POPULATION GROWTH MODELING

INTRODUCTION

All organisms tend to show the capability of unlimited exponential growth. Consequently, mathematical models have been developed to try to simulate this phenomenon. It is hoped that by creating models that include enough realism one might be able to explain and even predict the changes that occur in real populations. Realistically, no population grows in an exponential manner forever. Populations are limited by food, space, light, waste build-up, and by populations of other organisms. Once a particular resource becomes limiting, population growth will slow and eventually stop. Populations that are limited by the environment typically exhibit logistic growth.

This week, you will be working in the computer lab with a population growth program (*ECOLOGY*) that will allow you to manipulate constants in the growth models to generate different numerical response curves.

OBJECTIVES

In today's lab you will:

- explore the response of a virtual population to several values of r and K.
- be able to describe the effects of time lags and discrete growth on population dynamics.
- be able to describe the effects of fluctuating carrying capacity on population dynamics.

KEYWORDS

You should be able to define the following terms:

exponential growth	density-independent	boom and bust cycle
logistic growth	density -dependent	damped oscillations
intrinsic growth rate	discrete growth	chaos
carrying capacity	continuous growth	time lag

BACKGROUND

Mathematical models are created to describe and understand natural phenomena. Based on our knowledge of the reproductive processes of organisms we understand that with unlimited resources a population of organisms will grow exponentially. This happens when there is nothing hindering an individual's ability to access whatever resources it needs. *Exponential growth* is characterized by a jshaped numerical response curve (number of organisms vs. time). The population growth rate at any time (dN/dt) is directly proportional to the number of organisms (N). The proportionality constant is called the *intrinsic growth rate* (r).

It is important to realize that all populations have the potential to grow exponentially, but few ever do in reality. This is because there are restrictions that limit an organism's ability to survive. Some of these restrictions are brought about by an unlimited supply of resources (food, light, space) and/or competition for with other populations for these limited resources. As more organisms compete for the same resources, fewer are able to reproduce and population growth slows. Since the number of organisms in the population directly influences population growth, we say that growth is *density-dependent*. In this situation, the population exhibits *logistic growth*, and the numerical response curve has an s-shape. The maximum number of individuals that can exist in a habitat with limiting resources is referred to as the *carrying capacity* (K).

Sometimes population growth is restricted not by resource limitation but by abiotic factors from outside of the habitat. Storms, fires, earthquakes, and meteor impacts can all limit the growth of a population. These factors typically affect a specific proportion of the population (often 100%!) regardless of the population density. Therefore, they are referred to as *density-independent* factors.

DIRECTIONS

In the lab your instructor will guide you on how to access the *ECOLOGY* program and how to "maneuver" through it. It is in your best interest to spend time manipulating the model simulations until you feel you understand not only what they represent but also how the different variables influence various outcomes. Furthermore, it is always a good idea to run the program using the default values given in the menu before manipulating any of the variables.

USING THE PROGRAM

ECOLOGY allows you to create graphs of population size over time for up to 100 time intervals. Select *Single Species Logistic Growth* from the main menu. There are 6 possible control options: run, alter, erase, value-table, harvest-mode, and exit.

- **Run** Type "r" to run the simulation. During the run, a different menu will appear on the top of the screen. Type "p" to pause the simulation at any time. This is useful for recording model values at particular times during the run. Press any key to resume graphing. Typing "p" twice will cause the simulation to proceed to the next time interval and stop. Type "s" to stop the simulation and return to the main menu.
- Alter Type "a" to change any of the model parameters. Use the arrow keys to choose the parameters you want to change. You will be prompted for a new value at the bottom of the screen. Type "f' to finish and return to the main menu.
- **Erase** Type "e" to erase old plots. It is often useful to overlay plots so that you can compare the effects of changing model parameters.
- Value-table Type "v" to show/hide model value in lower corner of the screen.
- **Harvest-mode** Three harvest modes are available. Type "n" to have a constant number of individuals harvested and enter a number in the model parameter table. Type "p" to harvest a constant proportion of the current population and enter a proportion (0.0-1.0) in the model parameter table. Type "s" to harvest a constant proportion and enter a proportion of the carrying capacity and enter a proportion in the model parameters table.
- **Exit** Type "x" to quit the simulation.

POPULATION GROWTH EXERCISES

Here are some exercises that demonstrate the behavior of populations. These exercises will help you understand how model parameters affect population growth. Keep track of the results for each run so that you can answer questions at the end of this handout.

Exponential Growth

1. Erika is a microbiologist employed by a beer manufacturer in St. Louis, MO. Her job is to select an appropriate strain of yeast (*Saccharomyces cerevisiae*) to

ferment malt. She ordered three strains of yeast from a scientific supply company, each with a different intrinsic growth rate (r = 0.0, 0.05, 0.1). Use ECOLOGY to simulate the growth trajectories of each yeast strain on one graph. Set carrying capacity to 500 and the y-axis scale to 10. Use an initial population size of 0.1 yeast per mL.

Describe the shape of each trajectory.

Which strain of yeast should Erika use if she wants to ferment the most malt in the shortest amount of time?

Erika may want to call the company that sold her the yeast. Why?

Logistic Growth

2. Justin is a fisheries biologist in charge of managing the walleye population in Bear Lake, MI. Justin must decide how many walleye fry to stock in Bear Lake. He knows that walleye have an intrinsic growth rate of 0.2 and Bear Lake can support 125 walleye. Use ECOLOGY to simulate growth trajectories of walleye with an initial population size (N₀) of 2, 50, 125, and 150. Set the y-axis scale to 200.

Describe the shape of each trajectory.

Why is carrying capacity called a "stable" equilibrium?

If cost were a concern, how many fry should Justin stock?

3. Justin was impressed with the outcome of stocking only 2 walleye in Bear Lake. Yet he wondered whether stocking would produce quicker results (i.e., shorter time to carrying capacity) in a smaller lake or with faster growing fish. Help Justin answer his question. Compare the time to reach carrying capacity for walleye (r = 0.2, $N_0 = 2$) in three different lakes (K = 125, 100, 50). Then, compare the time to reach carrying capacity in Bear Lake (K = 125, $N_0 = 2$) for three different fish – walleye (r = 0.2), perch (r = 0.3), and bluegill (r = 0.4). Which has a greater effect on the time it takes an initially small population to reach carrying capacity, the size of K or the size of r?

- 4. Justin knows that fishermen will capture many of the walleye in Bear Lake. What will happen to the walleye population if fishermen catch 2, 4, 8, or 16 per day? Set K = 150, r = 0.2, and N₀ = 150. Use the harvest mode to manipulate fishermen catch. What is the maximum sustained yield for the walleye population?
- 5. Cindy studies *Daphnia*, a planktonic microcrustacean. *Daphnia* reproduces once every week. The number of young born, however, is determined by the amount of food available during their early development (1-2 weeks prior to birth). This means that there is a time lag in population growth. Help Cindy discover how time lag will affect growth of the *Daphnia* population. For *Daphnia*, r = 0.3. Begin with 1 animal (*Daphnia* is parthenogenic) and K = 200. Try time lags (tau) of 0, 1, and 2 weeks. The effects of time lags are accentuated by intrinsic growth rate. Increase r to 1.0 and create new trajectories using the three time lags above. Try r = 2.0 or 3.0.

What happens to the shape of the trajectories as you increase time lag? What happens to the shape of the trajectories as you increase r Which combination of time lag and r gives a high risk of extinction?

Cindy found it difficult to feed her *Daphnia* on a regular basis such that the carrying capacity of her aquaria fluctuated from day to day. You can model the *Daphnia* population in Cindy's aquaria by setting K = 120 and range = 20 (110-130). Use r = 0.3 and N₀ = 20. Fluctuations in K can interact with time lags. Run the following sets of parameter:

K = 120, range = 0, tau = 2

K = 120, range = 20, tau = 2

What type of population trajectories do you see for each of the three sets of parameters?

LOTKA-VOLTERRA COMPETITION

Return to the main menu and select *Interspecific Competition*. Choose appropriate K and r values for two competing species using the arrow keys and keyboard. Choose competition coefficients (α_1 and α_2) for the two species. Press F6 to run. Change one variable at a time and observe several outcomes. Using the inequalities below set the variables accordingly and generate graphs that demonstrate the 4 possible outcomes of the two species interactions.

 $α_1 > K1/K2, α_2 > K2/K1$ $α_1 < K1/K2, α_2 < K2/K1$ $α_1 < K1/K2, α_2 > K2/K1$ $α_1 > K1/K2, α_2 > K2/K1$

Next, given the data below, perform the three simulations:

Blue-winged warblers	Golden-winged warblers
K = 52 birds/km ²	K = 48 birds/km ²
r = 0.35	r = 0.42

Simulation one:

 α_1 = .9, α_2 = 1.3, start with 6 Blue-winged warblers and 46 Golden-winged warblers. Simulation two:

 α_1 = .8, α_2 = .7, same initial parameters.

Simulation three:

 α_1 = 1.8, α_2 = 1.2, same initial parameters.

DISCUSSION QUESTIONS

- 1. Does a reduction in K affect the time required to reach K?
- 2. Which is more effective at reducing the final size of a pest population: reducing k by _ or reducing r by _?
- 3. Which population will recover (reach K) faster from a catastrophe?
 - a. a population with r=2, k=1000 or a population with r=2, k=100?
 - b. a population with r=1, k=1000 or a population with r=2, k=1000?
 - c. a population with no time lag or a population with a time lag?
- 4. How does increasing the length of a time lag affect the logistic model? What are some possible causes of time lags? Do you think time lags are common in natural populations?
- 5. If a population has a time lag, how will different values of r affect the fluctuations? Are elephants or gnats more likely to exhibit chaotic population fluctuations?
- 6. Why is K/2 called the point of maximum sustainable yield?
- 7. Why might K fluctuate in nature?
- 8. What do α and β represent in the Lotka-Volterra competition model?
- What is the relationship between the two carrying capacities of the two competing species? Hint: observe the final population size compared to the designated K.
- 10. What do the changes in competitive coefficient values have on the final outcomes of the three simulations between the Blue-winged warblers and the Golden-winged warblers?

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Plot results from Exercises 1-6 on the graphs below





