Model Information

## WHAT IS IT?

This Netlogo simulation illustrates the life cycle of Bradysia ocellaris, commonly known as the dark-winged fungus gnat, native to the Palearctic region and has also been introduced to Australia (Menzel et al, 2003). These gnats thrive in moist, humid environments with an abundance of fungi and decaying organic matter (Duarte et al, 2022). As a result, they are commonly found in greenhouses, mushroom farms, and indoor potted plants (Duarte et al, 2022).

The simulation models the four stages of a gnat's life cycle: egg, larva, pupa, and adult. For each run, it tracks the remaining dynasties, larval deaths, pupal deaths, and overall gnat count. Additionally, a graph is generated to display the average strength of the gnat population over time.

## HOW IT WORKS

Each stage of the gnots life cycle is governed by its own set of rules. The gnots will follow four main sets of rules which will determine the stage of their life cycle, reproduction, movement and death.

- The world is initially cleared, resized and the global variables ('Dynasties Remaining', 'Larval Deaths', 'Pupal Deaths', and 'Gnot Count') are set to 0. A population of gnot eggs are then produced, the number set according to the value of the 'population' variable. Each gnot has a unique ID and have their age and speed set to 0, a size set to dot of 0.8, and placed at a random position. The created gnots are set as not-parents (is-Parent False) and a reproductive value of 1 which assigns the gnot a 'sex'. Gnots are not able to lay eggs if their reproductive value is 0 and are if the value is 1, meaning all initial gnots will have the ability able to lay eggs. The strength of each gnot is set randomly based on the normal mean-strength and the standard deviation of the strength. The ensures the data obtained from the simulation is obtained from each separate run.

- The age of each gnot is determined by the number of ticks that have passed. This age dictates the stage of the gnat's lifecycle. Gnots aged 0 to 35 are in the egg stage, characterized by a speed of 0, a dot shape, and a size of 0.8. Gnots aged 36 to 191 are in the larval stage, characterized by a speed determined by its strength (this speed is 0.03% the speed at the adult stage, making it much slower), a bug shape, and a size of 1.2. Gnots aged 192 to 239 are in the pupal stage, characterized by a speed of 0, a bug shape, and a size of 1.2. Gnots aged over 240 are in the adult stage, characterized by a speed determined by its strength, a default shape, and a size of 3.

- Gnots are assigned a sex by a random value of 0, male, or 1, female, set as the variable can-reproduce. Each female gnot has a random probability to reproduce by laying eggs, set by 'random 168 < 1'. The size of the egg clutch is determined by the number of patches in the specified egg-laying-radius and the expected egg quantity. Once eggs are laid, the parent gnot is then identified as a parent by setting the variable 'is-Parent' to true. The eggs will inherit the colour of the parent-gnot.

- The initial gnot's strength of the gnots are determined using a random value obtained from the normal distribution and the specified value for the standard deviation of the mean. If the inherit-parent-strength is turned on, the gnots will inherit the initial-strength of their parent gnot, whereas if it is turned off the eggs will be given a random strength value just as the initial gnots were.

- Only gnots at the larval and adult stages are the gnots set to be able to move. The gnots are set to randomly turn left and right and their speed is determined based on their strength. The strength of each gnot decreases over time to simulate aging, and female gnots' strength is halved after laying a clutch of eggs.

- As the gnots age or have laid eggs, their strength decreases. Once the strength of the gnot reaches 0, the gnot 'dies'. If the gnot has a low initial strength, it will die in the early stages of its lifecycle. If a gnot dies while in the larval stage, the "Larval Deaths" counter increments by 1. If a gnot dies while in the pupal stage, the "Pupal Deaths" counter increments by 1. When a gnot dies, a procedure called kill-gnot is activated where the appropriate death counter is incremented and the gnot is removed from the simulation.

## HOW TO USE IT

There are six global variables the user is able to adjust in this simulation. To adjust the initial population size of the gnots the user should use the 'population' tab. To adjust the strength of the gnots the user should use the 'mean-strength' and 'stddev-strength' tabs. To adjust the reproductive behaviour of the gnots the user should use the 'egg-laying-radius' and 'expected-egg-quantity' tabs. The strength of the laid eggs can be set to either a randomly selected value or inherited from its parent gnot.

- The population tab allows you to adjust the initial number of eggs the simulation begins with. The user is able to select between 20 and 40 eggs to start the simulation.

- The mean-strength tab allows you to adjust the mean value for the normal distribution to initialize the strength of each gnot. The gnot's strength is determined by a random value drawn from the normal distribution with the selected mean-strength. The user can select a mean-strength between 50 and 60, 50 giving the lowest normal distribution of strength and 60 the highest.

- The stddev-strength tab allows you to adjust the standard deviation for the normal distribution used to initialize the strength of each gnot. The gnot's strength is determined by a random value drawn from the normal distribution with the selected standard deviation. The user can select a stddev-strength between 5 and 10, 5 giving the lowest standard deviation of strength and 10 the highest.

- The egg-laying-radius tab allows you to adjust the radius around the gnot which the gnot is able to lay eggs within. When the gnot decides to lay eggs, it will consider patches within the radius as potential locations to lay the eggs. The radius can be set between the values of 4 and 9. The smaller the radius, the less patches the gnot has to consider laying eggs within, reducing the area the gnots are able to spread their eggs. The larger the radius, the more patches the gnot has to consider laying eggs within, increasing the area the gnots are able to spread their eggs. This tab will only affect 'female' gnots.

- The expected-egg-quantity tab determines the expected number of eggs each female gnot will attempt to lay within the set egg-laying-radius. This value will influence the probability of egg-laying on each patch within the set radius. The user can select values between 3 and 10, with 3 being the lowest number of expected eggs laid within the set radius and 10 being the highest.

- If the inherit-parent-strength switch is turned on, all eggs will inherit the initial-strength of their parent gnot. If the inherit-parent-strength switch is turned off, all eggs will be given a random strength based on a random value from the normal distribution and multiplied by the standard deviation of strength.

- The speed of the simulation can be adjusted using the 'normal speed' slider at the top of the simulation. The number of ticks refers to how many time steps have passed in the simulation. The further left the slider, the slower the simulation will run with less ticks passing per second, whereas the further right the slider, the faster the simulation will run with more ticks passing per second.

## THINGS TO NOTICE

The simulation has five key data trackers: 'dynasties remaining', 'larval deaths', 'pupal deaths', 'gnot count' and 'Mean Initial Gnot Strength'. These variables are useful in gaining an understanding of the dynamics of the gnot population such as the survival rates, reproductive ability of the population, and the overall strength of the population.

- The purpose of the dynasties remaining counter is to calculate the number of unique gnot dynasties (or family lines) that are still active in the simulation. This value is particularly important for studying factors including the genetic diversity of a population, survival of dynasties, population stability, and the effect of environmental changes. A high genetic diversity indicates an ability of the population to evolving and adapting to environmental changes and overcoming problems such as disease, whereas a low genetic diversity indicates the population is vulnerable to environmental changes and/or disease. The surviving dynasties provides insight into which families are more successful in terms of survival and reproduction. By studying the dynasties remaining, researchers are able to understand the long-term stability of a population. A stable or increasing number of dynasties can indicate a healthy population, whereas a decreasing number of dynasties suggests problems within the environment such as competition or inbreeding. NetLogo does this by collecting all the IDs of the living gnots and removing any duplicates. This gives the total dynasties remaining.

- The purpose of the larval and pupal deaths counter is to track the number of gnots that have died whilst in the larval stage of their life (aged less than 192) and gnots that have died whilst in the pupal stage of their life (aged between 192 and 240). This data is particularly useful in the study of population health and viability, resource allocation and life cycle analysis. Tracking the pupal and larval deaths provides insights into the early life-stage mortality rates within the population, where a high mortality can indicate underlying issues such as poor environmental conditions, lack of resources and/or genetic issues. Studying this data also provides an understanding of the resources necessary for each stage of the gnots life cycle which can be adjusted to ensure better survival rates. This data provides accurate and detailed information on the mortality rates at different stages of the life cycle allowing researchers to critical intervention points to improve the survival rates of the population. Understanding these factors can help in assessing the overall health and viability of the population.

- The purpose of the gnot count is to track the total number of gnots that have been created throughout the simulation which provides data on the overall population dynamics, effectiveness of the population's reproductive ability, and the impact of environmental factors on the population growth. This data is useful in tracking the overall population growth over time. By monitoring this variable, it is possible to determine whether a population is growing, stable of declining, which is vital for understanding population trends and dynamics. The data also suggests a measure of the reproductive success within the population as a high gnot count indicates the population is successfully reproducing and therefore the conditions are favourable for the population. This accurate data can be used to model the population dynamics and simulations for building and validating models that predict future trends in the population growth.

- The purpose of the mean initial gnot strength graph is to track the mean strength of the population of gnots as time increases. If the graph is increasing as time progresses, this shows the mean strength of the gnots is increasing, meaning the population is getting stronger and gnots have an increasing lifespan. If the graph is overall horizontal as time progresses, this shows the mean strength of the gnots is neither increasing nor decreasing, meaning the population has a stable lifespan. If the graph is decreasing as time progresses, this shows the mean strength of the gnots is decreasing, meaning the population is getting weaker and gnots will die quicker. A mean initial strength of 0 means the population has died out.

## THINGS TO TRY

You can adjust several variables to affect the results of each run. Try adjusting these variables to see the effects each variable has on the dynamics of the population. You could try to:

1. Maximise / minimise the dynasties remaining over a set number of ticks (e.g. 2000)

2. Maximise / minimise the larval deaths over a set number of ticks (e.g. 2000)

3. Maximise / minimise the pupal deaths over a set number of ticks (e.g. 2000)

4. Maximise the gnot count over a set number of ticks (e.g. 2000)

5. See what conditions would cause the population to become extinct

6. Maximise / minimise the mean initial gnot strength over a set number of ticks (e.g. 2000)

- Adjust the starting population of gnots. By adjusting the number of eggs the simulation starts with, the user can experiment to see how the population size impacts the population growth, dynasties remaining and the mortality rates at the larval and pupal stages.

- Adjust the mean and standard deviation of strength. By adjusting the overall strength of the gnots, the user can experiment to see how this effects the survival and reproductive ability of the population. For example, a higher average strength may result in a longer average lifespan and therefore more successful reproduction and a higher population growth. The user can use this data to evaluate how varying strength levels affect gnot movement and interactions, and whether the strength value effects the gnot's ability to reproduce.

- Adjust the egg-laying radius. By adjusting the radius within which female gnots can lay eggs, the user can see how this affects the distribution and density of new gnots. Larger radii may result in a more dispersed population, whereas smaller radii may result in more crowded conditions.

- Adjust the expected egg quantity. By adjusting the expected egg quantity from female gnots, the user can experiment with this parameter to see how it affects the population growth of the gnots. Higher expected egg quantities can lead to a rapid population growth, but this could impact other factors such as over-crowding and resource depletion.

- Observe life stage transitions. The user can pause the simulation after a set period of gnots to track how quickly or slowly the population is transitioning through their stages of the life cycle and can track individual gnots to see how long each one spends during each stage.

- Monitor dynasty survival. Adjust the variables available in an attempt to maximise and minimise the number of surviving dynasties and determine how the different settings affect the survival of the distinct family lines over time.

- Monitor mortality rates. Adjust the variables available in an attempt to maximise and minimise the mortality of gnots during the larval and pupal stages of their life cycle and determine how the different settings affect the survival of these stages.

- Monitor mean-initial-strength. Adjust the variables in an attempt to maximise the mean initial gnot strength of the population of gnots over a set time to see what their optimum conditions are for thriving and strengthening, thus increasing their life span and ability to reproduce. Adjust the variables in an attempt to see what conditions are required for the population to die out. Try finding a variety of combinations and listing the reasons behind the decline.

## EXTENDING THE MODEL

There are several real-life factors that affect the population growth of Bradysia ocellaris which this simulation does not consider. Implementing one or more of the variables listed below would make the simulation closer to a real-life population and give a more accurate representation of what would happen to the growth of the population and the rates by which they reproduce, survive and die.

- Incorporate resource availability. Food and water are necessary resources for all living organisms where availability will drastically affect the population growth. By implementing patches which can have varying levels of food resources, this will give the user another variable which they can adjust alongside the current variables to achieve more accurate and detailed results.

- Incorporate predators. In the wild, Bradysia ocellaris has natural predators such as the nematodes Steinernema feltiae and predatory mite Hypoaspis miles which predate on the larvae in the soil. Predators are often used as a biological control measure for population growth and therefore are an important factor to consider. The user could implement the ability to introduce a varying number of predator agents to the simulation to see how this would affect the data of the population of gnots, in particular the survival of larvae and pupae as these are the dominant prey items.

- Incorporate disease dynamics. Disease is a natural control for any population. Implementing the ability to introduce disease at a varying level will allow the user to obtain more accurate data on the affects it has on the population growth, survival and reproductive ability of the population at each stage of the gnots life cycle.

- Implement genetic variation and inheritance. The simulation has a basic level of inheritance where the colour can be inherited from the parent which does not affect the data in any way, and the strength of the offspring is inherited from the parent. The user could add genetic traits that influence survival and reproduction with inheritance mechanisms.

- Enhance reproductive mechanics. Currently female gnots are able to lay eggs under any circumstance, whereas in real-life the gnats would need to mate and there would be an energy cost to the female gnat after laying the eggs. These features would make the simulation more complicated but give a more accurate representation of how the population would act under these constraints. Females would only be able to reproduce once they've mated and in order to do so and to lay eggs they would need a specified level of energy. This would pair well with the implementation of food and resources.

## NETLOGO FEATURES

This NetLogo model uses several interesting features to simulate the population growth and reproductive ability of Bradysia ocellaris, such as:

- Using global variables (i.e. larval deaths, pupal deaths and gnot count) as a means of tracking data across the simulation.

- Each turtle has its own attributes (i.e. age, speed, strength and sex) which allows for individual modelling of agents as well as population modelling.

- The agents go through stages of their lifecycle (i.e. egg, larva, pupa and adult). Each gnot goes through these stages at different rates depending on individual factors and each gnot as a result has a different survival rate and speed due to its individual strength value.

- Adult female gnots are able to lay eggs based on random chance and find suitable laying spots within a radius determined by the user which demonstrates how the gnats must consider adequate areas within their vicinity to lay their eggs.

- The model tracks the number of gnot deaths across the simulation and separate this data according to the age of the gnot at the time of its death which adds an additional layer of detail to the mortality when tracking the mortality rates in the simulation.

- The model is able to track runs where the gnot population dies out. It does this by tracking the number of gnots on screen. The variable 'gnots-died-out' is initially set to false, where it will change to true if all gnots die.

The model also has a number of features used as workarounds for missing features, such as:

- NetLogo does not naturally reset the counters between simulations, so this model manually clears this data between simulations making the data obtained specific to each simulation run with the specific variables chosen.

- NetLogo does not have built-in support for many statistical distributions, so this model uses the random-normal function to initialize the strength of each gnot which is useful for modelling the real-world variability of each gnat.

- NetLogo does not have built-in support for decay mechanisms, so this model uses a manual implementation to decay the strength of the gnot where the strength reduces over time and also reduced by the presence of close gnots due to competition.

- NetLogo does not have a direct or straightforward way to track the number of dynasties remaining, so this model makes use of the 'remove-duplicates' feature on the ID to track this data.

- NetLogo lacks built-in spatial density functions, so this model manually calculates the patch density for egg-laying which is then used to determine the likelihood of laying eggs.

- NetLogo does not have a standard method of identifying when all agents have 'died' in the run, so this model makes use of a Boolean called 'gnots-died-out' which tracks whether there are gnots alive or not, meaning if the population has survived or died out.

## RELATED MODELS

- The 'Termites' model simulates the actions of termite colonies where behaviours such as foraging and interactions between agents can be studied. This is of interest if studying the behaviour of inspect populations.

- The 'Wolf Sheep' model simulates the predator-prey dynamics between wolves, sheep and grass. This may be of interest as this is a simulation to monitor population growth of specific species similar to that of the gnats, and tracks the number total number of grasses, sheep and wolves at each point of the simulation, plotting a time-density graph for each of the species, showing how the population levels affect each other.

- The 'Ants' model is another simulation based on the behaviours of insects where the ants forage for food and leave pheromones as a trail for other ants to follow. The model is predominantly based on how the population size affects the behaviour of the colony and is another simulation modelling the effects of population size.

## CREDITS AND REFERENCES

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How a Gnot-Inspired Approach might be Adapted  
for the Travelling Salesperson Problem

Introduction

The travelling salesperson problem was formulated in 1930 and since then has been one of the most intensely studied mathematical problems (Goyal, 2010). The problem entails a list of cities with known distances between each, the task is to find the shortest route the salesperson can travel to visit every city once only (Goyal, 2010). Although the problem sounds simple, it holds an exponential level of complexity the greater the number of cities for the salesperson to visit (Goyal, 2010). Biological models have been widely used in an attempt to solve the travelling salesperson problem, such as the use of ant colonies, studied my Dorigo, M. and Gambardella, L. M. (1997) in the paper “*Ant colonies for the travelling salesman problem*”, and the use of genetic algorithms studied by Larranaga, P. et al. (1999) in the paper “*Genetic Algorithms for the Travelling Salesman Problem: A Review of Representations and Operators*”.

Adapting the Gnots Model

To adapt the gnots model for the travelling salesperson problem, the simulation would be set up with a specified number of randomly placed locations with their own unique ID, i.e. the cities, and a specified number of gnots where each gnot represents a travelling salesperson and a potential solution to the problem. Each gnot will be assigned a random path through each city and will have a strength value which will be based on the total distance of the path it takes to complete the journey. The shorter the distance the gnot takes, the higher the value of its strength, giving it a better fitness which can be tracked. The gnots will use the unique ID of the cities to identify if they have already visited this location or not, ensuring it only travels through each city once. Each gnot will be able to make decisions to change the path it takes and will evaluate the new strength value to see if it is better or worse. Similar to the current model, reproduction can be implemented by mimicking genetic crossover where two gnots’ paths can be combined for the child gnot to travel and evaluate, and mutation could be implemented to occasionally make small random changes to the offspring’s path which would maintain diversity and continuing to check new paths. The greater the strength value of the gnot (i.e. the shorter the path), the more likely the gnot to survive and reproduce to pass on their shorter path to the next generation, whereas gnots with a lower strength value are more likely to die out from the kill-gnot function and will ensure they do not pass on their longer paths to the next generation. By having the stronger gnots reproduce and pass down their shortest routes, this will result in a generational improvement of results with each new generation converging toward the optimal solutions to the problem. There will be three ways to stop the simulation, the first being the user will be able to state a number of generations to have been produced that will cause it to stop. The second way the simulation would stop is the strength of the gnots is no longer improving which means the gnots have converged to find the best solution. The last way is the user specifies a strength value that once a gnot has reached will stop the simulation.

Advantages and Disadvantages

Adapting this model to the travelling salesperson problem is advantageous in several ways. Firstly, the model incorporates a specified number of gnots acting as individual and independent potential solutions to the problem which makes the problem robust and scalable. With multiple gnots searching for the optimum solutions to the problem, different routes are explored simultaneously which makes the model more efficient and potentially able to discover the optimum routes faster. Finally, the model is adaptable, and several variables can be created and adjusted to suit different variations of the problem.

The model does face some challenges if it were to be created, such as requiring large computational resources to manage larger populations of gnots for simultaneous path finding. The parameters and variables made must be considered carefully when creating this model as some parameters could negatively affect the populations’ ability to find the shortest path, such as too high a mutation rate of too fast a death rate. Another problem to consider would be the potential for gnots to become stuck in local optima, meaning they are looping the same pathing and no longer finding improved and shorter paths. This could be resolved by using strategies such as simulated annealing or other methods which consider the global minimum of a cost function which considers the cost of local minima (Aarts et al., 2019).

References

Aarts, E., Korst, J., & Michiels, W. (2019). Simulated Annealing. *Search Methodologies*, 187–210.

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NetLogo Code

**globals** [  
 larval-deaths  
 pupal-deaths  
 gnot-count  
 mean-initial-strength  
 gnots-died-out  
]  
  
**turtles-own** [  
 age ;;in hours  
 speed   
 initial-strength  
 strength ;;  
 can-reproduce  
 id  
 is-parent  
]  
  
**to** setup  
 clear-all  
 resize-world 0 100 0 100  
 set-patch-size 4.0  
 set larval-deaths 0  
 set pupal-deaths 0  
 set gnot-count 0  
 set gnots-died-out **false**  
 create-turtles population [  
 set age 0  
 set shape "dot" set size 0.8  
 set strength random-normal mean-strength stddev-strength  
 set initial-strength strength  
 set speed 0  
 setxy random-xcor random-ycor  
 set can-reproduce 1  
 set id who  
 set is-Parent **False**  
 set gnot-count gnot-count + 1  
 ]  
 reset-ticks  
**end**  
  
**to** go  
 if not any? turtles [set gnots-died-out **true** stop]  
  
 ask turtles[  
 let c color  
 let p-id id  
 let p-initial-strength initial-strength  
 (ifelse  
 age < 36 [set speed 0 set shape "dot" set size 0.8] ;;egg  
 age < 192 [set speed strength \* 0.0003 set shape "bug" set size 0.8] ;;larva  
 age < 240 [set speed 0 set shape "bug" set size 1.2] ;;pupa  
 [  
 set shape "default" set size 3  
 set speed strength \* 0.02 + 0.5  
 if random 168 < 1 and can-reproduce = 1 [  
 let patch-count count patches in-radius egg-laying-radius  
 ask patches in-radius egg-laying-radius [if random patch-count < expected-egg-quantity [ sprout 1 [  
 set age 0  
 set heading random 360  
 set speed 0  
 (ifelse inherit-parent-strength  
 [set initial-strength random-normal p-initial-strength stddev-strength]  
 [set initial-strength random-normal mean-strength stddev-strength]  
 )  
 set strength initial-strength  
 set color c  
 set can-reproduce random 2  
 set shape "dot" set size 0.8  
 set id p-id  
 set gnot-count gnot-count + 1  
 ] ]  
 ]  
 set strength strength / 2  
 set is-parent **True**  
 ]  
 ])  
 rt random 10  
 lt random 10  
 fd speed  
 set strength max list (strength - 0.1) 0  
 set age age + 1  
 if strength = 0 [ kill-gnot ]  
 if age > 36 [set strength strength - 10 \* (count (turtles-on patch-here) - 1)]  
 ]  
 (ifelse any? turtles  
 [set mean-initial-strength mean [initial-strength] of turtles]  
 [set mean-initial-strength 0]  
 )  
 tick  
**end**  
  
**to** kill-gnot  
 (ifelse  
 age < 192 [set larval-deaths larval-deaths + 1]  
 age < 240 [set pupal-deaths pupal-deaths + 1]  
 )  
 die  
**end**  
  
**to-report** gnots-died-out?  
 report not any? turtles  
**end**  
  
**to-report** dynasties-remaining  
 let \_unique remove-duplicates [id] of turtles  
 if gnots-died-out? [report -1000]  
 report length \_unique  
**end**  
  
**to-report** death-rate  
 report (larval-deaths + pupal-deaths)  
**end**  
  
**to-report** max-initial-strength  
 if gnots-died-out? [report -1000]  
 report mean-initial-strength  
**end**