1. Research Question

The aim is to construct an agent-based model to simulate the properties of desert locust and get the insight from their behaviours. The main question to study is:

- Can regional restrictions contribute to suppress the locust populations?

2. ODD description

In order to describe the model, this report would follow the Overview/Design concept/Details format, introduced by Grimm (2006, 2010). There are 7 parts in total. There is no change in biological quotation (Ariel and Ayali, 2015) (Bernoff et al., 2020).

2.1 Purpose and patterns

Within a limited area, this model replicates the consumption and other activities of locusts and their population distribution. The objective is to explore the useful way to control the dispersal of this swarm. The most important pattern should be reproduced is the gregarious type, which is considered as the one of the hardest problems of locust.

2.2 Entities, state variables, study scales

Each object in this model represents individual locust. They have coordinates to illustrate where they are in the grass network. Also, they have different colour to describe their status. The neighbourhood defined in Netlogo is used to measure the class of different locusts. Besides, there is a variable energy to explain their consumption and other activities.

This model uses geographic space with 2 dimensions without wrapping horizontally or vertically, so, it can act like a real grass. The location of each swarm is illustrated by the coordinates. Notice the default background set by Netlogo is made by 33 x 33 patches. To simulate the real world, each patch contains identical resource so they can be characterized by using the same variable, energy. Similarly, the food could grow back but slowly, as locusts always feed more quickly than grass grow back. Especially, this model focuses on the short time of period. For better view, each locust is set to only stay in the centre of each patch.

Every iteration in the model represents a move of a locust. It would be different for different kind of locusts.

2.3 Processes and scheduling

Table 1 Processes and explanation

Process	Explanation
Consuming	Locust eats grass (food) and gets energy, patch loses that energy
Grow back	Grass grows constantly, with the same speed. It can be adjusted.
Moving	Each move of locust would cost its energy. Each individual is moving. None is stationary. But the step is based on type.
Gregarization	If locusts cluster, they would transform from solitary type (coloured by green) to gregarious (coloured by yellow), vice versa.
Death	If the energy of a locust is 0, it would die.
Breed	If locusts have enough energy, they will cost energy to give birth to child.

2.4 Design concepts

- *<u>Emergence, Adaptive behaviour</u>*:
  Based on the biology of locust, if the locusts stay with others closely, they will become gregarious type (colored by yellow). Otherwise, they are solitary type (colored by green). And the classification is not fixed. Therefore, the model should always keep tracking about how many locusts are around an individual in the "neighbor" area, which is the 8 patches around the center one (that is, how many locusts in the 9 in patches).
- *<u>Objectives</u>*:
  There are 2 aims of locusts. One is to feed themselves. The other is to breed if they have enough energy.
- *<u>Learning, Prediction</u>*:
  Locusts have no knowledge about where the grass is more fertile. The direction of moving is set to be independent. So, no learning or prediction.
- *<u>Sensing, Interaction</u>*:
  The bugs don't monitor the environment. Their activities are just to move to find food and give birth to offspring.
- *<u>Stochasticity, Collectives</u>*:
  Locusts flood randomly toward nearby grass. So, the heading orientation is randomly picked within 360 degrees. For patches, their original energy is randomly allocated based on the selected maximum energy.
- *<u>Observation</u>*:
  First one should be the number of all locusts and those in solitary type and gregarious type at different time tick. Then it should record their energy distribution and average energy level. The total energy of grass (food) through whole process should be last indicator.

2.5 Initialization

Table 2 Value range of parameters in the model

AGENT	NAME	MEANING	RANGE
patches	n-patches	The density of patches that contain energy	[0,100]
	maximum_energy_grass	The maximum value of energy that each patch could have. The energy would be allocated to each patch randomly within the range.	[1,5]
	growback_speed	The number of energies that each patch can grow at each tick.	[0,0.5]
turtles	initial_pop	The initial population of the locust group	{200,500,1000}
	initial_energy_locust	The initial energy of each locust. (When the current energy of a locust has 5 times of it, it would breed.)	{3,4}
	num_gregarious	For an individual locust, the sum of the number of locusts in the surrounding 8 patches and in the patch where this locust stays at.	{5,6,7,8,9,10}
	move_energy	The energy cost to move each time (2 times of it is the energy cost of having offspring.)	{1,2}
	step_gregarious	The forward step of gregarious	{2,3}

2.6 Input data

No input data is going to be needed.

2.7 Sub models

- Move: For each move, locusts decrease energy to move to a new patch and eat the food in the patch to increase energy. According to the biological finding, gregarious would move faster. In order to make better view of comparison, the model use different step to illustrate this. For gregarious, their step is chosen in the initialization. For solitary, they always forward 1 step. Within the same group, the step is the same. Both directions are random.
- Breed: If the locusts have more than 5 times the initial energy, they will breed offspring. For gregarious, they would hatch 5 children while the solitary hatch 1 at each time. And the energy cost of breeding is 2 times of the cost of moving.
- Grow: After locust eating, the patch loses all energy and then grow with the constant speed until achieve its maximum value. The max value of each patch is randomly set at the beginning and is fixed until next set up. The grow back speed of resources would be much smaller than the consuming speed of locust.
- Colour (turtle): When the number of locusts in the 9 patches are higher than a number, they should be marked as gregarious (yellow). Otherwise, they are solitary (green).
- Colour (patch): The way to indicate the fertility of grass is by the darkness of lime. The darker the lime is, the higher the energy it contains. This would keep updating during the process.

For calibration, with gregarious ones flying further, the action of eating requires stopping, so, there is no eating while flying. They don't eat all the plants they pass, just the grass they stop at. In other words, flying further means eating further away, not eating more. To simplify the process, both consumptions caused by moving are set as the same.

Furthermore, when the 99% of locusts are dead, the simulation could stop. Based on experiments, this would never cause the breakout of plagues. Setting this could avoid pointless iterations.

In summary, the only 2 difference between gregarious and solitary are forward step and the number of offspring at each time.

The regional restriction means the no wrapping world in the model. The 4 observations are used to measure its efficiency. By changing the parameters in initialization, the model could simulate different scenarios.

3. Methodology

The simulation tool of agent-based model is implemented by software Netlogo (Wilensky, 1999). After finishing the coding part, it uses a tool inside Netlogo called Behaviour Space to get the output.

Table 3 Fertility Level and value of locust group parameters

Fertility Level	Low	High		Locust Variable	Small	Large
n-patches	60	100		initial_pop	500	1000
maximum_energy_grass	3	5		initial_energy_locust	3	4
growback_speed	0.3	0.5		(the energy would allow reproduce)	>= 3 x 5 = 15	>= 4 x 5 =20
				move_energy	1	2
				(cost of breed = 2 x move_energy)	1 x 2 = 2	2 x 2 = 4
				step_gregarious	2	3

The first step is to consider different fertility level of the resources. When a land is more fertile, there is less or even no wasteland, each part would have more energy and the grass would grow back quicker. The details of the groups are included in table 2.

Next, notice there is no exact figure about how many locusts stay together would lead to gregarization. In this model, 'stay together' is defined as the number of locusts in the 9 patches. So, say there is more than half of the patches are occupied by at least one locust would lead to gregarization. Thus, 'num_gregarious' is 5.

For locusts, this model would examine them at 2 levels. Note the minimum energy to reproduce and its cost are linked to initial energy and cost of moving. It is designed to test for large and small locust group, how would they act in different levels of fertility of land under regional restrictions. The detailed figure of parameters is in table 2.

In summary, there are 2 types of fertility and 2 levels of locust groups to investigate. There would be 4 groups of output to compare. For each test, it would be run for 10 times and use the average values to avoid possible bias.

4. Results

For low fertility, the model stops at 100 tick, while for high fertility, it ends at 1000 tick. Notice their trend would be stable at some point. The diagrams are adjusted for better view.

Figure 1 Low fertility: locust count (small VS large)

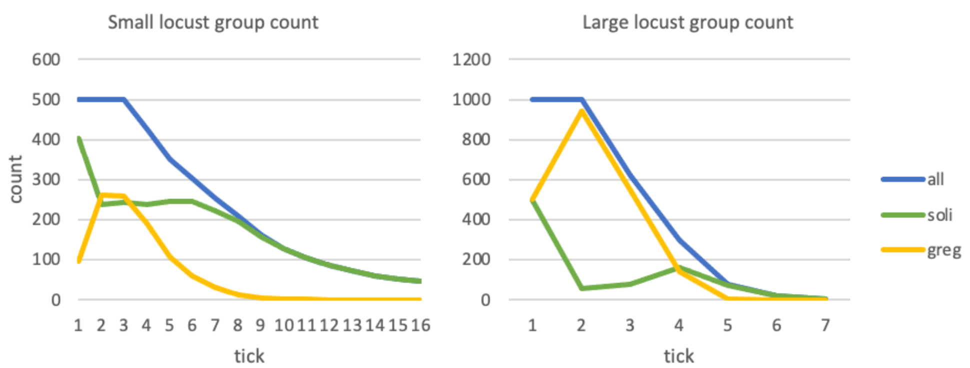
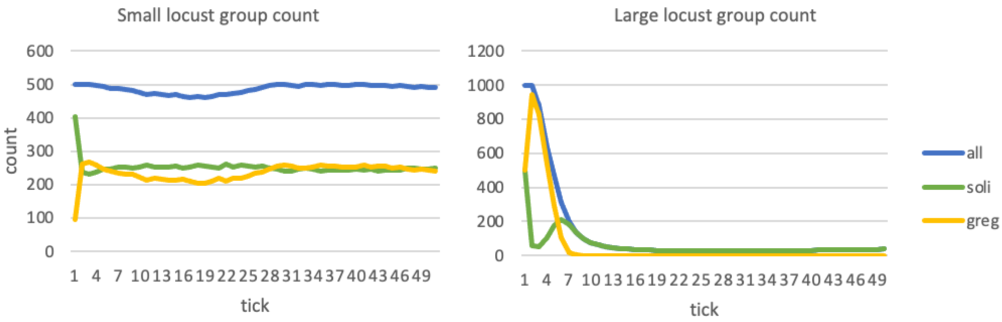


Figure 2 High fertility: locust count (small VS large)



The restriction method works well for less fertile area, the size of 2 locust groups decrease to 0 quickly.

For fertile place, the conclusion of larger group is similar as above. However, the influence on smaller groups is too tiny. The whole size remains at its initial number and solitary and gregarious type floats around 250.

Figure 3 Low fertility: locust average energy (small VS large)

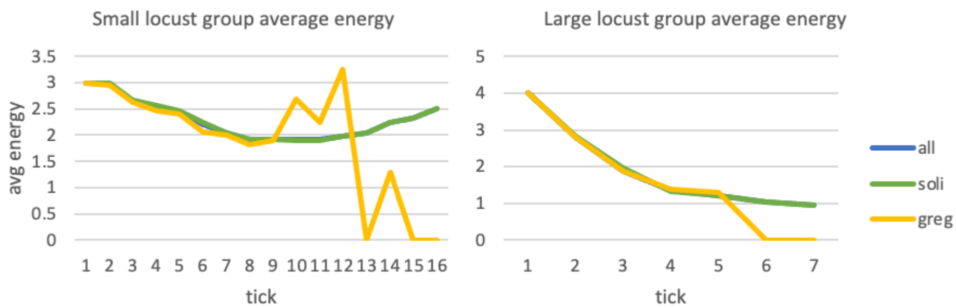
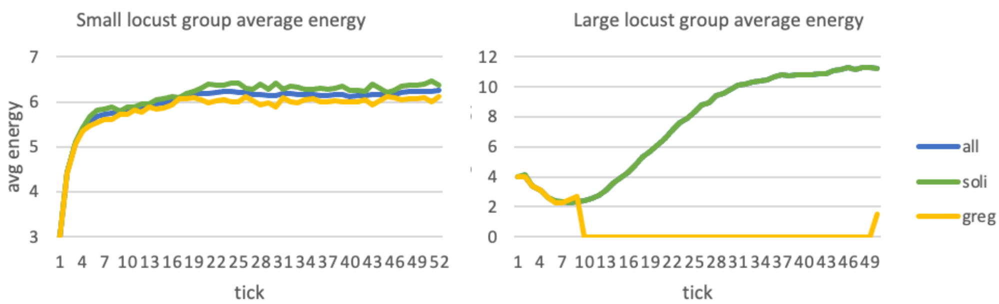


Figure 4 High fertility: locust average energy (small VS large)



To consider the average energy, the lower left diagram is more important than the others. By comparison, it is found when the average energy of gregarious type decreases, all 3 sizes would drop. It suggests limiting the gregarious type should be the key to solve the problem, rather than the solitary one. Without efficient control, they could acquire 2 times of their initial energy.

Figure 5 Low fertility: total grass energy (small VS large)

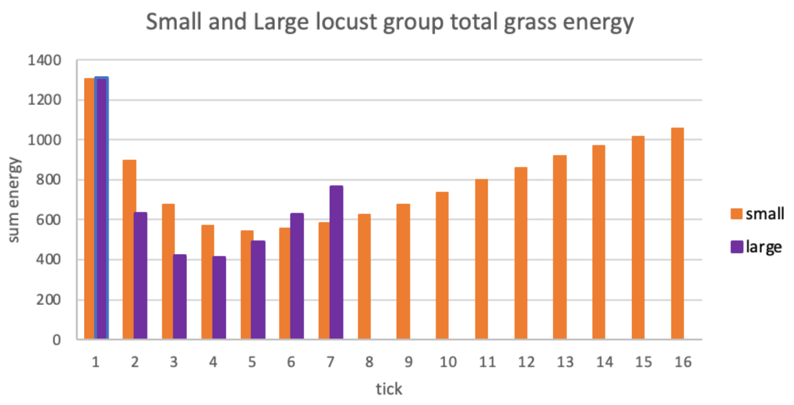
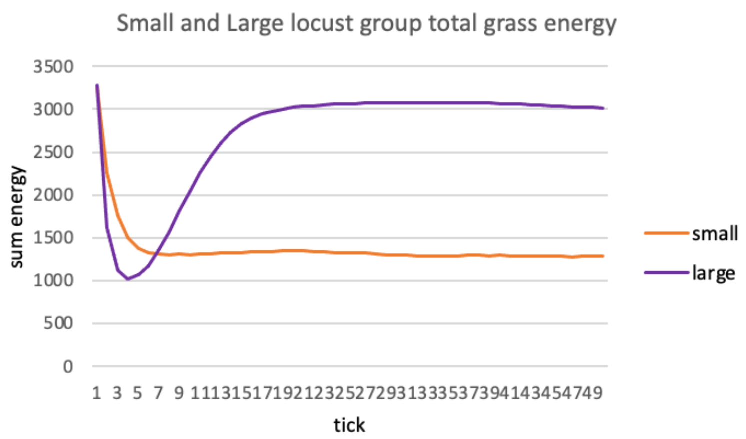


Figure 6 High fertility: total grass energy (small VS large)



Larger group at both cases would have larger damage than smaller ones. They could cause huge damage quickly at both level of fertility, but with the population drops, the grass could gradually recover. The break in figure 5 is due to the disappearance of the locusts. Actually, the land could grow back when time goes by.

In figure 6, there is a serious problem, the smaller locust group would pillage over half of the energy of the grass quickly and constantly. The method is less useful.

To summarise, when the locust group appears, it is effective to suppress their population size by limiting their activity areas. However, if the land is highly fertile and their group is relatively small, the result of this way is unsatisfied.

5. Conclusion

This model constructs an ABM model to simulate the feeding, breeding and moving activities of desert locust using Netlogo. Then through the tool, behaviour space, it compares the count, average energy of the small and large locust group and the total energy of land, which is less or highly fertile, at different tick. From that, it is found the regional restrictions is sufficient and applicable in most cases, unless the smaller locust group in highly fertile area.

6. Bibliography

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7. Appendix

The full documents used to create this coursework are hosted in my GitHub.
https://github.com/amberyli/ABM-cw3

As the instrument doesn't require the output .csv file of behavior space, they are not included in the submission.