Background Information on Simulation Created for Lesson 4: Waves of Change: Predator and Prey Dynamics

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in collaboration with the Creative Learning Exchange

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Lesson 4: Waves of Change: Predator and Prey Dynamics

Note: This lesson builds on Lesson 3 – Rabbits, Rabbits, and More Rabbits: Logistic Growth in Animal Populations within the Oscillation curriculum created for the Complex Systems Project. Lessons 3 - 5 work together to show how a population in isolation can experience growth or decline, but not oscillation (Lesson 3). Further, it is only when considering a population in relation to a wider system boundary, either interacting with another population (Lesson 4) and/or a food supply (Lesson 5), that we have the structure necessary to produce cyclic behavior.

Contents

Introduction

How do predator-prey cycles occur in nature? Biologists do not always agree on what causes such cycles (and some dispute that they even exist). Where cyclic behavior patterns have been observed, one hypothesis is that the environment creates a tight dependency between predator and prey. For example, Canada lynx are considered "specialist" predators of snowshoe hare; hares are their main food source. When the hare population is low, some lynx can survive by finding other prey, but overall the population as a whole suffers. The boreal forest, with its long, harsh winters, simply does not contain enough prey opportunities for lynx to thrive when hare populations are depleted. The drop in the lynx population then allows the hare population to rebound, which eventually fuels another growth in the lynx population.

Another example is that of wolves and moose on Isle Royale. Isle Royale features extreme dependency between these two populations because it is an island environment. Even though both species are believed to have reached the island by swimming from mainland Canada, neither has been observed leaving the island in the same way when food is scarce. Instead, wolves and moose populations seem to fluctuate in an interdependent relationship.

This simulation features one predator population and one prey population. The structure of the model represents a hypothesis about how two such populations can interact in a way that produces oscillation over time. Students can investigate what may cause the cycles to speed up, what may slow them down, and under what conditions the two populations could live together without cycling at all.

Overview of Model Behavior

Run the Model with the Default Settings

The model's settings are inspired by the wolves and moose of Isle Royale. Click the "Run" button to reveal the default behavior pattern produced by these settings. To see the graph shown in Figure 1, below, click the link "If you can't see the whole graph, click here."

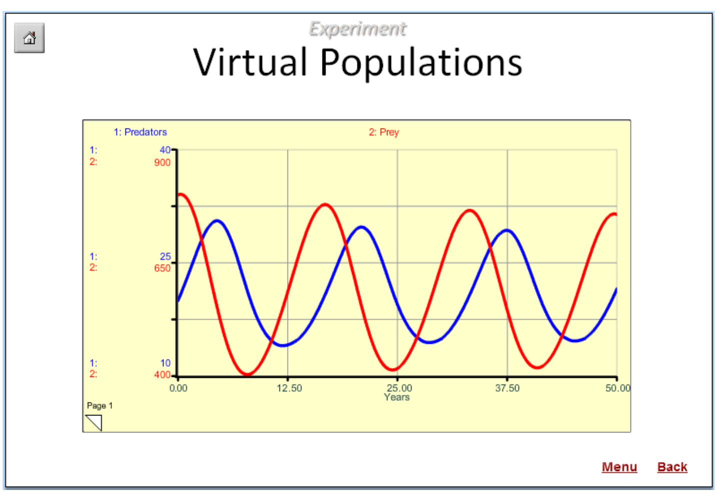

Figure 1: The default behavior of the model.

On your screen, click the white triangle in the lower left corner of the graph to page through comparative graphs showing prey and predators individually. When you simulate the model, the graphs in Figures 1, 2, and 3 will show each run of the simulation in a new color. Click the "Reset" button to clear the graphs and reset the parameter values to their default settings.

What Might Cause the Populations to Cycle More Quickly?

Animals are naturally added to a population via births; the more animals there are, the more babies that can be produced. In the model, a constant "births factor" is multiplied by the population to create births. Setting the births factors higher, i.e. increasing the number of babies produced per population member, will also create more births.

To recreate the runs shown in the following graphs (Figures 2 and 3), first change the prey births factor to 0.5, click "Run" and then change it back to 0.4. Change the predator births factor to 0.4 and click "Run" again. In the graphs, run 1 is the default behavior mode, run 2 shows the result of changing the prey births factor and run 3 shows the result of changing the predator births factor. Not only do the cycles appear to be coming faster as the years go by, but the size of the populations is affected as well.

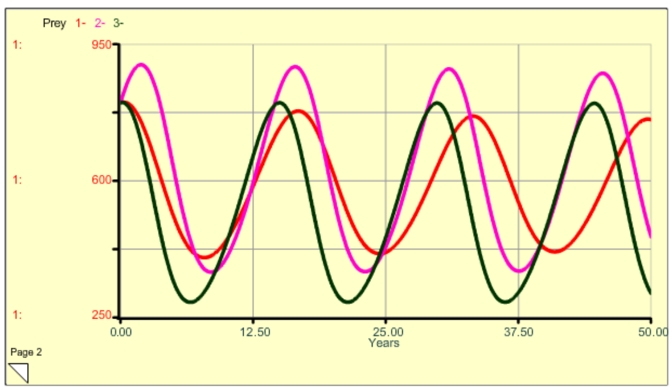

Figure 2: Graph of prey animals with changes to the births factors of both populations.

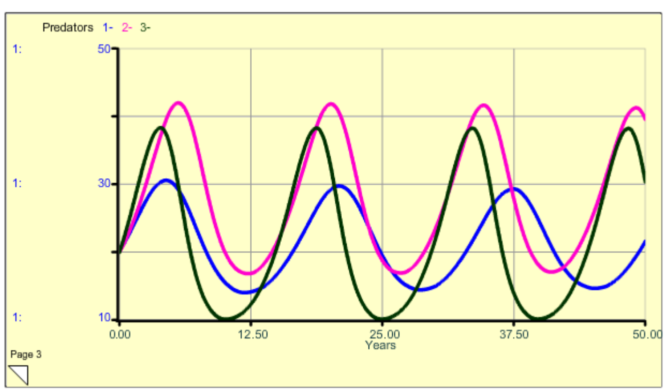

Figure 3: Graph of predator animals with changes to the births factors of both populations.

Notice in the top graph (Figure 2) that setting a higher births factor for the prey animals resulted not only in more prey at the height of each cycle, but also that predators (bottom graph, Figure 3, run 2) were able to take advantage and increase their numbers as well. Because animals are being added to the populations at a faster rate, density pressures develop more quickly than in the default run. Predators are able to find the more-abundant prey animals, increase their own numbers, and drive the prey numbers back down.

Even more interesting is that setting a higher births factors for predators (run 3) *also resulted in more prey* at the height of each cycle, as compared to the default run. This is because prey were driven to *lower* numbers due to the larger predator population, which then caused the predators to crash to lower depths than in the default run. The absence of predators allowed the prey more opportunity to expand before the predators recovered.

What Might Change the Shape of the Cycles?

The hypothesis of the simulation is that prey reproduce freely until their numbers create pressure on the population and lower the average lifespan of the members. This high density of prey also provides the opportunity for predators to find and kill more prey per member of the predator population. Prey numbers are thus reduced through natural deaths and predation, both of which are increased during times of high density. What if the animals had more space in which to interact? Would that provide the prey with a "safe haven" in which to spread out and enjoy life? For some time, it does.

In the graphs below (Figures 4 and 5), run 1 is the default behavior mode, run 2 increases "Area" from 200 to 600 square miles, and run 3 increases it again to 1000 square miles (use the "Reset" button to clear the graphs before simulating these changes). We can see that having more space stretches out the cycles so there are fewer peaks and valleys. In run 3, having five times the space even appears to prevent the populations from cycling for a full 25 years. The model structure that generates oscillation has not changed, however. The predators use time to increase their numbers to the point where they can hunt a significant number of prey animals, but once they do, the cycles reappear. Both populations enjoy much higher numbers overall due to the additional space.

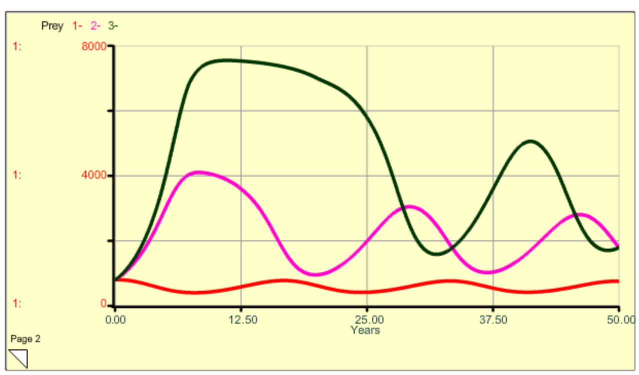

Figure 4: Graph of prey showing the effects of having more space.

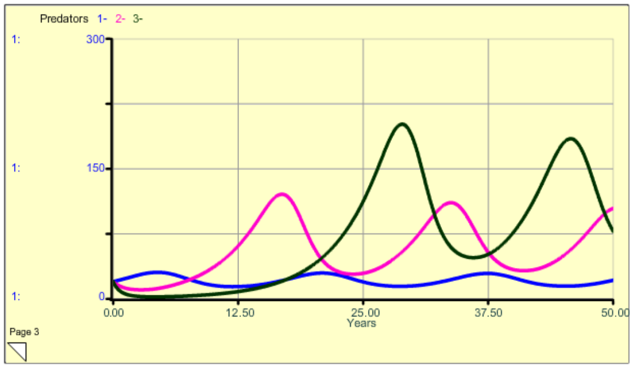

Figure 5: Graph of predators showing the effects of having more space.

What Might Cause Larger Fluctuations in the Populations?

In the spring model of Lesson 1, it was demonstrated that giving the spring a "larger push" results in cycles with greater amplitude. We can try that with the predator-prey model by starting with more animals in one of the populations. The graphs in Figure 6 show what happens when the simulation starts with 50 predators instead of 20.

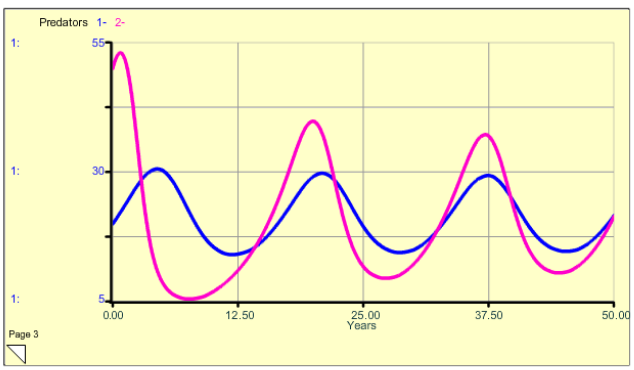

Figure 6: Graph of predators when the initial value of predators is increased to 50.

Not surprisingly, the higher number of predators is initially too high to be supported by the number of prey, so the predator population crashes quickly and reaches a very low number before starting to rebound. What might be surprising is the behavior of the prey animals shown in Figure 7, below: we end up with more prey than in the default run!

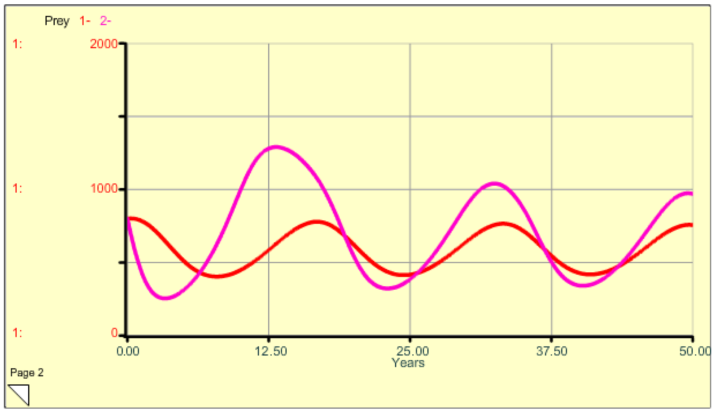

Figure 7: Graph of prey when the initial value of predators is increased to 50.

The amplitude of the prey cycles is affected by the change in the initial value of the predator population. Initially, the higher number of predators quickly drives the number of prey down, but once the predators experience their spectacular crash, the prey population is able to rebound to a higher level. It's as if the system has been "pushed" just like the spring – the larger swings in population numbers persist throughout the simulation. The cycles end up peaking at about the same times as the default run, but now with more animals during boom times and less during bust times.

Will the Populations Always Cycle?

The short answer is no, just like in real life. For cycles to occur, the two populations must be in a "sweet spot" where they are able to affect each other. If prey density is low (which could be the result of many factors) the predators may not have a chance to build their numbers. They may die out, or they may simply live off the prey they do find, without becoming a large enough force to overhunt the prey population. One such scenario is shown in the graphs below (Figure 8). "Predator births rate" has been changed to 0.1 from the default value of 0.3 (let's say disease has hit the predator population and fewer young survive).

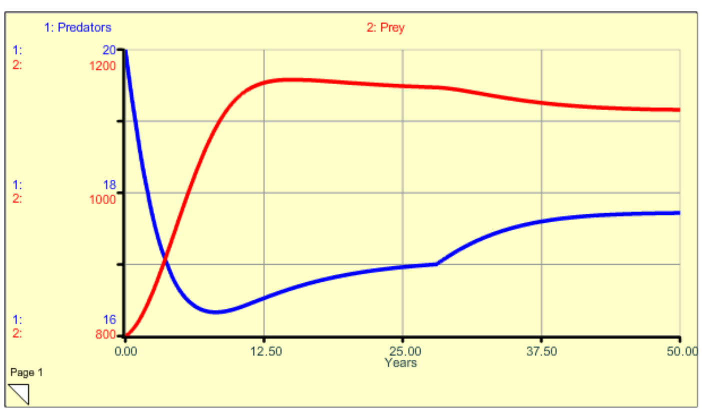

Figure 8: Graph of predators and prey showing that the populations do not always cycle.

It's plausible that given enough time, the predator population will grow large enough to drive prey numbers down, and the populations could start cycling together. For the 50 years of the simulation time, however, they live together without cycling.

Model Structure and Assumptions

The model structure is presented on the screen shown below (Figure 9). This screen is accessed via the screen titled “Explore the Model: Model as Hypothesis.” Click “Tour the Model Structure” and use the spacebar to toggle through the presentation of the structure in a step-by-step fashion. When you are finished, you will have the complete model structure, as shown below.

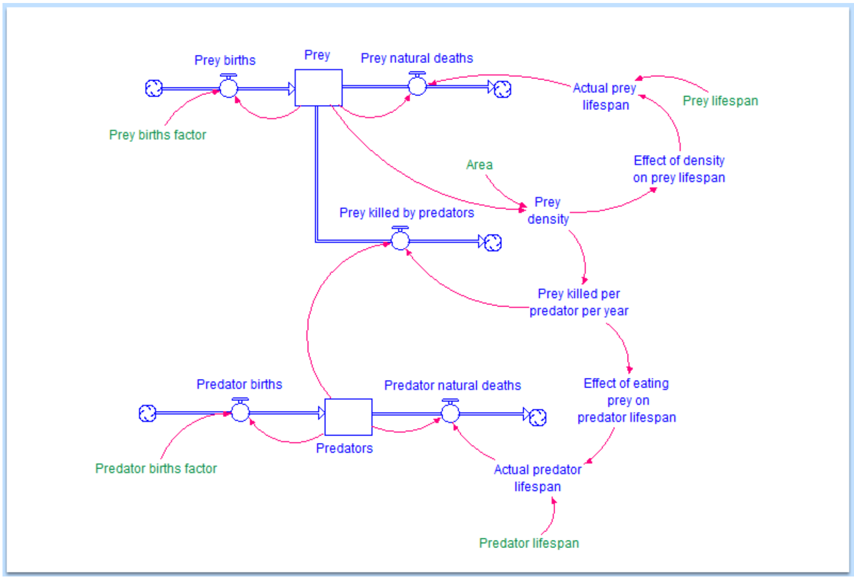

Figure 9: The structure of the model; green variables are changed in the Control Panel.

Notice that there are no outside influences that “drive” the predator-prey cycles. The green variables are parameters that are set on the Control Panel of the simulation. The remaining variables are defined internally, based on relationships indicated by the red arrows. The balancing feedback loop that is responsible for generating the cycles links the two populations via “Prey density.” Click on the link titled “Tour the Loops” (located under “Tour the Model Structure”) to read more about the feedback loops embedded in the model structure.

Limitations of the Model

Lessons 3 – 5 are a mini-series of lessons on population dynamics. The model introduced in Lesson 3 can produce a logistic growth pattern (one population in isolation that bumps against the natural limits of its environment), but could not be used to represent cyclic population dynamics. It simply lacks the structure (two populations in a balancing feedback loop) necessary to produce oscillation. The model presented in this lesson *does* have the necessary structure to explain a simple hypothesis of predator-prey cycles, but still has limitations.

Students may notice factors missing from the model that, in real life, would be likely to have an impact on any two populations in a predator-prey relationship. For example, prey need a food supply of their own in order to survive (an idea that is further explored in Lesson 5). Predators will generally have more than one type of prey available to hunt, even in situations where cycles occur with a particular type of prey. Conversely, prey animals often experience pressure from several types of predators, not only one. Many factors affect birth and death rates of both predators and prey, including disease, drought, introduction of invasive species, wildlife management policies, hunting by humans, and so on. The model presented in this lesson is an oversimplification of any *real* predator-prey system, but is an effective representation of a *general hypothesis* of predator-prey cycles.

Talking Points – Linking the Simulation to Real Life

Some useful questions for discussion with students include the following:

- Is there actually a "balance of nature" that would occur naturally if humans did not interfere? If so, what would that balance look like? In models such as the one in this lesson, "dynamic equilibrium" (also called steady-state) occurs when all the levels in the model are unchanging (the inflows match the outflows). Could two such populations in nature be in dynamic equilibrium at the same time? What factors could prevent that from happening, or, what would push them out of steady-state if they ever would be in it?
- When humans attempt to manage a population of wild animals, what are some factors over which they can hope to exercise control? Can people control the birth rates of a wild population of wolves or moose? The average lifespan of the animals? The area they have available to live? Based on running the simulation model, are any of these parameters particularly useful as leverage points to control the two populations?
- Why would population cycles be considered problematic? What kind of population dynamic would hunters like to see (growth, steady-state, decline, cycles) for moose or deer? What about non-hunting outdoor enthusiasts? Farmers? The insurance industry?
- If you had to make an assumption about the general health of the individual animals in either population, would you think that the animals are most healthy when the population is growing rapidly, is close to its natural carrying capacity, or experiencing a population crash? What would be your goal in managing a population of prey animals (an ideal behavior-over-time trajectory)?

The Cause of the Problem is Within the System

The overall goal of the Oscillation curriculum is to teach a principle of complex systems: The cause of the problem is within the system. Socioeconomic systems that oscillate are often not recognized as oscillating due to their intrinsic structure. Explanations often point to outside influences that are themselves oscillating, or to a particular combination of outside factors believed to "drive" the oscillation. Yet we know that a physical system such as a spring (presented in Lesson 1) oscillates because it is made to do so. It does not oscillate because a hand or other force continually pushes it in an up-and-down or back-and-forth motion. A spring gets set into motion with a push or a pull, and it oscillates due to its own structure.

Predator-prey systems are well-known real-life examples of biological systems that can oscillate. The cycles can be explained via the internal structure of the relationship between the two species. Understanding such systems for what they are is the first step in understanding how to influence them, and, if need be, to change the behavior pattern. Because the cause of a system's behavior is due to its structure, changing the behavior pattern is accomplished through changing the structure (rather than eliminating an outside influence). For example, this lesson illustrated that a predator population and a prey population can be intertwined but not oscillating. Lesson 5 shows how human influence can bring forth this dynamic as a direct result of managing the system.