Population Growth – Exponential and Logistic Models vs. Complex Reality

I. Exponential Population Growth

A population is a group of individuals of the same species that live in the same area at the same time. In this activity you will analyze patterns of population growth and some practical implications.

1. Food contaminated with Salmonella bacteria can cause food poisoning, including diarrhea and abdominal pain. These symptoms develop when there is a large population of Salmonella bacteria living in your intestines. Read the first column of this table and complete the second column.

<table>
<thead>
<tr>
<th>Here are some research findings about <em>Salmonella</em> food poisoning.</th>
<th>Suggest a hypothesis that can explain these research findings. (Hint: Think about why this question is included in an activity on population growth.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>You are more likely to get food poisoning if you eat contaminated food that is:</td>
<td></td>
</tr>
<tr>
<td>• raw or undercooked and</td>
<td></td>
</tr>
<tr>
<td>• has been kept at room temperature for several hours.</td>
<td></td>
</tr>
<tr>
<td>There is a delay between when a person eats contaminated food and the beginning of diarrhea and other food poisoning symptoms. This delay is:</td>
<td></td>
</tr>
<tr>
<td>• shorter for people who consumed more <em>Salmonella</em> bacteria and</td>
<td></td>
</tr>
<tr>
<td>• longer for people who consumed fewer <em>Salmonella</em> bacteria.</td>
<td></td>
</tr>
</tbody>
</table>

To better understand this example, you will analyze what happens if a single bacterium is placed in a flask that contains lots of food for this type of bacteria. Every 30 minutes, each bacterium in the flask divides into two bacteria. Thus, the number of bacteria in the population doubles every 30 minutes.

2. How many bacteria do you think there will be by 5 hours after the single bacterium was placed in the flask (just guessing)?

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1 By Dr. Ingrid Waldron, Dept. Biology, University of Pennsylvania, © 2017. This Student Handout, a longer version which includes equations, and Teacher Notes (with instructional suggestions and background biology) are available at http://serendip.brynmawr.edu/exchange/bioactivities/pop.
3. Complete this table to show how many bacteria there will be at each time if the number of bacteria doubles every 30 minutes.

<table>
<thead>
<tr>
<th>Time</th>
<th>0 min.</th>
<th>30 min.</th>
<th>1 hr.</th>
<th>1 hr. 30 min.</th>
<th>2 hr.</th>
<th>2 hr. 30 min.</th>
<th>3 hr.</th>
<th>3 hr. 30 min.</th>
<th>4 hr.</th>
<th>4 hr. 30 min.</th>
<th>5 hr.</th>
</tr>
</thead>
<tbody>
<tr>
<td># Bacteria</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Compare the calculated number of bacteria at 5 hours __________ with your guess in question 2 __________.

5. Graph the number of bacteria at each time. Connect the points to show the population growth curve.

6a. Approximately how long does it take for the population to increase from 1 bacterium to >500 bacteria?

6b. Approximately how long does it take for the population to increase from ~500 bacteria to >1000 bacteria?

Notice that, when a population doubles in each time interval, the number of bacteria in the population increases faster and faster as the population gets larger. This kind of population growth is called exponential population growth.

7a. Population growth for the bacteria in the flask is similar to population growth for Salmonella bacteria in contaminated food kept at room temperature. Explain why people are more likely to get food poisoning if they eat food that is raw or undercooked and has been kept at room temperature for several hours.

7b. Based on your analysis of exponential population growth, explain why people who have consumed fewer Salmonella bacteria experience a longer delay between eating contaminated food and the first symptoms of food poisoning.
For cottontail rabbits in the US:
- Each year has a breeding season. Baby rabbits born in one year become breeding adults by the beginning of the next breeding season.
- An adult female rabbit can have 3-4 litters of 4-5 baby rabbits each year.
- A rabbit can live as long as 8 years.

Our analysis of rabbit population growth assumes that food is abundant and there is no predation or disease, so:
- Each adult female rabbit produces 20 baby rabbits each year.
- There is no mortality in the first six years.

<table>
<thead>
<tr>
<th>Year</th>
<th># Breeding Adults for this year</th>
<th># Baby Rabbits produced during the breeding season</th>
<th>Total # Rabbits at the end of the year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>2</td>
<td>22</td>
<td>220</td>
<td>242</td>
</tr>
<tr>
<td>3</td>
<td>242</td>
<td>2420</td>
<td>2662</td>
</tr>
<tr>
<td>4</td>
<td>2662</td>
<td>26620</td>
<td>29,282</td>
</tr>
<tr>
<td>5</td>
<td>29,282</td>
<td>292,820</td>
<td>322,102</td>
</tr>
<tr>
<td>6</td>
<td>322,102</td>
<td>3,221,020</td>
<td>3,543,122</td>
</tr>
</tbody>
</table>

Notice that, as the size of the rabbit population increases, there is a proportionate increase in the growth of the rabbit population. Thus, the rabbit population shows exponential population growth.

8a. Why is the number of baby rabbits produced smallest in the first year and bigger in each successive year?

8b. The total number of rabbits at the end of each year is more than 10 times as large as the total at the end of the preceding year. What feature of rabbit biology allows the rabbit population to increase more than tenfold in a year?

9. Exponential population growth predicts ever greater yearly increases in the number of rabbits. So, why isn’t the world completely covered in rabbits? Complete this table to explore factors that can limit exponential population growth.

<table>
<thead>
<tr>
<th>Assumptions of the Exponential Population Growth Model for Rabbits</th>
<th>Is this assumption likely to be true for all rabbit populations, especially at large population sizes? Explain your reasoning.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Each adult female rabbit produces 20 baby rabbits each year.</td>
<td></td>
</tr>
<tr>
<td>There is no mortality in the first six years.</td>
<td></td>
</tr>
</tbody>
</table>
II. Logistic Population Growth

Exponential population growth cannot continue forever, since all organisms require resources to grow and reproduce, and the environment where a population is growing has a limited supply of resources (e.g. a limited supply of food).

As a population gets larger, there is increasing competition for resources. This results in increased mortality and/or decreased reproduction. Therefore, the rate of population growth slows down.

Eventually, the population will reach a maximum size which is called the carrying capacity of the environment. The carrying capacity depends on the amount of resources available in the environment.

This type of population growth is called logistic population growth.

10. In this figure one curve shows exponential population growth and the other curve shows logistic population growth in an environment with carrying capacity = K. Label the curve that shows logistic population growth.

Population density is the number of individuals per area of land or volume of water. Density-dependent factors have a stronger effect on population growth as population density increases. For example, for plants, competition for water, soil nutrients and sunlight increases as the number of plants in a given area increases. Thus, as population density increases, limited availability of water, soil nutrients and sunlight results in decreased plant survival and reproduction, which in turn results in slowed population growth.

11a. Which population growth model(s) include the effects of density-dependent factors?
   a. exponential population growth model
   b. logistic population growth model
   c. both exponential and logistic population growth models

11b. Explain your reasoning.

This figure shows the trends in population density for a laboratory population of Paramecia. These single cell organisms ate bacteria. This population of Paramecia received the same amount of food each day.

12. Explain why population growth stopped after about 16 days. Include the term density-dependent factor in your explanation.
III. Mathematical Models vs. Complex Reality

A mathematical model is a simplified representation of reality that highlights certain key features of a phenomenon like population growth. To create a model, scientists need to make some simplifying assumptions. For example, the simplifying assumption for the exponential population growth model is:

Due to abundant resources, an individual’s probability of survival and rate of reproduction is the same, even when population size increases. Therefore, on average, each individual’s contribution to population growth is the same, independent of population size. So, as a population gets larger and has more individuals, the rate of population growth increases.

13a. In two of the following situations, resources are likely to be abundant enough that the simplifying assumption will be valid and exponential population growth will occur. Mark these two with √s.

___ A species first enters a new area of suitable habitat (e.g. if humans transport a few members of a species from their original location to a new location).
___ Population size is close to the carrying capacity of the environment.
___ A population is recovering from a drastic reduction in population size (e.g. after a severe storm has killed most of the population).
___ A population has been the same size for a long time and there is no change in the environment.

13b. Explain your reasoning.

Both of these figures show data for populations of seals as they recovered from a drastic reduction in population size caused primarily by human hunting.

14a. Scientists believe that there was a larger food supply for one of these populations, so exponential population growth continued for at least 35 years. Label the graph for this population with “Exponential Population Growth”.

14b. What do you think was different for the other seal population? Propose a hypothesis to explain what happened to produce the population growth curve for this other seal population.
Simplifying assumptions for the logistic population growth model are:

- Carrying capacity is constant.
- As population size approaches carrying capacity, mortality increases and/or reproduction decreases quickly enough so that population growth slows promptly and population size does not exceed the carrying capacity.

When these simplifying assumptions are not accurate for a real population, then the model’s predictions will differ from the actual trends in population size.

15a. The dots show the trends in population size for a laboratory population of Daphnia (water fleas) that had a constant supply of food. Describe the difference between the observed trends in population size vs. the logistic population growth curve.

15b. What do you think is the reason that the observed trends in population size differed from the logistic population growth curve? (Hint: Think about which of the simplifying assumptions for the logistic population growth model were not valid for this population.)

This figure shows changes in the size of a population that began with 25 reindeer on an island off the coast of Alaska. Initially, food was plentiful. However, by the late 1930s the large population of reindeer had drastically reduced the amount of lichen (which the reindeer depend on for winter food). The slow-growing lichen had not significantly regenerated by 1950.

16a. Circle the part of the graph that shows approximately exponential population growth.

16b. Draw the expected population trend if population growth had followed the logistic population growth model and the carrying capacity of the island was 1000 reindeer.

16c. Why didn’t the trends in reindeer population size match the predictions of the logistic population growth model? Explain how both of the simplifying assumptions of the logistic population growth model were not accurate for this population of reindeer.

16d. Trends in population size can look quite different, depending on which data are available for analysis. What feature of trends in reindeer population size would have been missed if the researchers had stopped collecting data in 1937?
17a. Clearly, this population of cottontail rabbits did not show logistic population growth. Describe how carrying capacity varies with the season in Ohio where these rabbits lived. Explain how seasonal changes in carrying capacity can account for the annual cycles in population size.

17b. Many researchers only measure population size once a year. What important feature of population trends would be missed if the researchers had only measured population size in July of each year?

**IV. Review**

18. For exponential population growth, explain why population growth is slower at the beginning and then gets faster and faster.

19. Describe one type of situation where exponential population growth is often observed in natural populations.

20. In the logistic population growth model, population growth eventually slows down and stops. Explain why.

21. Explain why actual trends in population size often differ from the predictions of the logistic population growth model.