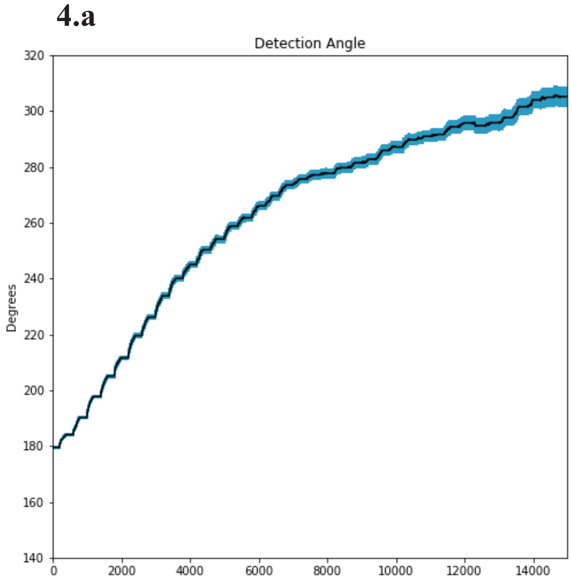


Figure 3: Change in mean neighbor sensitivity ± SEM over time with a) random mating and b) energy-based mating

4.a



4.b

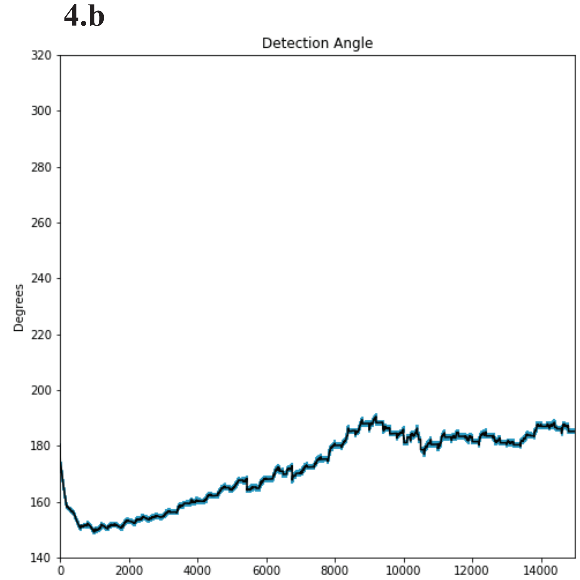


Figure 4: Change in mean detection angle ± SEM over time with a) random mating and b) energy-based mating

5.a **5.b**

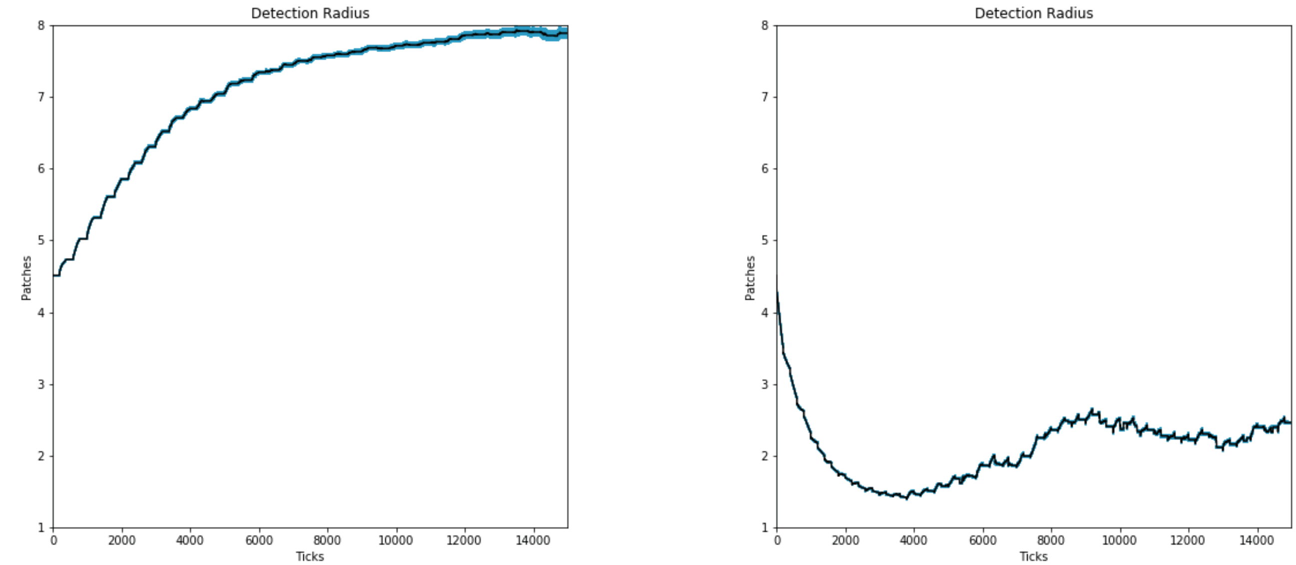


Figure 5: Change in mean detection radius ± SEM over time with a) random mating and b) energy-based mating

6.a **6.b**

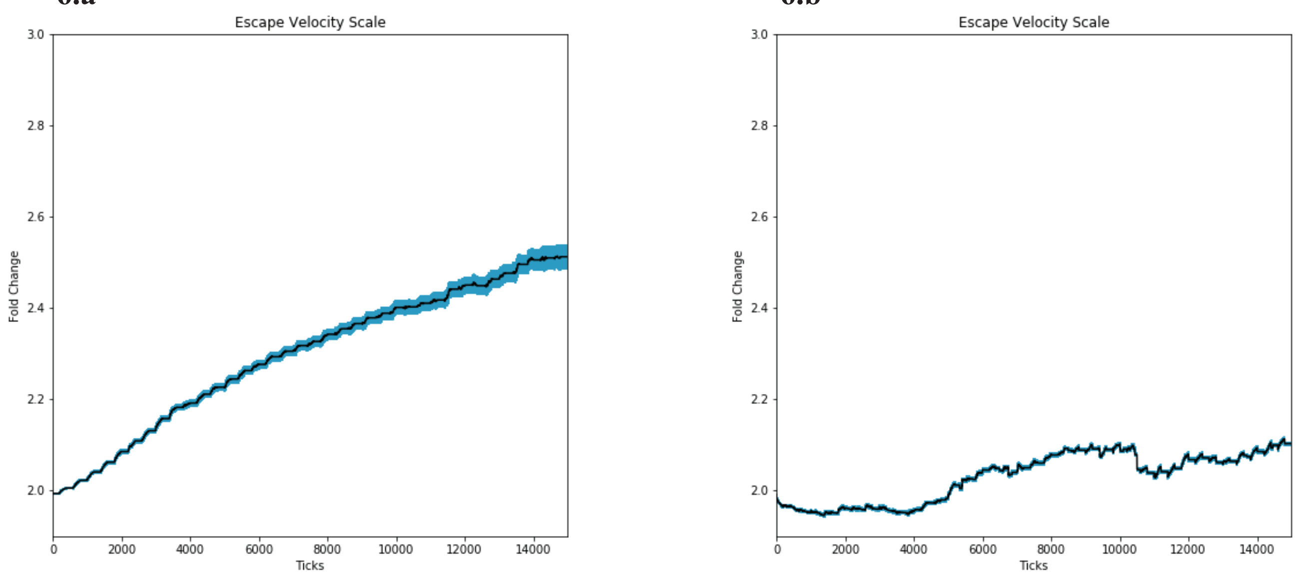


Figure 6: Change in mean escape velocity scale ± SEM over time with a) random mating and b) energy-based mating

7.a **7.b**

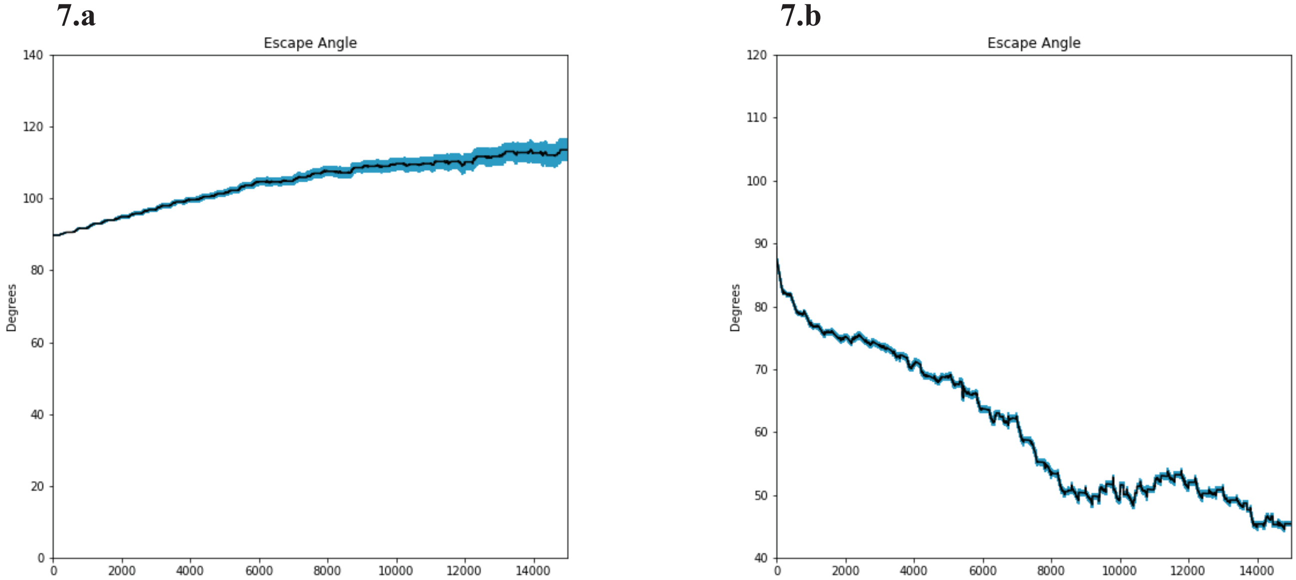


Figure 7: Change in mean escape angle ± SEM over time with a) random mating and b) energy-based mating

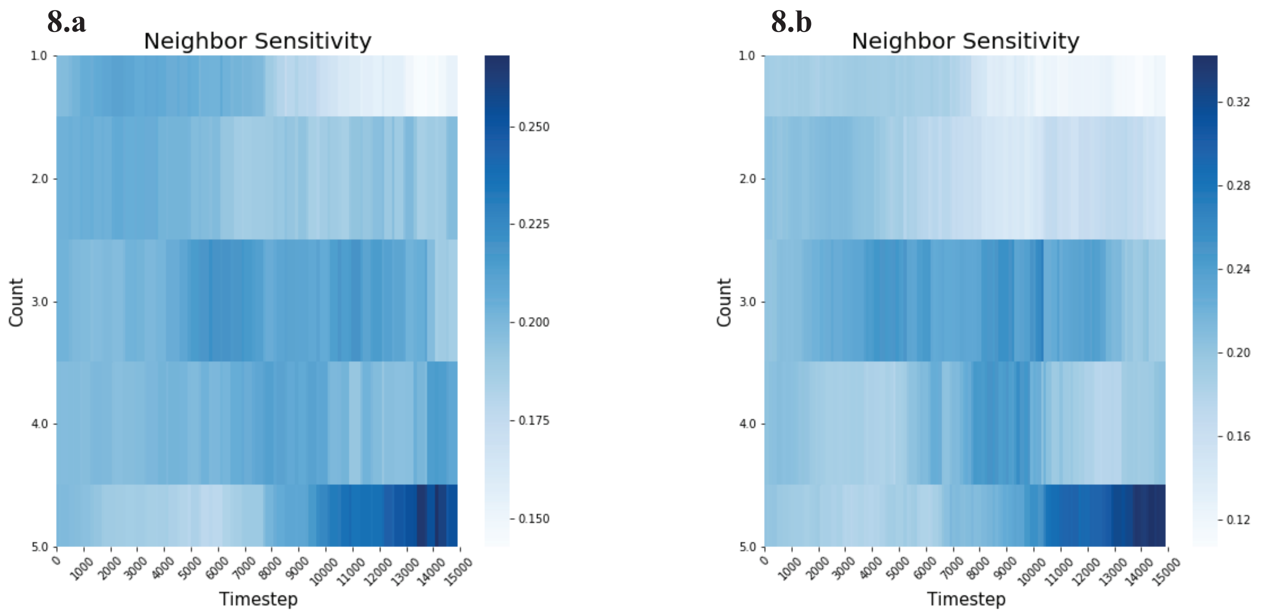


Figure 8: Histogram of neighbor sensitivity over time with a) random mating and b) energy-based mating

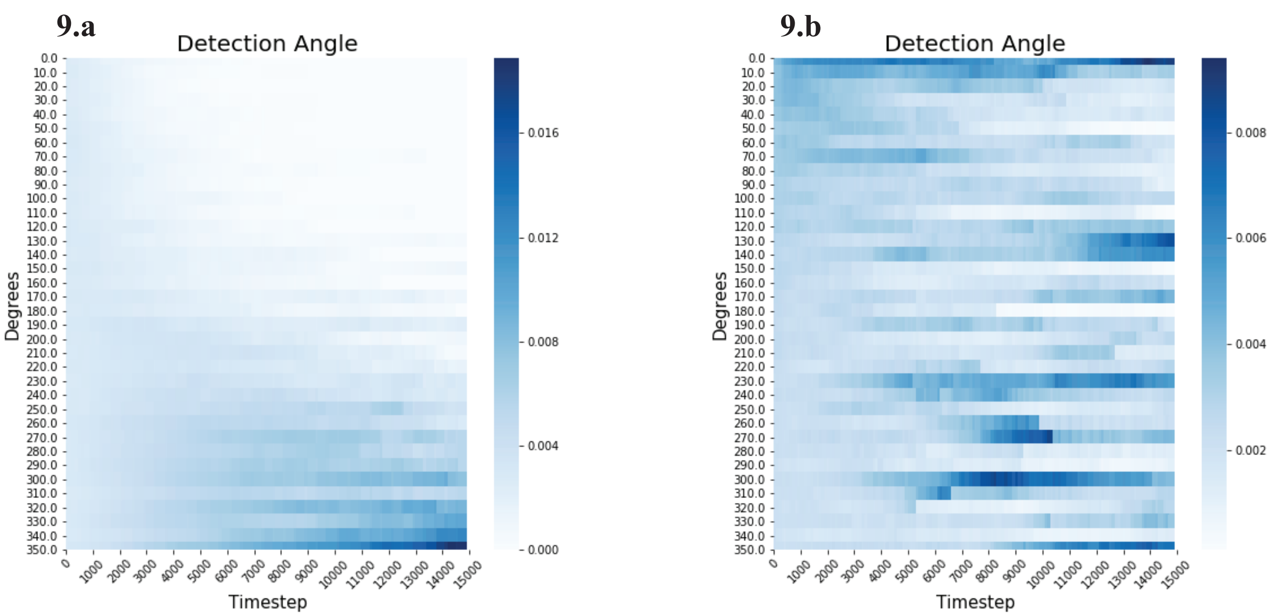


Figure 9: Histogram of detection angle over time with a) random mating and b) energy-based mating

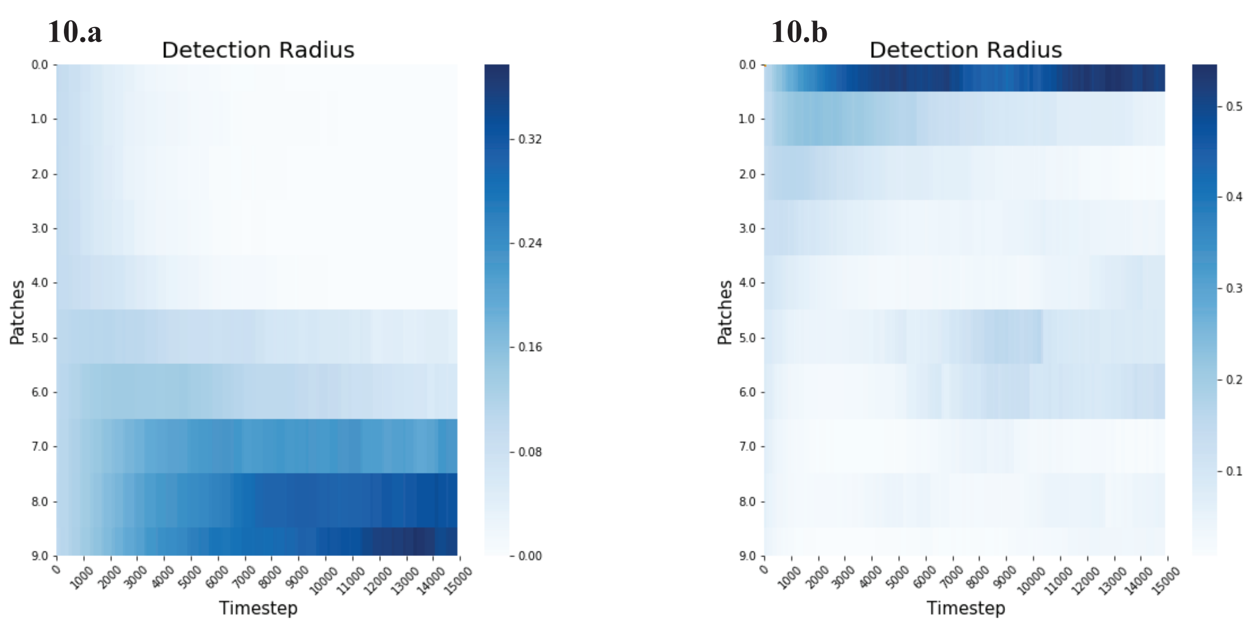


Figure 10: Histogram of detection radius over time with a) random mating and b) energy-based mating

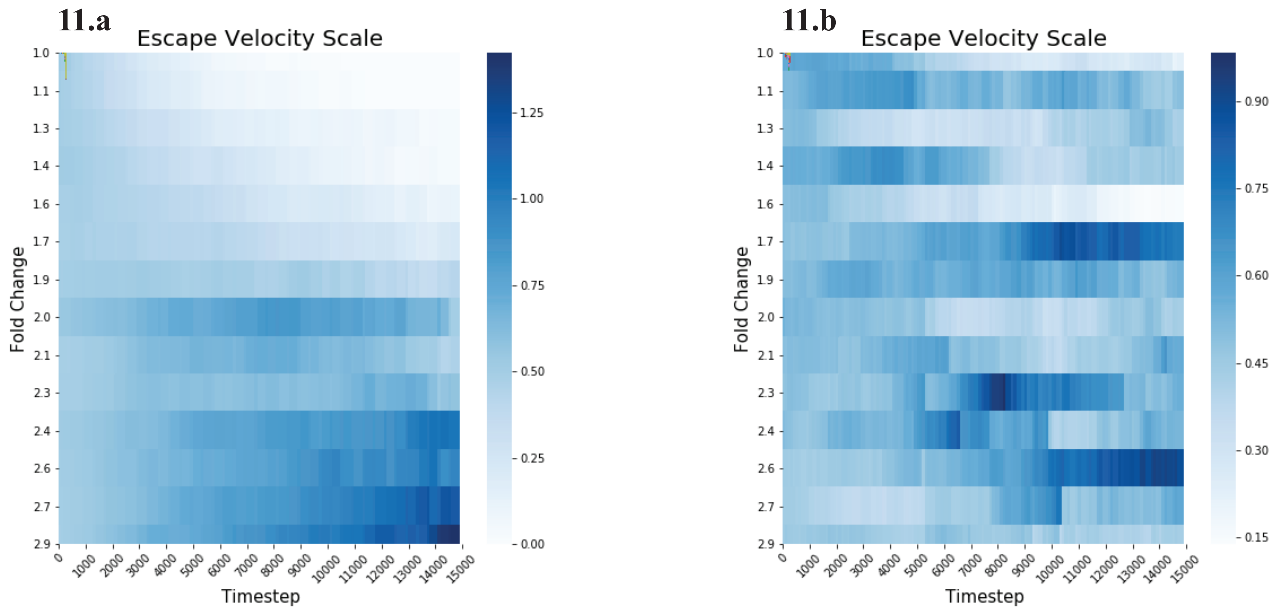


Figure 11: Histogram of escape velocity scale over time with a) random mating and b) energy-based mating

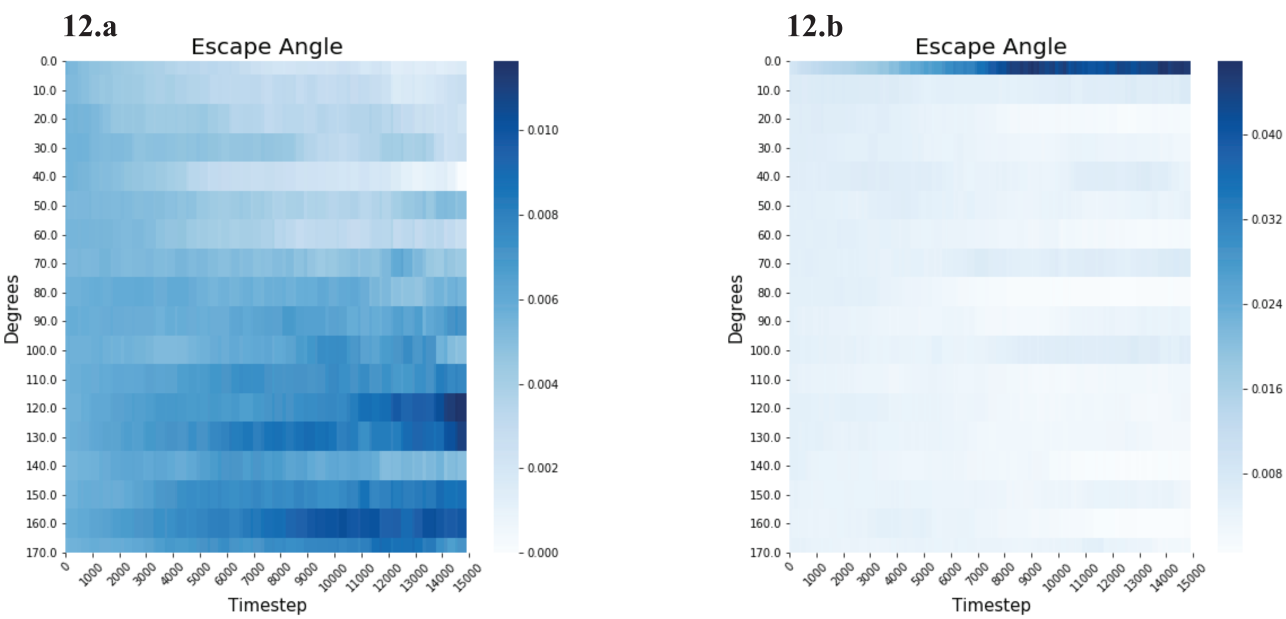


Figure 12: Histogram of escape angle over time with a) random mating and b) energy-based mating