Hyena Packing and Preference in Multi-Predator, Multi-Prey Ecosystems
EECS 372: Multi-Agent Modeling
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Introduction:

The African Savannah is a complex ecosystem with numerous different animals, each with their own unique characteristics and behaviours. As with most ecosystems there is a hierarchy of predators and prey. The predator population and the prey populations are closely connected and balance between the two populations is crucial for the long term sustainability of the ecosystem. Creating this model was inspired by the African Savanna, but the model does not specifically pertain to it. The model could be representing any predator prey ecosystem. This model was inspired by wanting to gain a better understanding of the delicate nature of an ecosystem and explore how subtle micro-behavioural changes to food preference and packing tendencies affect the population outcomes. This model shares many similarities with other predator-prey models. The Savanna ecosystem model's distinguishing factor is hyena packing and food preference.

A predator-prey ecosystem is a good fit for agent based modeling, because animals are well represented by agents in Netlogo. Animals in the wild act mainly on instinct and each type of animal tends to follow the trends of its species. Animal species can each be modeled for their own unique characteristics. Each animal has their own set of parameters which will be explained in greater detail. The model shows the impact of subtle changes in the characteristics of an animal on their respective population. One of the characteristics this model explores is food preference. Animals have tendencies to eat certain food. However, in the case of lions and hyenas, they are capable of eating more than their main preference. The model incorporates this concept by having an energy threshold that changes what an animal is willing to eat. The other main area this model explores is how animal packing can alter the success of a population. This model looks into what happens when hyenas are prone to form groups and how it changes population growth and sustainability.

Introduction to the Model Agents:

1. "Lions" 
    a. Apex predator, capable of eating all other animals in the model
2. "Hyenas" 
    a. Predator capable of eating Impalas individually, but can also eat lions and impalas when in large enough packs.
3. "Impalas" 
    a. They are the preferred prey to lions and only eat grass in the model.
4. "Royal Antelopes" 
    a. They are the preferred prey to hyenas in this model, because they are much smaller and easier to kill than impalas. They will be referenced as simply antelopes and also only eat grass.

Model Rules for Agents

General Rules

1. **Movement:** The ecosystem model uses random movement for all animals, with the exception of hyenas when packing is introduced. This is done for simplicity, because complex movement is not important to this model's functionality.
2. **Eating:** Predators will eat when they collide with an animal they are able to eat. The grazing animals, impalas and antelopes, will eat if there is enough grass on their current patch.
3. **Reproduction:** Each animal has an energy threshold where they reproduce if they are above the threshold.
4. **Grass:** Each tick grass will grow by the grass-regrowth-rate parameter in the model. Grass has a maximum length of 15.

Animal Specific Rules

1. **Lions:**
    a. **Eating:** Lions will prioritize eating an impala, but will also eat a hyena if there are no impalas present. A lion will also eat an Antelope, if its energy level is below the "preference-threshold."
2. **Hyenas:**
    a. **Eating:** Hyenas will eat an antelope if they collide with one. Hyenas are also capable of eating impalas if they have a pack size greater than 5 and will rate a lion if their pack size is greater than 20.
    b. **Movement:** Hyenas have a parameter called "random-hyena-movement-probability." As the name implies this is the chance a

hyena has of moving randomly on a tick. If a hyena does not move randomly it will pick a specific hyena inside the "pack-radius" and move towards the selected hyena. This creates packs of hyenas and the strength of the packing effect can be modified with "pack-radius" and "random-hyena-movement-probability."

3. **Impalas/Antelopes:**
   a. **Eating:** Each eats a specified amount of grass when they eat.
   b. **Reproduction:** Each has their own reproduction threshold, in order to simulate the differences between the species.
   c. **Reasoning:** The reason for having two animals as prey is to implement food preference. Hyenas prefer to eat antelopes and lions prefer to eat impalas. Having two separate species facilitates easy monitoring of the two populations.

Hyena Packing Analysis

The two parameters controlling hyena packing are "pack-radius" and "random-hyena-movement-probability." These both have empirical and visual differences in population behaviour. Below we will look into the results of modifying these parameters.

Random Movement Image Examples:

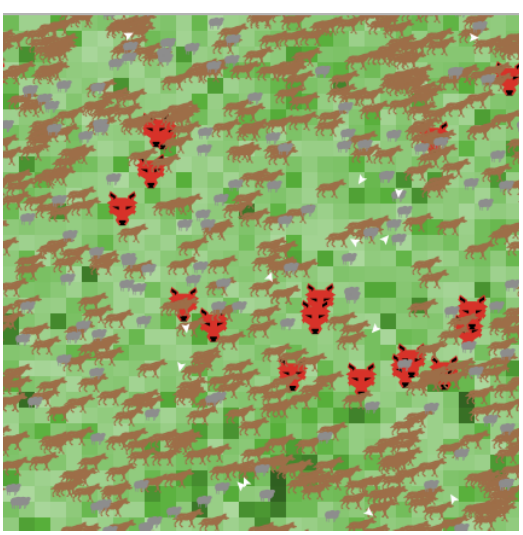

Figure 1.0: No hyena packing

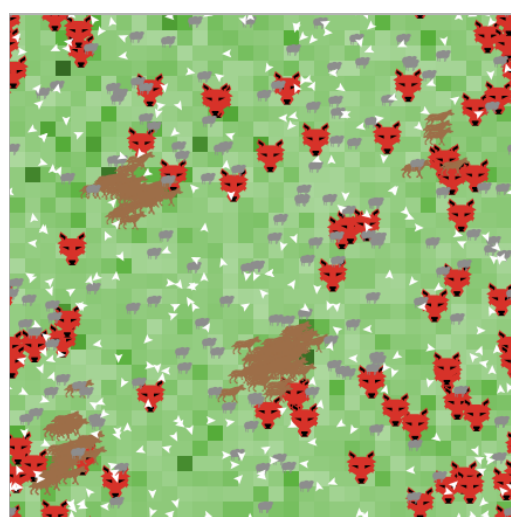

Figure 1.1: Setting random-hyena-movement-probability to zero.

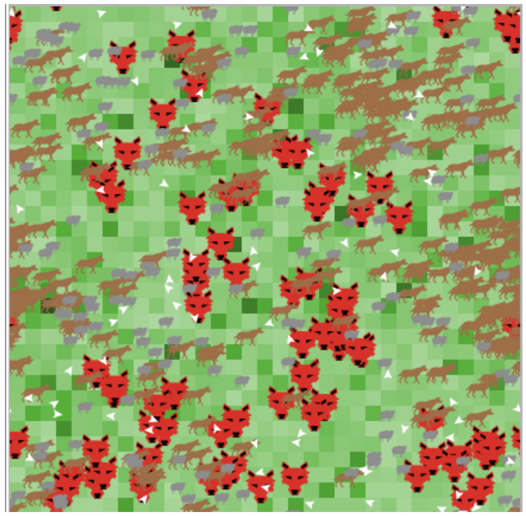

Figure 1.3: When hyenas have a 50% chance of random movement.

Random Movement Packing Effects Analysis:

Strong hyena packing tends to create a longer lasting hyena population. Figures 1.0 and 1.1 show the sharp contrast between when hyenas have the strongest possible packing setting and do not have any tendency to move towards each other. If the hyenas are set to always move towards another hyena, then packs will form and stay tightly located, and never move until most of the pack dies.

The emergent behaviour of stationary hyena packs allows for much greater longevity for the overall hyena population for two reasons. The first reason is the packing effect prevents explosive population growth throughout the entire model. In figure 1.0 you can observe how the hyenas population spreads throughout the map. This has the negative effect of killing most of the food for hyenas, causing many to starve at once when resources are depleted. As seen in figure 1.1 you can see the tightly clustered hyenas allow antelopes to roam and reproduce in most areas of the window, leading to a more reliable food source for hyenas. Somewhat counter intuitively this effect is negative for many individual hyenas, because within the packs many hyenas starve.

However, the hyenas that starve within the packs are overall helping the population by not depleting resources and facilitating the protection of the pack as a whole. This leads us to the second reason hyena packing leads to greater longevity in the hyena population.

When a hyena pack forms with a hyena count great enough to kill a lion, it becomes a pseudo apex predator. In figure 1.1 each of the hyena packs is large enough to kill a lion, therefore lions are effectively no longer on the top of the food chain. This protects hyenas from being eaten and also keeps the lion population from having explosive growth. Without hyena packing, an explosion in the hyena population would lead to a surge in the lion population. This effect would lead to the prey animal populations being decimated and lead the lions with only hyenas to eat. Therefore, hyenas would have very few food sources and have a high chance of being eaten, causing the hyena population to quickly plummet to zero.

Pack-Radius Image Examples:

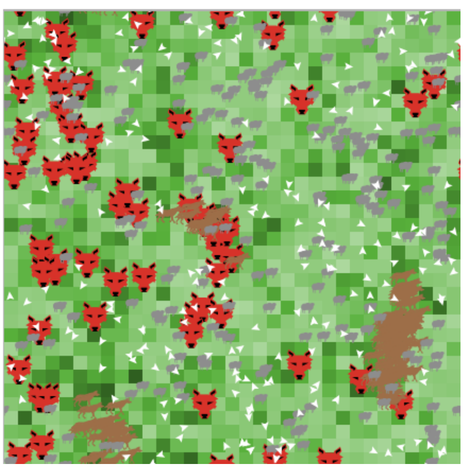

Figure 2.0: Pack-radius set to 3

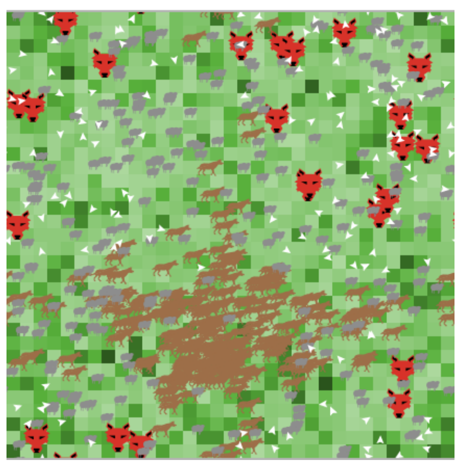

Figure 2.1: Pack-radius set to 8

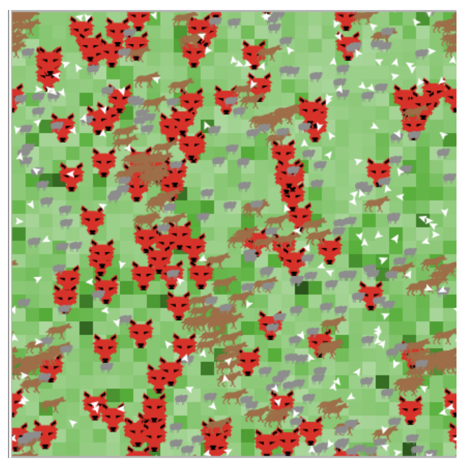

Figure 2.2: Pack-radius set to 20

Pack-Radius Analysis

The pack-radius has a subtle effect on packing behaviour by causing different clumping patterns. A smaller pack radius will often lead to more smaller hyena packs that eventually will find their way into larger packs and this will occur until there are few large packs interspersed in the model. With a larger pack radius you tend to see a majority of the hyena population quickly becoming part of a single pack that begins as very spread out, but slowly shrinks.

These different patterns of pack formation cause empirical change in the population dynamics of the hyenas. In figure 3.1 below you can see an initial surge of the hyena population when the pack radius is set to a high value of 20. The surge then leads to a very quick extinction of the hyena population in around 100 ticks. Figure 2.1 is an example of what the surge looks like. This rapid expansion in population is due to hyenas almost immediately all being in the same pack. Therefore the pack is effectively one massive apex predator and can consume everything, leading to very high levels of reproduction. However, when there is no longer enough food for the entire hyena population to expand, the hyenas starve and the pack shrinks. It is important to note that the hyena pack shrinks from the inside as the interior hyenas do not have access to food. Only the outer hyena will be able to eat, as food sources will be eaten before reaching the interior of the pack . Therefore, with a very large hyena pack it takes a very large amount of food for reproduction rates to outpace death rates. When the interior hyenas die the outer hyenas will move towards each other, shrinking the size of the pack. The high pack-radius leads to there only being one pack which increases the chance of extinction for the hyenas, because the one pack may not receive the necessary resources from wandering impalas and antelopes to survive.

A smaller pack-radius leads to a lower peak in population size, but enables a greater number of smaller packs to exist. Figure 2.0 is an example of what occurs with a small pack-radius. In the image you can see there are three distinct packs. With larger packs a greater percentage of the hyenas in the pack will starve, because there is more inequality between the inner and outer hyena's access to food. Smaller packs are more stable and therefore it is more effective for the species to have multiple smaller packs than one large pack. Figer 3.0 shows how having a smaller radius ends up creating a longer lasting population. The hyena population from figure 3.0 lasted double the number of ticks than with the large radius and this holds true consistently.

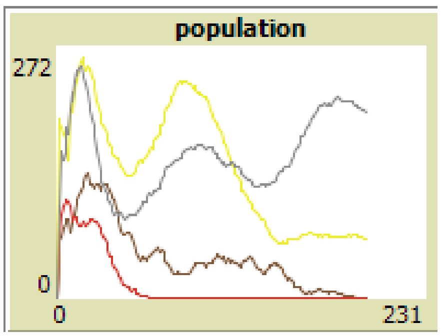

Figure 3.0: Pack-radius set to 5 The brown line is the hyena population.

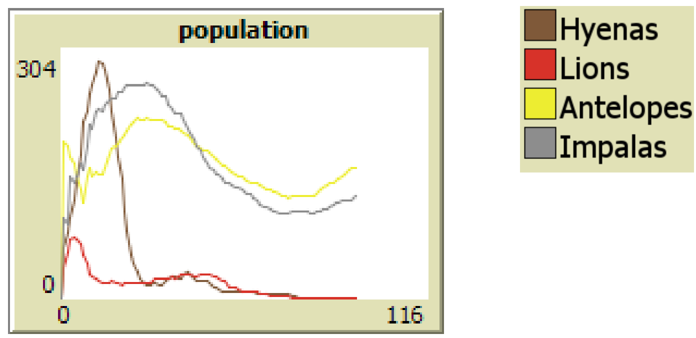

Figure 3.1: Pack-radius set to 20. The brown line is the hyena population.

Relating to the Real Hyena Packing:

These results relate well with real to real hyenas. There are numerous different species of hyenas and each have their own behaviour patterns, but the most commonly reference hyena is the spotted hyena and it will be the focus of this comparison between the model and reality. Spotted hyenas travel in clans. The clans have a strong matriarchal hierarchy. Hyenas will often kill weaker clan members. Hyena cubs who are the offspring of a high ranking clan member will often work together to kill adult hyenas of a lower rank. My model does not simulate this hierarchy in any way but does exhibit the similar result of hyenas dying within the pack and the model shows benefits of packing for the longevity of the hyena population in general. This connects well with what is seen in reality, where clans play a pivotal role in hyena populations.

The Effects of Food Preference

Lions, being the apex predator, are able to eat any animal. The model includes two methods for lions to eat. One method will have lions prefer to eat impalas, but will eat a hyena if there are no impalas present. Furthermore, if a lion has low enough energy it will eat an antelope. The other lion eating method does not utilize the preference threshold, so the lion will eat one of whatever animals it encounters no matter how much energy the lion has.

Preference Effect on Population Images:

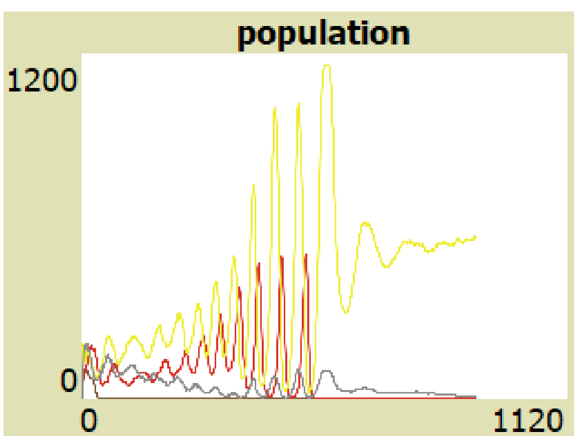

Figure 4.0: Preference-threshold deactivated and no hyena packing

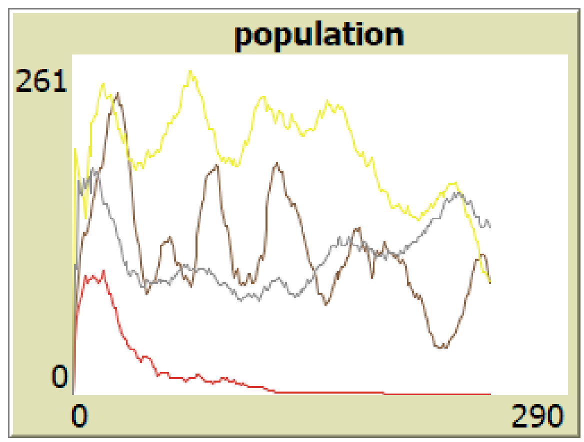

Figure 4.1: Preference-threshold deactivated with hyena packing

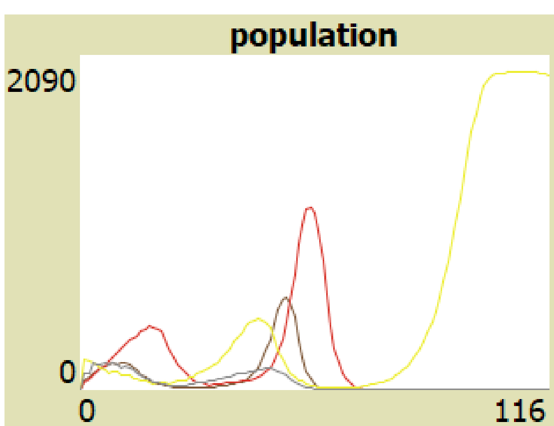

Figure 4.2: Preference-threshold activated and no hyena packing

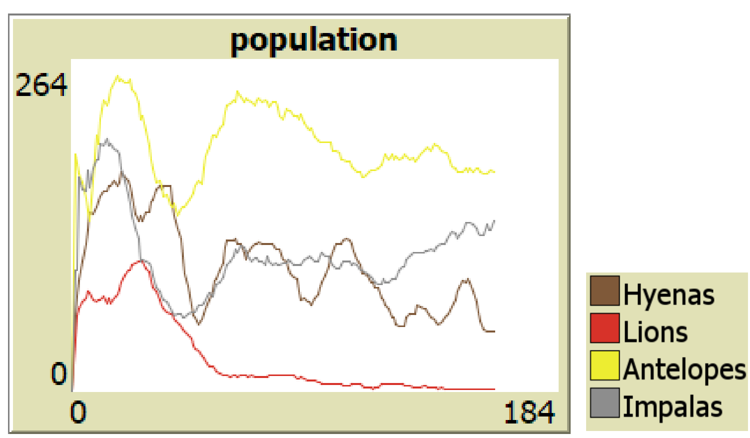

Figure 4.3: Preference-threshold activated with hyena packing.

Analysis of Preference Without Hyena Packing:

Without hyena packing we see a clear difference when lions eat all animals versus when lions only eat antelopes below a certain energy level. Figure 4.0 shows that almost immediately hyenas are wiped out due to having low food sources from lions eating their prey and also being eaten by the lions. This causes the oscillation pattern between lions and the antelopes to occur. The antelopes are able to reproduce more efficiently than the impalas and without hyenas present to eat the antelopes they end up becoming the surviving prey. Once the antelope population surges, the lions surge behind it. This back and forth pattern accelerates itself. Antelopes will always end up being the last surviving species in this scenario with only lions and antelopes because they are capable of eating anywhere, but lions need to find an antelope to eat. This is why antelopes are able to survive when their population dwindles. If there are only a few lions remaining it is unlikely they will be able to find enough food to survive and reproduce, because they will not encounter other antelopes.

In figure 4.2 we see the population graph with the preference-threshold activated. The key thing to notice in this graph is the initial uptick in antelope population. This is due to the lions not preferring to eat antelopes until they get a low enough energy. Because lions need a certain energy level to reproduce, if they do not have their preferred source of food then their population cannot grow, but can only decrease or remain the same. This leads to the increase in hyena population as their main source of food, antelopes, becomes more readily available from the dwindling lion population. However, the quick surge in hyena population allows the lion population to recover and leads to the hyenas extinction.

Analysis of Preference With Hyena Packing:

In figures 4.1 and 4.3 we see the population graphs when hyena packing is activated. The results with hyena packing explicate the notion of a new pseudo apex predator, the hyena pack itself. When these packs form and reach a large enough size, they no longer are able to be eaten by lions. This makes it very challenging for the lion population to expand in the model due to having hyena packs hindering their population growth. This again connects well to what is seen in the wild. Hyena packs defend themselves well against lions. Isolated lions can and have been devoured by packs of hyenas.

Conclusion

This paper has analyzed hyena packing and food preference in a multi-predator, multi-prey ecosystem. It has shown how packing together is critical for the longevity of hyena populations. We have also seen how the food preferences of an apex predator has a critical impact on the populations of an ecosystem. In the future, more work can be done with the savanna ecosystem model to explore these findings further. Food preferences can be expanded to the hyenas and further elaborated on in lions in the model for testing separate combinations of preferences to see if there is one optimal for finding an equilibrium point in the model. Hyena packing can be expanded by analyzing the size and number of packs in a given ecosystem to find the optimal size of a given pack. By looking further into the parameters behind optimal pack formation, we could gain a more nuanced understanding of packing in the wild. Overall, this model reinforces that ecosystems are fragile. Small changes compound over time and lead to drastically different outcomes, meaning careful consideration and research should be done to ensure critical ecosystems remain healthy.

References

1) Nicholls, Henry. "Earth - The Truth about Spotted Hyenas." BBC. BBC, October 28, 2014. **http://www.bbc.com/earth/story/20141028-the-truth-about-spotted-hyenas.**
2) Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.