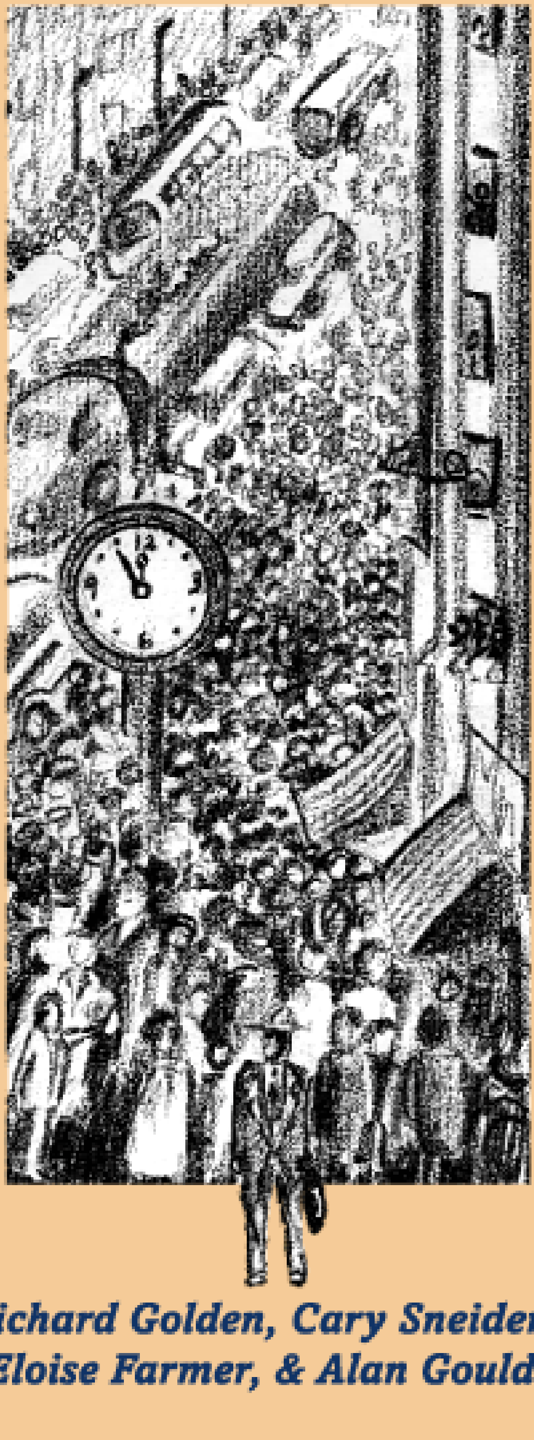
POPULATION GROWTH



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Eloise Farmer, & Alan Gould

Global Systems Science
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Lawrence Hall of Science
University of California, Berkeley
LHS

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Global
Systems
Science

Population Growth

Richard Golden, Cary Sneider,
Eloise Farmer, Alan Gould

Contents

News and updates are available at the GSS
website http://www.lhs.berkeley.edu/GSS/
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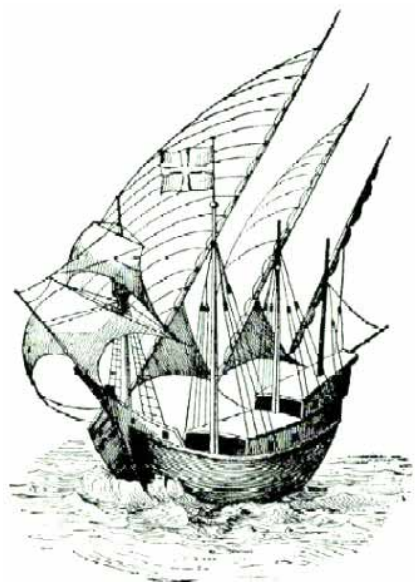
1. What is a Population?



The word "population" can refer not only to people, but to groups of beetles, or cacti, or even fireflies! A population is a group of individuals of one species living in an area and occupying a particular ecological niche. This book is about the impacts of populations on their environments and on other populations. It is also about how populations grow, things which limit their growth, what happens to populations when limits to their growth are not present, what has happened to various populations in the past, and what is presently occurring. Key questions in this book concern what could happen to the world in the future as a result of the growth or decline of populations.

What is the Connection Among Robinson Crusoe, Juan Fernández, and Goats?

Robinson Crusoe is a subtropical island. It appears as an imposing and unexpected structure that raises from the surface of the ocean as you sail towards it. For a sailor like Juan Fernández and his crew coming from the loneliness of an unending sea, their first encounter with this island might have been like they were in an incredible fantasy, like a miracle.

The first documented humans to find Robinson Crusoe Island were the sailor Juan Fernández and his crew, on November 22, 1574. He dedicated the discovery to Spain and named the three major islands Más a Tierra (today known as Robinson Crusoe), Más Afuera (today known as Alejandro Selkirk), and Santa Clara.

Acceding to the Spanish Crown's wishes, Fernández settled the islands bringing 60 Indians, and goats and chickens. After he left there were only sporadic visits of ships and crews, so the goats Juan Fernández had taken to the island in his colonization project multiplied. Diego de Rosales, a Jesuit who came a century later was astonished to see them when he stopped at Robinson Crusoe Island. He stayed at the island for a few days to plant trees and vegetables to help feed the crews of visiting ships.

Many sailors, explorers, and pirates often stopped at island Más a Tierra throughout the 17th century. The most famous visit was that of Alexander Selkirk, who decided to abandon his ship, the "Cinque Ports" after a dispute with his captain and stay at Más a Tierra Island. He lived on this island for 4 years and 4 months alone until rescued by a British Ship. Years later, the author Daniel Defoe heard about Alexander Selkirk and the story of his exile on a faraway island and used it as a basis for his character Robinson Crusoe. What follows is the story of Goat Island with a scenario of what it might have been like to be a sailor on the ship commanded by Juan Fernández.

The Story of Goat Island

To the lookout at the head of the mast the vast expanse of the Pacific waters stretched endlessly from horizon to horizon. His captain, Juan Fernandes, had warned him that their lives depended on the keenness of his eyesight. It was fifty years before the American revolution that created the United States. The great nations of the world in the early 1700s were England and Spain. Those two countries sent sailing ships across the world's seas competing for the wealth of unknown lands.

Photo by Andrys Basten, University of California, Berkeley

The crewman squinted against the glaring sunlight as the ship rocked lazily on rounded swells. A light wind was slowly moving them westward. The last landfall was two months before and there had been no rainstorms to refill their water casks. Their ration had been reduced to two cups of water a day. A blur of white seemed to hang low off to the northwest. He tried to clear his vision. If it was an English ship it could mean anything from a verbal exchange of insults to an exchange of gunfire and a boarding party. If it was a cloud it could mean rain or an island. Excitedly he called down to the deck. The captain's telescope revealed a brown smudge under a distant cloud and they changed course to head for what later was called Goat Island.

When the ship of Juan Fernandes sailed up to Goat Island they found, to their relief, that the tiny island had a plentiful supply of water. It was not inhabited by man or beast and there was much fertile pasture. On board his ship the Spanish captain had six goats whose flesh was a reserve of food for his crew. To establish a future food supply he chose to put ashore one male and one female goat. He noted the position of the island and on his return informed his superiors of its existence.

In the next few decades, the island was visited by Spanish sea captains who noted changes on the island. The lush conditions so favored goat life that in the first years their population grew quickly. There were goats feeding in every part of the island. Yet only a few years after that the Spanish captains were disappointed, for they found the goats greatly diminished in number, weak and bony. Yet again, on subsequent visits, their numbers were up and their condition good.

Observant visitors noted that the plant life on which the goats depended likewise waxed and waned. Goat overabundance reduced the limited food supply and then the goat population was decimated by famine. Released from the demands of large numbers of plant destroyers, in only a year or two the plants responded with increased growth only to again suffer destruction at the mouths of the new young goats. Thus did the goat population of "Goat Island" rise and fall and was never permanent. Good times and increase in numbers were inevitably followed by starvation and death.

If ships arrived with starving men aboard when the goat population was up, the goat herd was their salvation. As the ships sailed away, leaving the goat population reduced, the death toll served as a benefit for those remaining. Now the danger of death by famine was staved off. If a goat philosopher could contemplate the departing ships he might console his fellows with the knowledge that the sacrifice of some of their companions was a benefit to the family of goats as a whole.

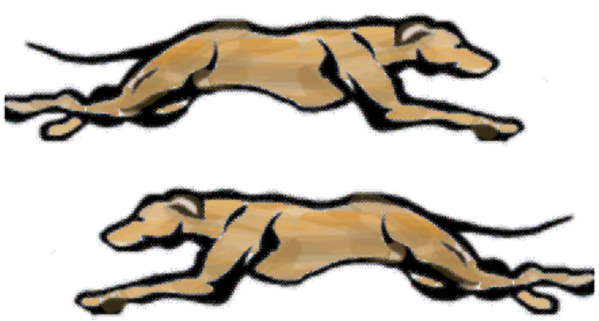


Illustration adapted from *http://www.adopt-a-greyhound.org/treats/body_clipart.htm*

In the course of time English ship captains found out about Goat Island and also used it as a food reservoir. Too frequently the Spanish would arrive at the island to find the supply of goats so diminished that there were none they could take. Goaded by the evidence that the English had preceded them the Spanish decided to forgo the benefits of the island if they could also deprive the English of them—they delivered to the island one male and one female greyhound, with the following result:

Feeding on the plentiful supply of meat of young goats, the dogs increased their numbers prodigiously. As the Spanish had foreseen, the population of goats was reduced. But the more agile of the goats retreated to the rocky heights of the island where they were safe from the dogs. They descended to the lush valleys only to feed and then retired quickly to safety as the dogs approached. Only the weak and careless became prey.

Likewise the dog population declined. Deprived of an easy source of sustenance only the quickest, strongest and most watchful dogs survived. A new kind of oscillating balance was established on the island wherein a quantity of plants, a number of goats, and a population of dogs continued in good health and in good harmony for many years. This harmony did not, however, extend to native species that existed on the island before the Spaniards and English mariners arrived. They either became extinct or were driven to the brink of extinction.

A number of "Goat Islands" have been created in tropical archipelagos as mariners traveled to them and left their animals behind to breed unchecked by their natural predators.

A modern-day goat island exists in the Galapagos Islands on the Island of Santa Fe. Here the endangered land iguana (Iguanas terrestris) was once described by Charles Darwin in 1845 as so numerous that "we could not for some time find a spot free from their burrows on which to pitch our single tent." Since Darwin's time, they have drastically declined in numbers due to introduced animals, including large herds of goats. The goats feed on all the vegetation, and churn up the resulting barren volcanic soil into a fine choking pumice-like dust. Efforts by Park rangers to keep the goat population under control by shooting them has been unsuccessful.

The story of Goat Island is based on the writings of Joseph Townsend, born 1739, died 1816 (as reported in Population, Evolution, and Birth Control assembled by Garrett Hardin, W. H. Freeman, 2nd Edition 1969), and on a history of the Juan Fernandez Islands supplied by the Chilean government.

Photo by Eloise Farmer

Another animal which suffers from the overpopulation of goats is the rare and endangered giant tortoise. Tortoises also depend on vegetation for their food and compete directly with the goats. As we'll see in this book, the story of Goat Island is not unique. It is similar in many ways to the story of how any population grows. Populations of rabbits, deer, grasshoppers, and even people, display certain patterns as they grow to fill their natural environment.

Photo by Mark Jacobson

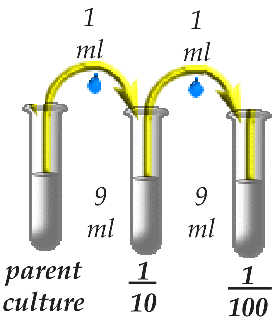
Investigation

Population Growth Behavior

Conduct an experiment growing live organisms which are much, much smaller than goats. Determine whether or not this population behaves in much the same manner as a population of goats.

Mix 1 ml. of molasses solution prepared for you by your teacher, a pinch of dried yeast, and 9 ml water in a test tube. Grow for 24 hours. Observe and count all yeasts visible in the field of view under a microscope using a drop of yeast culture at 400X magnification. Continue to count cells every few days for 2 weeks. It may be necessary to use serial dilution to make yeasts easier to count. Graph the yeast population growth.

A similar experiment can be done with fruit flies in a vial, duckweed in a small dish, or human fibroblasts.



http://www.brooklyn.cuny.edu/bc/ahp/MBG/MBG4/Dilution.html

Serial dilution

Serial Dilution may be achieved by diluting cultures before counting them:

Take 1 ml from a parent culture and add it to 9 ml distilled water. After mixing thoroughly, take 1 ml of culture from your diluted tube and add it to a 3rd tube containing 9 ml of distilled water. Mix thoroughly before counting. This gives a total of a 100-fold dilution. (Multiply your counts by 100 to get the original number of organisms)

Observe the appearance of the test tube and odors detected. Graph your yeast counts, and log your observations.

What has happened to the population of yeasts in the test tube?

Have the yeasts encountered limiting factors?

What might they be?

Limiting Factors

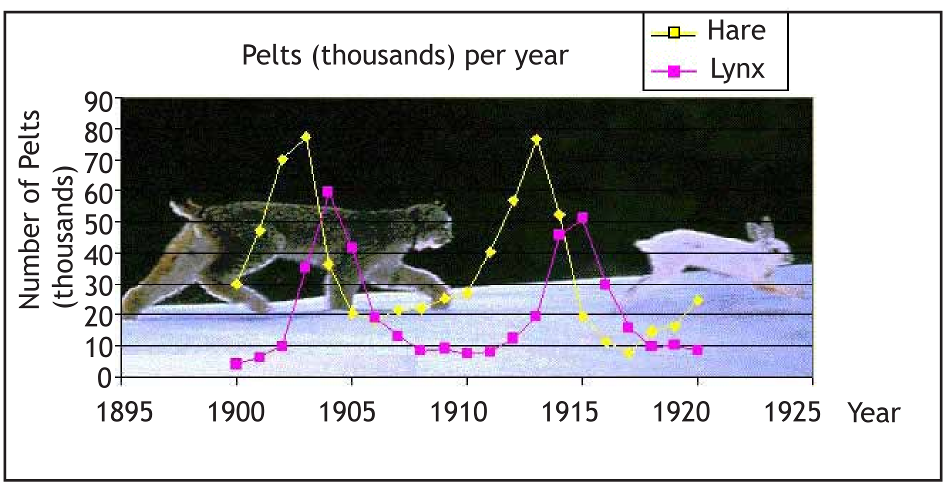
Limiting factors can be summarized as the conditions that restrict the growth of a population. For example, food supply limited the carrying capacity of the goat population, and even the tiniest of organisms like yeast have similar limiting factors.

http://quest.arc.nasa.gov/ltc/nps/images/shark.jpg

In 1925 an Italian mathematician named Vito Volterra studied the relationship between sharks and their prey in the Adriatic Sea. He devised a mathematical model describing how their numbers change over time. His equations predict that the two populations—sharks and the smaller fish on which they feed—will always vary periodically. No matter what the numbers of predators and prey are at the start of their relationship, they will tend to return to the same values—the carrying capacity of the two populations— again and again. This can also be seen in the "Lynx and hare" predator/prey population graph on this page. If the hare population shoots up, the lynx population does also, a short time later.

All populations have limiting factors and no population can continue to grow forever. Elephants are very slow reproducers, but if all their young survived they could double their population in a little under 50 years. George G. Simpson and William S. Beck in their book Life estimated that if all the offspring of one elephant pair survived and reproduction of elephants continued for 100,000 years, their mass would fill the visible universe.

Lynx and Hare



http://www-rohan.sdsu.edu/~jmahaffy/courses/f00/math122/lectures/intro.html

Questions to Ponder

1.1 What are limiting factors other than space that might hold down or even reverse the growth of populations? [Make a list.]

1.2 Just as the growth of dogs affected the carrying capacity of goats on Goat Island, the growth of human populations are affecting populations of plants and animals. What are some limiting factors caused by humans that are affecting plants and animals around the world?

1.3 Why are island species so vulnerable to new kinds of organisms?

1.4 What are some limiting factors which might be causing the decline of tortoise and iguana populations?

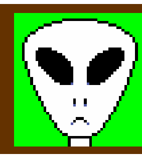
1.5 What kind of growth would you expect from a newly introduced species which has no enemies?

1.6 What kind of growth would you expect from a newly introduced species with many enemies?

1.7 Which is a more likely scenario—a newly introduced species which has no enemies or a newly introduced species with many enemies?

Investigation

Alien Invaders



(No, not this kind of alien)

- Search the internet for “alien species” or “alien invaders” and list at least five species which have invaded your area of the United States.
- Select one of these and write a page on their success or lack of success in remaining alive.
- Be ready to report on this species to your class.

Questions

1.8 Is it true that only islands are vulnerable to invasion from alien species?

1.9 What can be done to avoid these alien invasions?

For new material relating to this chapter, please see the GSS website “Staying Up To Date” page: http://lhs.berkeley.edu/gss/uptodate/8pop. We invite you to send us new articles for the ”Staying Up To Date” web page for this chapter. Articles may be from local newspapers, magazines, websites, or other sources that you think would be of interest to classrooms around the country. To send us articles please go to the link http://lhs.berkeley.edu/gss/uptodate/newarticle.html and find the ”Submit New Article” button.

2. Patterns in Populations

Understanding the patterns of population change has become possible by creating mathematical models, or equations, that have the same characteristics as actual populations. An equation that successfully models population growth must display some of the same patterns that we saw on Goat Island. Making a graph that is a visual expression of a mathematical equation can be very helpful in understanding the meaning of the equation.

Goat illustration adapted from Eron Cohen, http://alt.binaries.clip-art
Greyhound illustration adapted from
http://www.adopt-a-greyhound.org/treats/body_clipart.htm

Investigation

Making Graphic Representations of Population Behavior

Draw a graph which fits each of the scenarios below.

Scenario One: When the population was young, there was lots of food, room to grow, and no natural predators, so the population grew rapidly.

Scenario Two: After a few years of unchecked growth, the goats ate nearly all of the available food. Many goats died of famine. When the food grew back, their numbers increased, and they devoured the food again. The population oscillated up and down, above and below a certain average number.

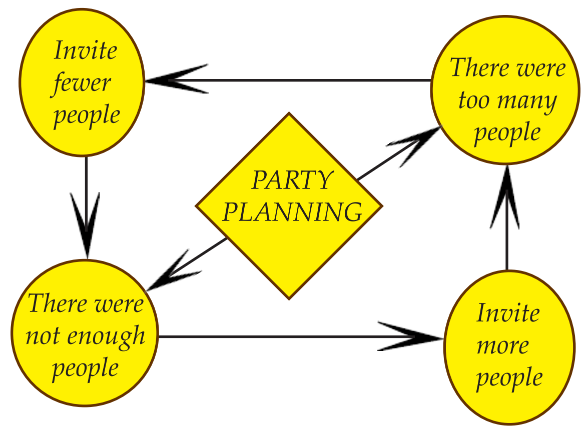
Scenario Three: When the herd of goats was culled regularly, by sailors or later by dogs, the numbers of goats were kept low enough so they did not eat all of the food. The population grew to a certain maximum size and a population of healthy goats remained stable for a long time.

Question 2.1 Can you think of some other ways that the populations could grow and decline?

Get together with a group in your class and brainstorm all of the additional population patterns you can think of and list the limiting factors which affected these populations in all your scenarios. Be ready to show your graphs to other groups in your class and to explain your rationale in each case.

Feedback Loops

Another way to understand the reasons for changes in the goat population is to draw a concept map of the island ecosystem. If you do this, you will notice that the map has loops. These are called *feedback loops*. You probably have heard the term *feedback* when someone asks you a question such as, "How did you like the party? I would like your feedback." Just answering a question is not necessarily feedback. Only if the response changes the future situation is it proper to call the response feedback. For example, if the question was, "Do you think there were too many people at the party?" The response is feedback because it can change future actions.



In the language of science, feedback only occurs when the result automatically controls the process of change—the output of a system controls its input. A room thermostat is often used in illustrating the principle.

Investigation

Human Thermostat

Materials for one or two people:

- container of hot water
- container of cold water
- container of room temperature water
- thermometer.
- graph paper and pencil.

Take the temperature of the water in each container. The goal is to raise the temperature of the room temperature water exactly 5 degrees Celsius. Students must add enough hot water to achieve this goal, and maintain this temperature for 10 minutes, recording the temperature of the container every minute. The temperature should be placed on a graph, and the questions below answered.

Question 2.2. Was it easy to maintain a temperature at one exact point?

Question 2.3. What did the temperature actually do?

Question 2.4. Do you think real thermostats also behave in this manner?

Question 2.5. Diagram a feedback loop for your thermostat.

You have just completed a negative feedback loop! This kind of loop always maintains a balance, or in biological terms, *homeostasis*.

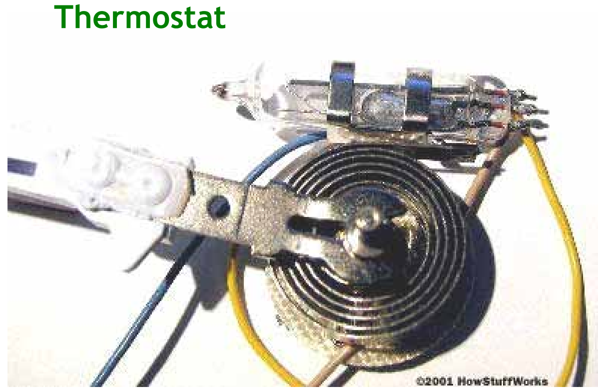
The type of feedback loop in a thermostat is called a *negative feedback loop*. A room thermostat is often a wall-mounted switch which works as follows:

There are two thermometers in the thermostat. One displays the temperature and is located in the cover. The other controls the heating and cooling systems and is simply a coiled bimetallic strip (two different types of metal laminated together). The metals in the strip expand and contract when they are heated or cooled, but each metal has a different rate of expansion, so when heated, the metal on the inside of the coil expands more and the strip tends to uncoil.

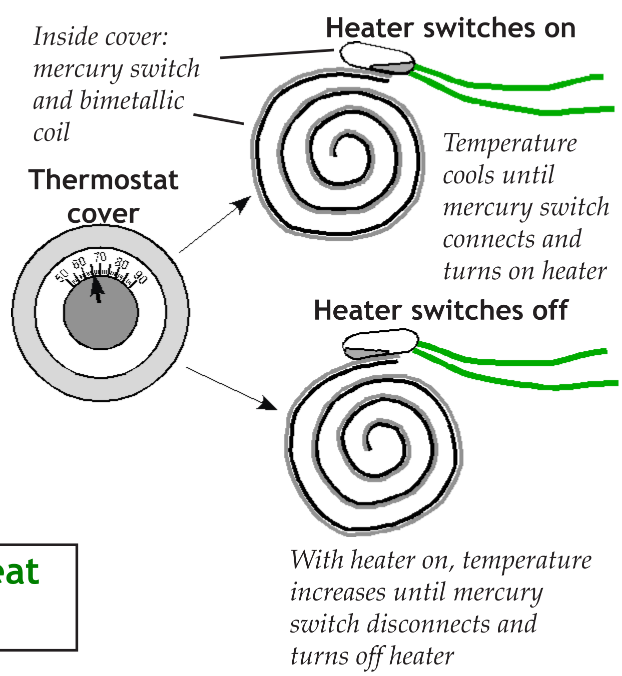
The center of the coil is connected to the temperature-adjustment lever, and a mercury switch is mounted to the end of the coil so that when the coil winds or unwinds, it tips the mercury switch one way or the other.

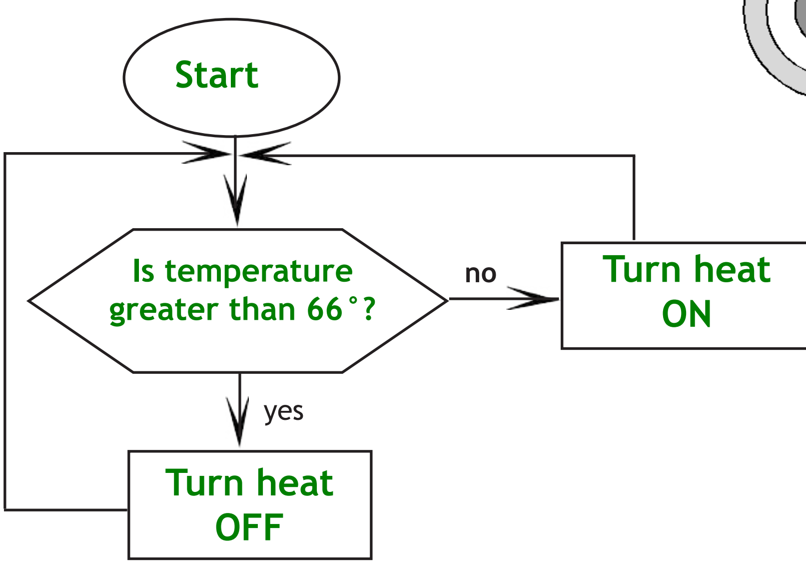
Your concept map of the thermostat may have looked like the one below. The Thermostat represents a negative feedback loop which tends to keep the condition of the system stable.

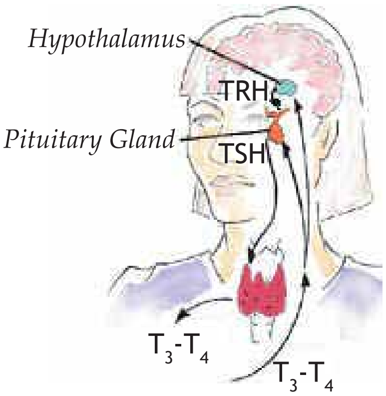
Thermostat



www.howstuffworks.com







http://www.endocrineweb.com/thyfunction.html

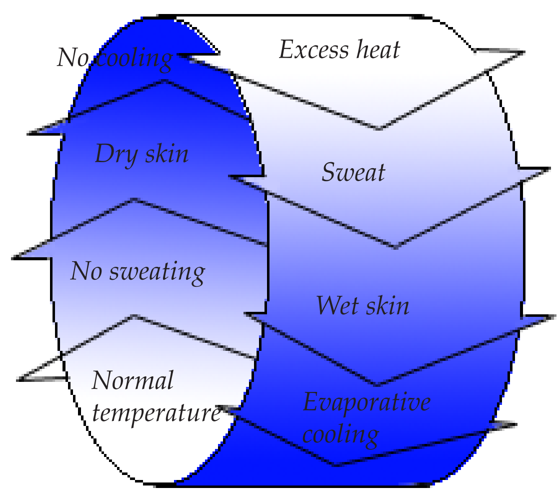
There are negative feedback loops in your body which maintain stability in your living system. In biology, these negative feedback loops are called *homeostasis*. A good example is the interaction between your thyroid gland and your pituitary gland. The thyroid gland is under the control of the pituitary gland, a small gland the size of a peanut at the base of the brain (shown in the diagram). When the level of thyroid hormones (T3 & T4) drops too low, the pituitary gland produces *Thyroid Stimulating Hormone (TSH)* which stimulates the thyroid gland to produce more hormones. Under the influence of TSH, the thyroid will manufacture and secrete T3 and T4 thereby raising their blood levels. The pituitary senses this and responds by decreasing its TSH production. One can imagine the thyroid gland as a furnace and the pituitary gland as the thermostat. Thyroid hormones are like heat. When the heat gets back to the thermostat, it turns the thermostat off. As the room cools (the thyroid hormone levels drop), the thermostat turns back on (TSH increases) and the furnace produces more heat (thyroid hormones).

Question 2.6. There are many other examples of negative feedback found in nature. Can you think of any? Find an example in a book or on internet and diagram it as a negative feedback loop.

Question 2.7. Can you think of negative feedback in manufactured substances? Make a diagram of one such feedback loop.

Negative and Positive Feedback

The kinds of feedback illustrated by all the examples used so far maintain many natural systems at proper working levels. It is called negative feedback because the change to the system is restored each time to the start by canceling out the change. Therefore, the change is added, but then subtracted. This keeps the system within bounds.



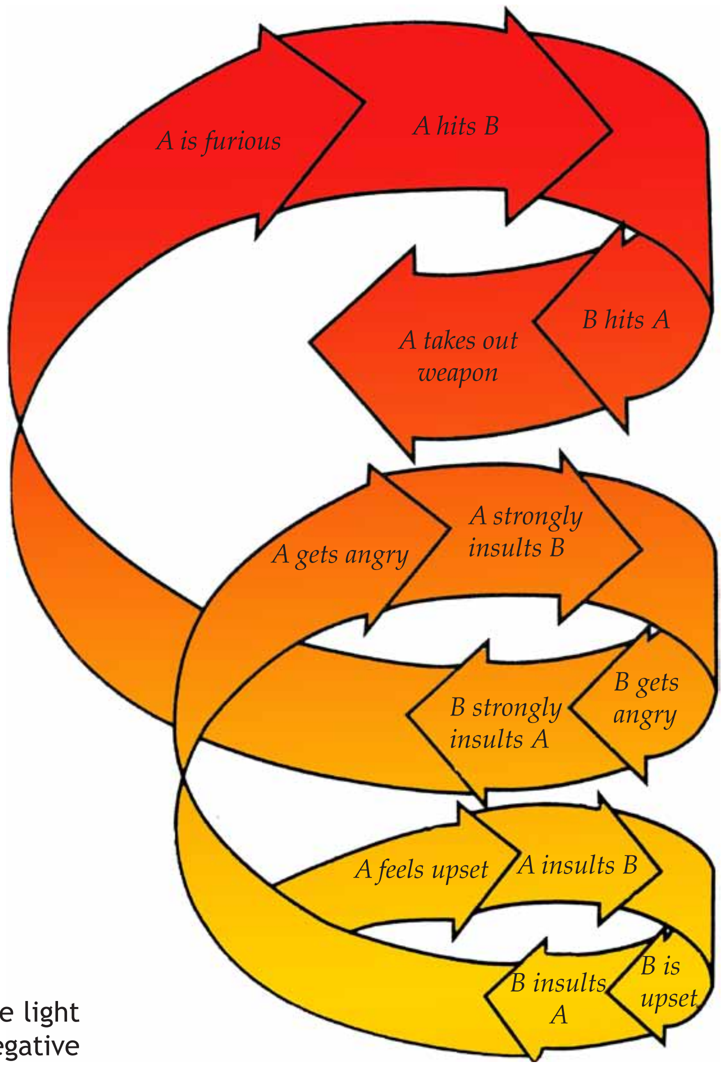
Question 2.8. Can you explain how the amount of light coming into your eye controls how much more light comes in? Diagram this loop.

When the topic of feedback is discussed the idea of positive always being good gets turned on its head. Physicists long ago labeled positive feedback as feedback which added to the change in the system. This creates a situation which escalates until the situation is out of control.

Question 2.9. Using the Palestinian-Israeli conflict as an example, can you make a positive feedback loop?

Another example of positive feedback can be when the very condition that makes a place special makes it overused. Ecotourism is an example. These tours usually consist of groups of people who love nature who want to see some of the rare and beautiful wonders of the world. Our beautiful Yosemite National Park has been overrun by so many tourists that traffic jams and air pollution are the norm. So many people wish to view the beauty that they have spoiled the beauty.

Question 2.10. Can you think of other natural wonders in danger from ecotourism? Make a positive feedback loop illustrating your choice.

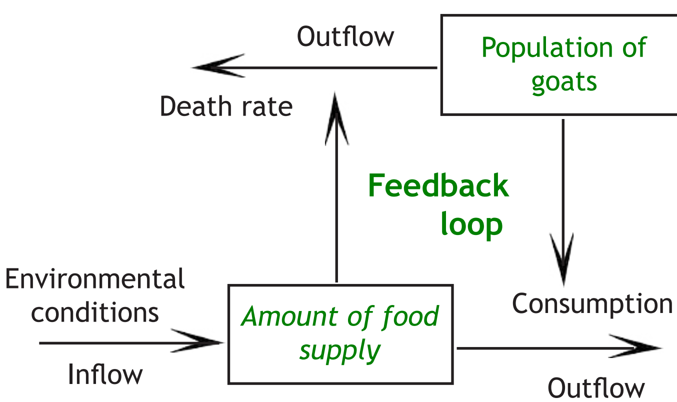


Let's return now to Goat Island in the light of our new knowledge about positive and negative feedback loops.

The diagram below shows the island ecosystem before the introduction of dogs.

Question 2.11. Does the diagram show a positive or negative feedback loop?

Feedback Control of a Population of Goats



Here are some clues.

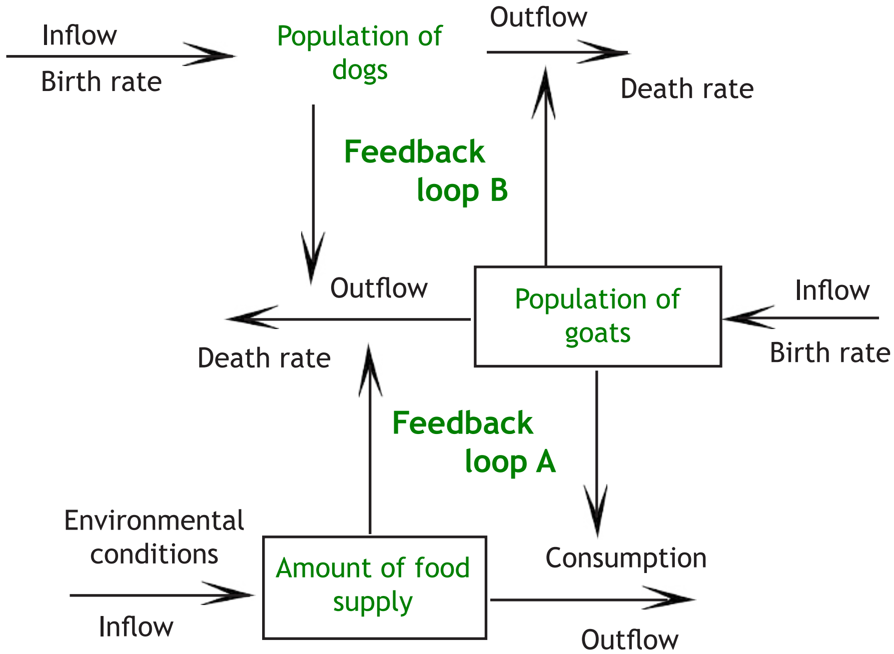
Looking at the bottom line, we can see that the amount of food depends on the environmental conditions (which determine how quickly the food grows) and consumption (which determine how rapidly it is depleted). Looking at the top line, we see that the population of goats depends on the birthrate and death rate.

The connection between the upper and lower parts of the diagram is crucial.

Looking at the vertical arrows, we can see that the population of goats affects the consumption of plants; and that the number of plants affect the death rate of the goats. The number of goats affects the food supply, which affects the number of goats, which affects food supply, and so on.

Feedback Control of a Population of Goats and Dogs

The second diagram shows what happens to the system when the dogs are introduced. The bottom and middle layers are the same as before, but a top layer has been added. The death rate of the goats is now affected not only by the available food supply, but by the population of predators as well. The population of goats, in turn, affects the death rate of dogs. When the population of goats falls, the dogs have less to eat. There are now two feedback loops in the system; one linking the goats and plants, and one linking the goats and dogs.



The ecosystem map is a simplified picture of reality that can show us things. As an example, consider this question:

Question 2.12. What would happen if a blight sweeps the island, and most of the plants that the goats depend on for food die? How would that affect the goats and the dogs?

Try making a feedback loop for this situation.

Positive feedback loops often can result in the total breakdown of the system, and with living organisms, possible extinction or huge cycles of feast and famine. This is often the result of populations exceeding the carrying capacity of their environments due to the exponential growth in numbers.

What is Exponential Growth?

When populations grow rapidly because there are few limiting factors the growth is exponential. This happened on Goat Island at the beginning when there were no dogs and there was plenty of food and water for the goats. Exponential growth can have tremendous impacts.

Investigation

How Many is a Billion?

The mind dulls when we are faced with large numbers that are outside of our daily experience. A million, a billion, what's the difference? We tend to put them in the same category—large numbers, and let it go at that. But in dealing with human populations, as in dealing with money, a billion is a lot different than a million. For one thing, a billion (1,000,000,000) has three more zeros in it than a million (1,000,000). That means a billion is equivalent to 1,000 million.

Suppose your parents offer you two alternatives for your allowance: They will give you ten dollars every day for the year, or they will give you a penny the first day, and double the penny every day for a year. Which offer would you take? After you write your choice, you will do a one-month sample which will tell you which would be the better offer.

Take the copy of the calendar for February and a calculator, and write in each day the total amount you will have in your pocket. At the end of the month, write your grand total.

Which is the best deal?

What has happened here?

Does this happen with some populations?

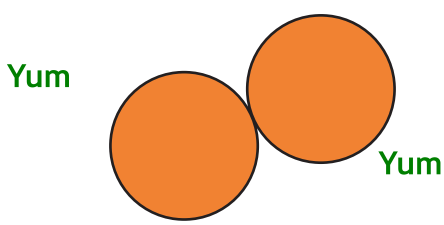
What would the numbers be like if you substituted bacteria for pennies? The following investigation will help you to find out.

Investigation

Bacterial Growth and Populations

Supposing that you grow bacteria in a petri dish, giving them the diet they like best.

These bacteria can then divide approximately once every 20 minutes, doubling their numbers in that time period.



How many bacteria would there be in the petri dish at the end of 24 hours?
(Answer this before you go on to the next question—write it down on a sheet of paper)

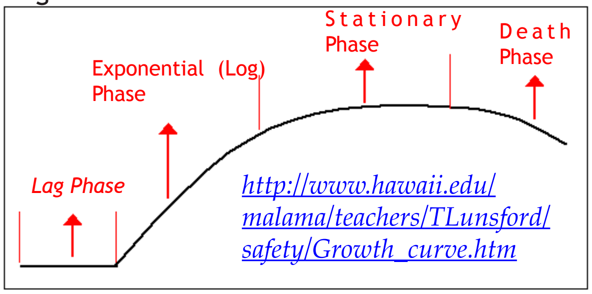
Of course, the number of cells after one full day of growth is interesting and surprising! There is another thing we must think about when such a great number of things, no matter how small, collect in one place. Cells like the ones we are talking about weigh something. For example, suppose that each cell weighs 1.1×10^{-15} pounds. That is .000 000 000 000 0011 pounds. That is very, very light.

First, try to guess about how many pounds of cells there would be at the end of 24 hours. Write the amount you guess on a sheet of paper.

Now try to figure out the weight of 4.3 sextillion cells after 24 hours.

If you multiplied 4,300,000,000,000,000,000,000 cells by the weight of one of them, .000 000 000 000 0011, you would find the weight after 24 hours to be 4,730,000 pounds—over four million pounds!

4,730,000 pounds is about the same weight as 1300 large cars. Surely, the building holding all those cells would buckle under all that extra weight.



The growth of the bacteria is shown in the graph. The curve rises very steeply after 11 to twelve hours.

This is called exponential growth.

We know that many things can happen to keep the cells from growing that much or we would be buried by bacteria!

Question 2.13. Can you think of what kinds of things might happen to keep the bacteria from filling the laboratory and then the world?

Write any ideas you might have in your notebook or on paper provided by your teacher.

A number of things might keep the cells from growing to such a great mass. Did you guess that these are:

Limited food supply

Amount of space for growth

Death rate of the cells

Buildup of waste products

Attack by or competition with other cells

Weight of the mass of cells upon itself

There may be still other possibilities, too. The growing body of cells after ten hours or so may begin to change the temperature of the air around it. As a result, the temperature change may slow the growth rate.

We are talking here of things in the surroundings that may hold back the growth of the cells. The surroundings can only support a certain number of the cells. This is called the ***carrying capacity***.

When that number is reached the population growth slows. Finally, it levels off. The same ideas would hold for humans and their population growth rate. Has this happened yet with the human population? How can you find out?

Investigation

What Do You Mean? It's Only a Drop in the Bucket!

Adapted from a lab by Fred Goldberg and James Shuman, The Physics Teacher*, October 1984, p.444.*

Hypothesis: How much time do you estimate it will take to fill the bucket completely?

WRITE DOWN YOUR HYPOTHESIS ON PAPER.

Materials

An empty bucket, a number of different sizes of droppers and beakers, and a water supply.

Procedure

Your task is to begin by putting one single drop of water into the bucket, and then doubling that amount every 30 seconds until the bucket is full. Make sure that one member of the group is keeping track of the number of drops you use each time.

Graph your data.

What would be your independent variable?

What would be your dependent variable?

How long did it take your group to fill the bucket?

Was your hypothesis close?

Write your reactions to these results. Can you think of a real life situation for which this is an analogy? (Other than the water torture).

Exponential Growth , Road Kill, and Sexual Reproduction

If you have traveled in the southern part of the United States and in Mexico, you may have noticed a particular animal which is often run over by automobiles. Why are these animals often the victims of drivers, and how do they manage to survive despite the large numbers being killed on the highways?

So far you have only applied the idea of exponential growth to nonliving objects or to organisms which reproduce by simple cell division. What about organisms which reproduce sexually like the goats and the dogs? Are they also subject to periods of exponential growth? Let us find out by meeting Mamadillo and Papadillo and some of their descendents.

Investigation

Adding Armadillos

(Adapted from ZPG's Elementary Population Activities Kit)

In the wild, the nine-banded armadillo of North and South America lives about three years after reaching maturity, and mates and produces four litters of offspring each year. We will study one such armadillo family that begins with Mamadillo and Papadillo, and figure out what it looks like in three generations (when Mamadillo is a grandmother).

Mamadillo and Papadillo mate and have one litter a year for three years. Each litter is always four little female armadillos. We will assume that each female successfully finds a mate from some other litter.

Question 2.14. What is the total number of baby armadillos borne by Mamadillo, her offspring, and their offspring, in the three years?

***Extra challenge! At this rate, how long would it take for there to be more than 2000 armadillos? Why aren't there very many armadillos today?

Make a table like the one shown on the next page. Graph the population of armadillos from your results. Your independent variable is the time, and your dependent variable is the number of armadillos.

Remember that earlier in the book you read about what would happen if all the elephants born survived. Would the same situation occur eventually with armadillos? What limiting factors prevent us from being up to our arm pits in armadillos?

Table of Armadillo Population—Offspring of Mamadillo and Papadillo

Year	A Offspring from one year ago [D, prev. line]	B Offspring from two years ago [D, 2 lines up]	C Offspring from three years ago [D, 3 lines up]	D New offspring [4F, 1 line up]	E Deaths	F TOTAL Females [1+D-E]
0	Originally there are two armadillos, Mamadillo & Papadillo.			——	0	1
1					0	
2					0	
3					0	
4						
5						

Question 2.15. What might prevent the numbers of armadillos from being as large as you calculated? Refer back to the activity on the bacteria to get some ideas. Do the limits on bacterial populations also apply to armadillos, goats, or dogs? Discuss your ideas with your classmates and prepare to present them to the class.

Question 2.16. What are some limiting factors caused by humans that are affecting plants and animals around the world?

How Do We Know Population Size?

We often talk about how big a population is and how fast it is growing, how many are surviving in a certain area, and whether or not a population is endangered. How can ecologists find out what is happening in a population in the wild? After all, they cannot go out into the field and see every individual organism. They can collect pelts and count them as they did with the lynx and the hare, or they can use what field biologist call "mark-recapture" You will perform an activity which shows how this works.

If weather and your terrain around the school permit, you can do a mark-recapture activity with real organisms other than grasshoppers. There are many suggestions on the internet.

Obviously, we normally do not go out and mark and recapture humans for study. (Can you think of a way that a mark-recapture activity could be done in a high school to estimate the total number of students?) Instead, we use a method called a survey. The Nielson ratings used for television are an example of this type of counting, as are telephone surveys where a computer randomly dials numbers to be called.

Investigation

Grasshopper Mark and Recapture

This investigation involves a method of estimating the population size of grasshoppers and other animals. This activity is conducted outside in the fall, in an open field that will remain undisturbed for 1-2 weeks. We capture grasshoppers and mark them in a way that will not injure them.

The marked grasshoppers from the first sample (M) are released where they were captured. A week or two later, a second sample from the same population is taken (p). Some individuals will be marked, or recaptured (m) from the first sampling, while others will be captured for the first time, and thus will be unmarked. The ratio of marked animals (m) to the total number of animals in the second sample (p) is assumed to be the same as the total number of marked animals (M) is to the total population size (P). Mathematically, $m/p = M/P$ or $P = (M \times p) / m$ which can be used to estimate of the total population of grasshoppers.

http://www.uidaho.edu/so-id/entomology/grasshoppers.htm

Materials:

2 insect sweep nets	Paint or nail polish	4 flags or stakes to mark sampling plot
1 large sheet	Paper and pencil	1 large plastic container with lid
Field guide to insects	1 metric tape measure (Or pace off the area)	

Strategies for Investigation:

1. Mark off a grassy area that is 10m x 10m. Mark corners with flags.
2. Two student collectors move through the site vigorously sweeping their nets through the vegetation. Students begin at opposite sides of the site to avoid driving grasshoppers out of the sampling area.
3. Take the animals caught to the side of the sampling plot. Carefully open the net just enough to catch the grasshoppers one at a time. While one student holds a grasshopper, another puts a dot of nail polish or liquid paper on its thorax, being careful not to get the marking substance on the wings or the head. Put each grasshopper into the plastic container as it is marked. One student must keep a tally of how many grasshoppers are marked (M).
4. Repeat steps 2 and 3 two more times.
5. Release all grasshoppers into the center of the sampling plot.
6. Return to the same plot in 1-2 weeks and repeat the sampling. This time you will capture some insects that are marked, which have been recaptured from the original sampling, and some individuals that are unmarked, or captured for the first time.
7. Calculate the population size estimate using the equation $P = (M \times p)/m$, where M = the total number of individuals marked in the first sample, m = number of marked individuals in the second sample (marked + unmarked), P = population size estimate $((M \times p)/m)$.

Method of Evaluation:

Write a paragraph describing how you felt about handling insects before and after you participated in this activity.

Write a "Today I learned... " entry in your journal.

Write a paragraph explaining what you can learn about grasshoppers by doing the GMR that you can't learn by dissecting them (and vice versa).

**(Adapted by Carolyn S. Nevin, co-author, from the 1993 Curriculum Guide of the Northeast Alabama Network of Environmental Educators)*

For new material relating to this chapter, please see the GSS website "Staying Up To Date" page: http://lhs.berkeley.edu/gss/uptodate/8pop. We invite you to send us new articles for the "Staying Up To Date" web page for this chapter. Articles may be from local newspapers, magazines, websites, or other sources that you think would be of interest to classrooms around the country. To send us articles please go to the link http://lhs.berkeley.edu/gss/uptodate/newarticle.html and find the "Submit New Article" button.

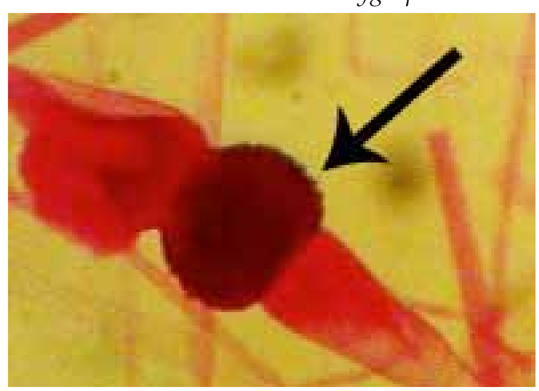
3. Population Reproduction, Growth, and Change Over Time

Unfortunately, neither the Spanish nor the English sailors were terribly interested in taking a census of the number of goats or dogs on the island during any of their visits, and they did not do a mark-recapture that we know of. We can only guess at the number of animals on Goat Island and how they grew and declined. We do generally know, however, that populations grow and reproduce exponentially unless limiting factors intervene.

Reproduction in Populations

All populations grow exponentially when they do not have too many limiting factors operating upon them, but their methods of reproduction are different. There are two main types of reproduction: asexual (for example bacteria and yeast) and sexual (for example armadillos). There are evolutionary advantages and disadvantages to each. Asexual reproduction is usually a lot faster—yeast and bacteria population increases are counted in days or weeks, while armadillo population increases are counted in years.

Rhizopus nigricans, the common black bread mold. Seen here is a zygospore



Clayton State University Biology, http://a-s.clayton.edu/biology/biol1108L/Fungi/fungi.htm

Asexual reproduction can be accomplished in a number of ways. A bacteria cell does not have a nucleus and reproduces in a process called *binary fission*, in which DNA replicates and cellular material merely splits into two equal parts, each containing half of the original cellular substance. This is just about the simplest and fastest means of reproducing. In yeast, a cell will form part of its material into a small *bud*, which is a replica of the parent sell. The bud breaks off and grows into a new yeast cell which in turn grows buds. Sponges can reproduce by *fragmenting*.

Sexual reproduction always involves two parent organisms, though in some cases it is difficult to tell which is which! For example, *Rhizopus nigricans,* the common black bread mold, has hyphae or strands which are called plus and minus because no one can tell the difference by looking. However, the mold can tell, since when these two strands meet, the mold forms a big black sexual spore called a zygospore.

There are many interesting ways in which organisms have adapted for sexual reproduction. Some fish change sex when necessary. In some cases, the male has the babies and in some cases, he alone raises them. One fish even keeps the babies in his mouth to protect them from predators until they are big enough to escape on their own. The many strategies organisms have evolved to keep and attract a mate and protect their young make very interesting reading. The end result of all this effort, however, is successful propagation of the species.

There are even some organisms, certain sponges, algae, and bread mold, that can use either asexual or sexual reproduction, depending on environmental conditions.

Investigation
Moldy Bread

Next time you get a piece of moldy bread, don't throw it away right away. Get a magnifying glass and see if you can see the zygospores. They look like miniature peppercorns. Better still, look at it through a microscope.

Geometric Growth

Belgian mathematician, Pierre Verhulst (1804–1849), while working on the theory of numbers, became interested in social statistics. In 1845, he took up the challenge of creating an equation which simulated population growth and to describe, in a mathematical way, the forces which tend to prevent population growth from increasing without limit. He was able to predict that an upper limit of the Belgium population would be 9,400,000. Belgium population in 1994, over 150 years after Verhulst's prediction, was 10,118,000, so his prediction looks pretty good. [Source: http://www-gap.dcs.st-and.ac.uk/~history/Mathematicians/Verhulst.html] It may be worth it to have a look at his math.

To start Verhulst knew he would have to greatly simplify the patterns of growth. His most rudimentary population equation is a great deal like the armadillo activity you did in Chapter 2. As an illustration of Verhulst's principles, imagine a population of ladybugs, which are sexually reproducing organisms. We will use the following symbols:

P = Population (number of ladybugs)

n = year, starting with year 1.

For example, if we start with
year 1 as 2003 (n = 1), then
for year 2004, n = 2,
for year 2005, n = 3, and so forth.

http://home.ptd.net/~insect/ladybug.html

P_n (pronounced "P" sub "n") is the population (of ladybugs) in year **n**.

Verhulst reasoned as follows:

1. The size of next year's population depends on the number of parents this year. Using our symbols as shorthand, we could express this as

   P_{n+1} depends on P_n.

2. Populations increase by a certain factor every year. For example, suppose that our imaginary ladybugs double their number each year. 100 insects in year one means 200 insects in year two. In shorthand this is:

   P(next year) = 2 times P(this year).

   and in the shortest shorthand (mathematically)

   $$P_{n+1} = 2\,P_n$$

(In real life, of course, insects lay thousands or millions of eggs. Most of the eggs are eaten by birds or spiders, or destroyed by other natural causes. The assumption that the population doubles every year is despite all of these complex events.)

Investigation

Verhulst's Population Equation

The easiest way to visualize how populations vary in time is to make a graph. The horizontal axis represents time, and the vertical axis represents the number of individuals in the population. If we start with 100 insects (**P_1 = 100)** , in year two, there will be 200 insects (**P_2 = 200)**.

Make a graph of the equation

$$P_{n+1} = 2\,P_n$$

using the graph points tabulated in the table at right.

n	P_n	P_{n+1}	=	$2P_n$
1	P_1 = 100	P_2	=	2(100) = 200
2	P_2 = 200	P_3	=	2(200) = 400
3	P_3 = 400	P_4	=	2(400) = 800
4	P_4 = 800	P_5	=	2(800) = 1,600
5	P_5 = 1,600	P_6	=	2(1,600) = 3,200
6	P_6 = 3,200	P_7	=	2(3,200) = 6,400

The factor 2 was put into the equation because we imagined that each year our insect population would be double the year before. But, said Verhulst, if we want to think about all kinds of increases we must recognize that they all don't double each year. Some grow faster, some slower. Instead of the number 2 let's put in a letter which will stand for the number, or factor, that we multiply by the previous year's population to get this year's population. Let's call G the population growth factor. Our equation now looks like this:

Pn+1 = G * Pn

Now make a table and graph showing how the population would change over six years if G= 3. On the same graph show how the population would grow if G=1, and if G= 0.5.

Question 3.1. How do these different growth factors affect the population?

Question 3.2. What would the population be after ten or fifteen years for these different growth factors?

The method of calculating the population for each year based on the previous year is called iteration. The invention of calculators and computer spreadsheets has made the process of iteration a very popular and easy way to calculate population growth. If you have access to these tools, you may want to calculate the population for a wide variety of growth factors and lengths of time.

The result of our calculation is called a geometric progression. Geometric population growth can occur in special situations where the food supply is plentiful and there is space for organisms to grow. An example is the growth of bacteria in a petri dish. They can double their population in an hour. The population explosion of rabbits in Australia is another example. But no population can grow geometrically forever. Limitations always exist. The petri dish has just so much space. There are limits to the rabbit food supply. The first years on Goat Island were those of geometric growth for the population of goats because the small population of goats had not yet discovered the limits to their growth.

Carrying Capacity

Carrying capacity of an ecosystem is the size of the population that can be supported indefinitely with the available resources in that ecosystem. By now, you may realize that limits to population growth include scarcity of food, disease, and predators. In order to reflect the idea of carrying capacity in a population equation, we need to use a different way of representing a population. One way of doing that is using the idea of *normalized population*. This concept is a bit like when you say to your friend, "On a scale of one to ten, how would you rate the quality of that spaghetti sauce." Except that a *normalized* spaghetti sauce scale is not one to ten, but zero to one (as a decimal number), with one being the best sauce and zero being the most awful imaginable sauce.

Until now the population in a given year, $\mathbf{P_n}$, represented the total number of individuals in a population. We now define the normalized population ρ_n as a decimal number between 0 and 1 that represents the size of the population in relation to the carrying capacity of the environment.

> *ρ is the Greek letter rho and was chosen here because of its similarity to our letter p.*

If $\rho_n = 1$, the population is at its maximum size; it has reached its carrying capacity. If $\rho_n = 0$, there are no individuals left at all.

$\rho_n = 0.5$ means that the number in the population is just half of the maximum that can be supported in that area.

$\rho_n = 0.25$ means that the population has reached one quarter of its maximum size.

A More Realistic Population Equation

Verhulst noticed that when a population was small it grew very rapidly. But when the population neared its carrying capacity, it grew slower and slower. The first few generations of goats on Goat Island had lots of food and no predators. But when their numbers grew, they competed with each other for food and many starved. A large population of goats could support a large population of predators, so many goats were killed each year. And if disease struck when the population was high, many would die. To reflect this idea, Verhulst realized that he would have to include a factor which would slow the population growth as the population came closer and closer to the carrying capacity. He found success with the term as a "population limiting" term:

$$(1 - \rho_n)$$

Remember that ρ_n varies between zero and one, where 1 is the population that has reached carrying capacity. The table at right shows how this *population limiting term* changes as the normalized population changes.

ρ_n	$(1 - \rho_n)$
0.00	1.00
0.25	0.75
0.50	0.50
0.75	0.25
1.00	0.00

The term gets smaller when the population gets bigger. Verhulst inserted the term into the population equation as follows:

$$\rho_{n+1} = G \rho_n (1 - \rho_n)$$

In words, the equation says that the normalized population next year, ρ_{n+1}, is equal to the growth rate, **G**, times the normalized population this year, ρ_n, times the population limiting term $(1 - \rho_n)$.

The population equation does not exactly predict what the population will be in real life. Its purpose is to simulate the general patterns of population growth, and then to see what insights this can give us. In this next activity you will see if the equation can produce the various population patterns that we observed on Goat Island.

Investigation

Playing with the Population Equation

This is a perfect job for a computer or a scientific calculator which doesn't mind doing simple calculations over and over again. If you have a computer available or a TI82 or above that has a spreadsheet program, you can write an equation which will automatically produce graphs for different growth rates and different starting populations.

We've worked out two examples in this chart. In both examples we start with a normalized population of .1 (10% of the carrying capacity), and calculate the normalized population each year for a total of twenty years. Example 1 assumes a population growth factor of 2.0. Example 2 assumes a population growth rate of 3.0. Since these numbers represent the normalized population, they might represent hundreds, thousands, or even millions of individual goats, rabbits, or insects. Graph the two examples.

Compare the graphs. Describe how the populations which grow at these two different rates change over time. How do they apply to the population of goats on Goat Island?

Year	Population 1	Population 2
n	$2.0\ \rho_n\ (1 - \rho_n)$	$3.0\ \rho_n\ (1 - \rho_n)$
1	0.100	0.100
2	0.180	0.270
3	0.295	0.591
4	0.416	0.725
5	0.486	0.598
6	0.496	0.721
7	0.499	0.603
8	0.500	0.718
9	0.500	0.607
10	0.500	0.715
11	0.500	0.611
12	0.500	0.713
13	0.500	0.614
14	0.500	0.711
15	0.500	0.616
16	0.500	0.709
17	0.500	0.618
18	0.500	0.708
19	0.500	0.620
20	0.500	0.707

Mathematical Models and Real Systems

Let's now go back and apply what we have learned to what occurred on Goat Island and what happened with the lynx and the hare. Before the dogs were introduced to Goat Island the population of goats fluctuated up and down as the goats periodically ate their food supplies, suffered famine, then recovered as their food grew back. Each oscillation would have taken several years. This pattern can be modeled by the population equation if n is taken to be certain number of years rather than one year, and if the growth rate is taken to be about 3.0, or a little larger.

The addition of the dogs presented a new variable to the goat population. The goat population grew at a slower rate because some were killed by dogs, and because the goats were not free to forage for food wherever they wanted. The number of dogs controlled the goat population and the number of goats controlled the dog population. In a few years their populations settled down to certain population sizes—the carrying capacity of the island for goats and for dogs. The goat population would be better modeled by the population equation with a growth factor around 2.0, or a little larger. Would the lynx and hare follow the same pattern as well?

All species, however, do not mindlessly propagate in large numbers. Many have strategies which limit the amount of competition for the resources needed by the organism to survive.

Investigation

Optimum Number of Offspring

Using books on animal behavior, or the internet, find a strategy used by an organism in the wild to preserve its resources so it can raise the optimum number of offspring. Speculate on what might happen to this organism if it stopped using this strategy.

The Story of Lonesome George

Why Is "Lonesome George" Lonesome?

Lonesome George is a giant tortoise that comes from the island of Pinta in the Galapagos Islands. Many years ago, there were thousands of tortoises on the island, but some people put some goats on the island and those goats ate all of the food that the tortoises were using for their food. Now, there are no more tortoises on that island. George is the last tortoise from that island that is still alive!!! (And he's about 80 years old!!!) When he dies, his species of tortoise will become extinct. He is "lonesome" because he is the last one of his species. All of his friends are gone. That's sad, isn't it?

Lonesome George now lives at the Charles Darwin Research Station in the Galapagos Islands where scientists are trying to help him make baby tortoises with tortoises from another island. You can still visit him there with your family.

Story from http://www.darwinfoundation.org/misc/kids/5.html

Question 3.3. After reading the story of Lonesome George, can you name one possible advantage that asexually reproducing organisms would have over those that reproduce sexually? Why, then, has sexual reproduction even evolved?

Many people would answer that it is pleasurable to the organism. That certainly is often the case with humans, but with other organism such as sponges or jellyfish, that is probably not the answer.

Photo by Eloise Farmer

Advantages and Disadvantages of Sexual Reproduction

Brainstorm with classmates some ideas about the advantages of sexual reproduction—other than pleasure—and report back to the class. (Hint: check into Darwin's tenets, below.)

If you came up with the idea that variation in offspring is an advantage, then take it a step farther and explain why variation in offspring could lead to better survival.

Can you come up with some disadvantages of sexual reproduction? (Hint: think of the cheetah or the blue whale, or Lonesome George, the tortoise).

Now how about advantages and disadvantages of asexual reproduction? Here you need to consider a scenario where every single organism is an exact copy of another, and there is a sudden environmental disaster. What then?

Make a table like the one below in preparing a report to the class:

	Asexual	Sexual
Advantages	1.	1.
	2.	2.
	3.	3.
Disadvantages	1.	1.
	2.	2.
	3.	3.

Populations and Change Over Time

Charles Darwin read "An Essay on the Principle of Population" written by Thomas Malthus, an English clergyman back in 1798. Although the essay was about human populations, Darwin applied it to populations of all living organisms when writing his tenets on natural selection.

Darwin's Tenets:

"It is interesting to contemplate an entangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent on each other in so complex a manner, have all been produced by laws acting around us. These laws, taken in the largest sense, being Growth and Reproduction; Inheritance which is almost implied by reproduction; Variability from the indirect and direct action of the external conditions of life and from use and disuse; a Ratio of Increase so high as to lead to a Struggle for Life, and as a consequence to Natural Selection, entailing Divergence of Character and the Extinction of less-improved forms.

"Thus, from the war of nature, from famine and death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly follows. There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, and from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved."

(Charles Darwin, 1859, On the Origin of Species, p. 489-490)*

To paraphrase, Darwin's theory consisted of four (4) basic tenets*:

Inherent Variability: Individual members of any population vary in their outward appearance or phenotype. Variation is an essential characteristic of populations.

Overpopulation and Limited Resources: Populations produce more offspring than can be supported by the resources in a given area.

Competition and Survival of the Fittest: Those individuals that are more efficient at competing for the limited resources will survive. These individuals possess the best adapted characteristics

Differential Reproduction: The more efficient (adapted) individuals will have more efficient (adapted) offspring and in greater numbers.

Question 3.4. In which of Darwin's tenets are limiting factors listed? Write the limiting factors stated by Darwin.

Question 3.5. How did Darwin use the exponential growth of populations to develop his ideas?

Question 3.6. Do you agree with Darwin's ideas about populations? Explain your reasoning.

Density-dependent and Density-independent Factors

What we have been discussing up to now in this book is what is called "density-dependent" factors. These are factors which depend upon the numbers of individuals competing for the same resources. They can be between different species needing the same resources (interspecific), such as the tortoises and the goats, or between members of the same species competing for space or food (intraspecific) such as two finches needing the same nesting territory. Many organisms regulate their reproductive activity based on whether there is enough food, enough space, or enough mates. Competition and predation are two key factors in keeping most populations of organisms well below their carrying capacity.

Blue-footed booby. Photo by Eloise Farmer

Competition among species for survival takes many forms. Over fifty per cent of lion cubs will starve to death during their first year. Each weaned cub must compete with the adults for the meat of the kill. Only the most aggressive and strongest cubs will survive. How does this fit in with Darwin's tenets?

In the case of the blue-footed booby, only one chick of the two in the nest will survive, since one chick will kill the other as soon as it is able. Albatross babies must actually starve for a while to lose weight so they can fly, and some are starved so long that they die. Many animals guarantee a dependable food supply by defending space. They will use behavioral rituals like head-bobbing, or brilliant color, or even pick up stones as a threat.

Other animals, like gibbons or birds, sing in defense of their territory. In some animal groups, such as wolves, only the dominant male and female mate. If others in the pack want to mate they must leave the pack and start their own. Some species divide up the territory, so that some finches will feed on the ground, while others feed in bushes or trees. The famous study of "Darwin's finches" has shown us that different species can evolve from common ancestry by using this strategy of dividing up the territory as well as the types of food utilized.

Cactus. Photo by Eloise Farmer.

Plants also use strategies to maintain their territory and compete with other species. Some plants, like the black walnut, put out chemicals that prevent other plants and even their own offspring from growing near enough to crowd them. Other plants grow thorns or hairs which aid in survival, while still others enlist animals to defend them in return for food, as the acacia tree enlists ferocious ants in its defense. Other plants cooperate with fungi growing in the soil to help them get more nutrients.

Density-independent limits on growth are not influenced by the number of individuals in the population. Fires, floods, and other weather-related variations are all density-independent limiting factors. Again, those organisms most able to survive catastrophes will be successful. Some organisms even depend on an occasional catastrophe for their reproduction. Black locust seeds and bristle pine seeds must be exposed to high temperatures before they can germinate. Therefore, forest fires are necessary for the reproduction of these species.

Investigation

Research on the Internet

Before you begin, list at least 4 density dependent factors for which you will search. Give specific examples for each which you have found by searching on the Internet and tell how each affects population growth.

List at least 4 density independent factors. Give specific examples for each which you have found by searching on the Internet and explain how each has affected population growth.

Putting together some things we have learned:

- Populations can grow very quickly if there is nothing to slow their growth.
- Exponential growth causes awesome increases in populations.
- Populations may grow very quickly, but with normal checks and balances their growth will level off as carrying capacity is reached. Populations can decline and even reach extinction if they have no defense against an alien species.

Now it is time to find out how all of these factors can determine the evolution of life on Earth. Upon reviewing Darwin's tenets, you can see that if only some individuals survive, these individuals will be the founders of future populations. What determines which individuals are most fit to survive?

Genes, Populations, and Evolution

If a population survives, traits which are optimum for survival are more likely to prevail in a population. Over long periods of time, populations will change, or evolve, as more and more members of the group retain these desirable survival traits. In fact, recent studies by field ecologists have shown us that these changes occur more rapidly in some populations than previously thought. Some animal groups must adapt rapidly to environmental stress or completely disappear. The organisms with the traits most useful for survival and reproduction will prevail.

> "Evolutionary biologists continue to test the theory of evolution by natural selection and, though refined, no one has put forth compelling evidence to reject natural selection. It was not until the rise of modem genetics that this process was understood as the cause for certain traits remaining in the population while others disappeared."
>
> *(J. B. Losos and K. deQueiroz, 1997, Darwin's Lizards, Natural History 106 (11):38.*

One can determine whether or not evolution is occurring in populations by studying the genes in a population. If a population is in equilibrium, or not evolving, its genetic composition will show no change over time. However, if a population is evolving, the frequency of the genes in a population will change.

A population that is in equilibrium has the following characteristics:

- a population must be large
- there must be no immigration or emigration
- there must be no natural selection occurring
- mating is random

Under such conditions, evolution will not occur. Obviously, in nature, unless a population is isolated and unable to move about, these conditions do *not* occur. Population ecologists use sampling techniques which can tell them how much a population is changing or evolving. The study of population genetics can alert an ecologist to the impact of various limiting factors on a population. The activity Mark-recapture (end of Chapter 2) is one method of finding out what is happening to populations. Another would be one which counted lynx and hare pelts.

Investigation

Earlobes: A Study of Human Gene Frequencies

All of us have genes in pairs. We received one gene of each pair from each of our parents. For example, whether or not you have lots of room for earrings is determined by the pair of genes you received from your parents. In the case of earlobes, you can see below that you may inherit either attached or unattached earlobes.

Free ear lobes (dominant trait) vs. **Attached Earlobes** (recessive trait)

Free earlobes are those that hang below the point of attachment to the head.

Attached ear lobes are attached directly to the side of the head.

Photos by Eloise Farmer.

Pair up with another student and look at each other's earlobes. Once that is done, count all the students in your class who have the dominant gene (free earlobes, and all of those with the recessive attached earlobes. If a student has attached earlobes, then they have two recessive genes, often represented by two small letters. Let us use "aa" for attached earlobes, and a "A" for unattached earlobes. Why can't we just write two big A's for a person with attached earlobes? (Remember, everyone has two parents!) Is it possible for someone to have one big A and one little a? How could that happen?

In a large population, if you have two possible genes for earlobes, either attached or unattached, and if the attached only shows when there are two of them, what are the chances of a person having attached earlobes? Here are the possible combinations: AA, Aa, aA, or aa. In the first case, the gene given by each parent to the child is a "A". In the second case, the mother gives the child a "A" and the father gives the child a "a". In the third case, the father gives the child a "A", while the mother provides a "a". In the fourth case, both parents provide a "a". Therefore, the chances of getting a "AA" , a "Aa", or a "aA" are .75 or 75%, while the chances of getting a "aa" are only 25%.

Count as many students in your school as you can.

Once you are done, you should make a data table like the one below:

Column I	Column II	Column III	Column IV
Name of trait	Number with trait	Frequency of Trait (Column II ÷ total)	Expected Frequency (3 to 1)
aa Attached Earlobes			.25
AA or Aa Unattached Earlobes			.75
Total Number Counted			1.00

Now you have the gene frequency of a population. If the numbers counted were large, if no one moves in or out of the school, if no genes are mutated or none of the group is selected out by disease or disaster, and mating is random in the community, then the population frequencies should stay the same year after year. How likely do you think this is? Any frequency change means that evolution, or change over time, is occurring.

The Big Question

Now, the big question. Do humans follow the same population rules that govern other organisms?

Obviously, we do not easily go out and mark and recapture humans for study.

We can, however, see if the gene frequencies of human populations are changing. Here is an example of a recent study.

The data below, collected during the 1940s and 1950s, showed the relationship between the percentage of the population found to have a sickling gene (i.e., individuals with one sickle cell gene and one normal gene) and the frequency of individuals with sickle cell disease, meaning they have two genes for the disease):

Location	%Sickle-cell Trait	% Sickle-cell Disease
Africa	20	2
United States*	6	4

http://www.nslc.wustl.edu/courses/Bio296A/allen/sicklecell/part3/ biogeography.html

Question 3.7. Why has the sickle cell frequency declined in the United States? (Hint: how much malaria do we have occurring in the US?) Look up the relationship between the sickle cell gene and malaria. Discuss this with your teacher.

Dunkers of Pennsylvania: The Dunkers are a small religious sect which was established in the middle of the 18th century by 27 families who emigrated from Germany. After arriving in the United States, they were essentially genetically isolated because they generally did not reproduce with people in nearby populations.

A number of traits are either more or less frequent in the Dunkers than they are in Germany or other populations in Pennsylvania. Blood type A (I^AI^A or I^AI^O) has been observed in 60% of the Dunkers, but occurs in 40-45% of Germans. Similarly, the blood-type allele M occurs in 65% of the Dunkers and 54% of Germans. In contrast to these data, the blood-type trait I^B has nearly been lost, occurring in only 2.5% of the Dunker population.

http://www.tulane.edu/~eeob/Courses/Heins/Evolution/lecture12.html

Investigation

Dunkers Blood Types

Make a table for the Dunkers' blood type frequency similar to the one on sickle cell trait. Why have the Dunker gene frequencies stayed the same? Search on the internet to find out more about the Dunkers and come up with a hypothesis.

From these studies, can you hypothesize whether or not the human population is evolving? What does it take for populations to change their gene frequencies? Which population may do better over the long run, the sickle-cell group, or the Dunkers? Give reasons for your answers.

Much discussion is now occurring regarding whether or not genes should be manipulated to better serve human needs. What impact do better health care and the cure of disease have on human populations?

Investigation

Health Care and Population Growth

Search the Internet to find a correlation between health care and population growth in humans. Has it made a difference?

"That's a good technical solution, Thok.
The only problem is, we can't breathe!"

For new material relating to this chapter, please see the GSS website "Staying Up To Date" page: http://lhs.berkeley.edu/gss/uptodate/8pop. We invite you to send us new articles for the "Staying Up To Date" web page for this chapter. Articles may be from local newspapers, magazines, websites, or other sources that you think would be of interest to classrooms around the country. To send us articles please go to the link http://lhs.berkeley.edu/gss/uptodate/newarticle.html and find the "Submit New Article" button.