

DemographyLab

Background

Ecology includes a broad and fascinatingly complex range of topics related to the interrelationships between living organisms and their nonliving environments. Ecologists classify these interactions into a hierarchy based on the complexity of interrelationships that occur between living (**biotic**) components, and nonliving (**abiotic**) components (such as soil, water, weather, temperature, pollutants, light, and nutrients). At the simplest level of this hierarchy, organismal ecology focuses on the interactions between individual organisms and the environment. Individual organisms can be grouped into a **population**, which is defined as a group of individuals of the same species that occupy and are adapted to a particular geographic area at the same time. Populations of different species that inhabit a particular area at the same time are grouped together into **communities**. All of the organisms and nonliving components within a given area are classified as an **ecosystem**. At the highest level in this hierarchy, all ecosystems on Earth are part of the **biosphere**.

Population biologists are interested in the many factors that influence the size, health, growth, and distribution of a population. The scientific study of the factors that affect population size and growth over time is called **demography**. Two important factors that affect population growth are population **density** and the spacing or **dispersion** of individuals within the geographical boundaries in which a population lives.

Ecologists have established a variety of methods for estimating the density of a population and for studying density-dependent and density-independent factors. Depending on the abundance and wariness of a species, sampling techniques can include signs of an organism such as nests, droppings, tracks, and reduction of specific forage.

Ecologists who study dispersion are particularly interested in the patterns of spacing that many species exhibit within a particular geographical range. Interactions of individuals within a population and the influence of abiotic factors will affect the spacing patterns of individuals within their geographical range. These patterns can involve grouped (clumped), evenly spaced (uniform), and unpredictable (random) dispersions of organisms.

Both density and dispersion of a population are directly influenced by three primary factors: (1) reproduction or birth rate (fertility), (2) death rate (mortality), and (3) migration. In migration, the addition of an organism to a population is known as immigration while the loss of an organism from a population is called emigration. Population growth remains the same (zero population growth; ZPG) if the number of individuals that join a population, either by immigration or by birth, is equal to the number of individuals that leave a population by either emigration or death. If the number of births and immigrating organisms exceeds the number of deaths and emigrating organisms, then population growth occurs. The reverse is true when a population is on the decline. In addition, both the birth rate and death rate of a population

rely on the age of its members (**age structure**). For example, a population that has a higher percentage of older individuals that may be past their reproductive prime compared to younger individuals is likely to show a higher degree of mortality compared to birth rate.

Given the aforementioned factors and additional factors such as generation time and sex ratios, biologists, demographers, and sociologists can use statistical data and computer programs to predict future changes in the size of human populations. When studying populations of other organisms, factors such as competition and predator-prey relationships must also be considered.

Human population growth has wide-reaching impacts on human health and the infrastructure, resources, and carrying capacity of a given geographic region. The importance of understanding human population growth is exemplified by the following quote from the opening chapter of *The Population Explosion*, by Paul and Anne Ehrlich: “The population of the United States is increasing much more slowly than the world average, but it has more than doubled in only six decades; from 120 million in 1928 to 240 million in 1990. Such a huge population expansion within two or three generations can by itself account for a great many changes in the social and economic institutions of a society. It is also very frightening to those of us who spend our lives trying to keep track of the implications of the population explosion.”

DemographyLab is designed to simulate how different demographic factors may influence human population size and growth, although most of the factors that you will consider in this lab have similar effects on the population growth of other animals and plants.

References

1. Kates, R. W. “Sustaining Life on the Earth.” *Scientific American*, October 1994.
2. Raloff, J. “The Human Numbers Crunch.” *Science News*, June 1996.
3. Ehrlich, P. R., and Ehrlich, A. H. *The Population Explosion*. New York: Simon & Schuster, 1990.

Introduction

DemographyLab will help you learn about the current demographics for human populations of seven countries. You can use this lab to investigate how population size, population structure, mortality rate, and fertility rate influence the size and growth of human populations over time. For simplicity, the effects of immigration and emigration are not included in DemographyLab. However, because the demographic data presented in this lab have been determined from actual current demographic statistics for each country, the population changes you will examine may simulate future demographic realities for these seven countries.

Objectives

The purpose of this laboratory is to:

- Demonstrate fundamental primary demographic factors that influence human population size and growth.
- Simulate the effects of demographic factors on human population growth.
- Use demographic models to predict future changes in human population growth.

Before You Begin: Prerequisites

Before beginning DemographyLab you should be familiar with the following concepts:

- The four major levels of study in ecology based on the complexity of interactions between organisms and their environment (see Campbell, N. A., Reece, J. B., and Mitchell, L. G., *Biology 5/e* and Campbell, N. A., Reece, J. B., *Biology 6/e* chapter 50).
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- Important determinants of organism distribution within the biosphere (chapters 50 and 52).
- The definition of demography and examples of important factors that affect human population size and growth (chapter 52).

Assignments

For your ease in completing each assignment, the background text relevant to the experiment that you will perform is *italicized*, instructions for each assignment are indicated by plain text, and questions or activities that you will be asked to provide answers for are indicated by **bold text**.

The following assignment is designed to help you become familiar with the operation of DemographyLab.

Assignment 1: Getting to Know DemographyLab: Demographic Differences Among Nations

Countries differ with respect to population numbers, age structure, and fertility and mortality rates. These differences are caused by many factors, such as geographic size and location, level of economic development, government policies, and religious practices. The following exercises are designed to help you understand the influence of some of these factors on the size and growth of human populations.

1. Select the Population Structure view on the input screen of Demography Lab. Using the Country popup menu, examine the estimated 1998 population structure of each nation.

Can you classify the population structures into two general patterns? Consider what you know about each of these countries. What do you think is the biggest factor distinguishing these two groups of nations?

2. Select the Fertility Rate view on the input screen of DemographyLab. Using the Country popup menu, examine the estimated 1998 fertility rates of each nation. (Try changing the scale to magnify these differences.)

Do you see any trends for the fertility rates compared to the population structures? What are they?

3. Select the Mortality Rate view on the input screen of DemographyLab. Using the Country popup menu, examine the estimated 1998 mortality rates of each nation.
 - a. **Do you see any general similarities and differences between nations? Provide possible reasons for these similarities and differences.** *Hint:* To help you determine differences in mortality rates, click on the Run button and choose the Vital Rates view. Export the data from this table to your notebook by clicking on the Export Data button. Click OK to export data to your notebook as text.
 - b. **Do you see any trends for the mortality rates compared to the age structures? What are they? Which age groups show the biggest differences in mortality rate among nations?**
 - c. **Do you see any differences in the mortality rates of males compared with females for any of the countries? What are they? What might account for some of these differences?**
4. *Most scientists believe slower population growth is beneficial to the sustainability and quality of human life on Earth. In the mid-1980s, the World Health Organization (WHO) Task Force on Contraceptive Vaccines specifically designated a large sum of research funds for scientists to design novel contraceptive methods that could be used to slow population growth. The WHO identified certain developing nations of Africa, South America, and Asia, including India, as populations that could benefit from new contraceptive approaches (such as contraceptive vaccinations) that could easily be administered on a large scale.*

Select the Fertility Rate view on the input screen of Demography Lab. Examine the fertility rates for Nigeria and India.

- a. **Develop a list of differences and similarities that appear for the fertility rates of each country. Why might each country show these differences and similarities?**
- b. **Can you think of common societal issues shared by India and Nigeria that might account for the similarities?**

- c. **Provide possible explanations for why it may be difficult to establish contraceptive techniques in these countries that would have a significant impact on population growth.**

Assignment 2: Historical Effects on Demographic Changes

For a variety of reasons, populations sometimes undergo periods when there are large changes in reproduction or mortality. For example, desert plant populations may produce a large cohort of seedlings following heavy rains, or a fish population may experience a peak in reproduction due to a La Niña weather year. Human populations exhibit similar demographic changes. For example, the history of human civilization includes many well-documented events, such as plague (Black Death of medieval Europe) and famine (Irish Famine of 1845–1847), that produced pronounced demographic changes in human populations. The following exercises illustrate some examples.

1. *In the United States, a peak in reproduction occurred after World War II from the late 1940s through the early 1960s; this produced the “baby boom” generation.*

Select the Population Structure view on the input screen of DemographyLab. Using the Country popup menu, examine the estimated 1998 population structure of the USA.

Can you find the baby boomers?

Click the Run button and choose the Population Structure view. (You may wish to use the Scale button to make the differences in age structure more obvious.) Use the arrow buttons at the top of the view to advance the population structure forward in time. Follow the baby boom generation as they age. Compare the population in 1998 with the projected population for 2028.

What do you think the social consequences will be for these changes? Provide at least three examples of social consequences that will result from these changes.

2. *In 1980, China’s government adopted a policy advocating one child per couple.*

Select the Population Structure view on the input screen of DemographyLab. Using the country popup menu, examine the estimated 1998 population structure of China.

Can you see evidence of China’s population policy?

Click the Run button and choose the Population Structure view. (*Hint: You may wish to use the Scale button to make the differences in age structure more*

obvious.) Use the arrow buttons at the top of the view to advance the population structure forward in time by 5-year increments.

What changes will occur in China's population structure as a result of its policy?

3. *At the same time the baby boom was occurring in the United States, there was a "baby bust" in post-World War II Japan, when fertility rates decreased.*

Select the Population Structure view on the input screen of DemographyLab. Using the Country popup menu, examine the estimated 1998 population structure of Japan.

Can you see evidence of the postwar baby bust? What has happened to fertility rates in Japan in recent years?

Click the Run button and choose the Population Structure view. (You may wish to use the Scale button to make the differences in age structure more obvious.) Use the arrow buttons at the top of the view to project the population structure forward in time.

If you were a demographer, what advice or concerns would you have for Japan's government in planning for the future?

Assignment 3: Stable Age Structure

If vital rates remain constant, what will happen to population structure over time? This question is investigated in the following exercises. Keep in mind that although we are working with a human population model, the same principles will apply for any population of plants or animals

1. Set the number of years to 300 and simulate the population growth of each of the seven nations by using the Population Structure view as described in the previous assignment. Examine the pyramid plots as they change every five years.

What happens to each population over the long term? How do the plots differ for each nation? Which nations show the biggest changes over time? Speculate about why these changes occur.

2. *If a population's age structure stops changing from year to year, demographers say that it has a stable age structure. Two typical patterns of stable age structures are pyramids and inverted pyramids.*

Compare the stable age structures and intrinsic growth rates of the seven countries. Do you see a pattern? Develop a hypothesis about the relationship between growth rate and the shape of the stable age structure.

Test your hypothesis by selecting a nation and altering its fertility rates. Can you create the pyramid and inverted pyramid patterns?

3. *Suppose the human immunodeficiency virus (HIV), the virus that causes acquired immunodeficiency syndrome (AIDS), were to mutate into an airborne virus that could easily be transmitted by casual contact with infected individuals.*

Choose any country, decrease its 1998 population size based on mortality due to this new strain of HIV, and simulate the population for 300 years. Note: Be sure to change mortality rates for both males and females.

What effect, if any, does this have on the long-term age structure? Examine the pyramid plots as they change every five years.

Repeat the procedure for alteration in the population structure by decreasing the population of sexually active males and females in the 20-year-old categories. Examine the pyramid plots as they change every five years.

Formulate a hypothesis to describe how changes (increases and decreases) in fertility rate will affect the long-term population structure. Do the same for changes in female mortality rates. Design and carry out simulations to test your hypotheses.

Assignment 4: Zero Population Growth

Zero population growth (ZPG) is of special interest to demographers and ecologists because population numbers will remain constant over time. The net reproductive rate (NRR) is a good indication of how close a population is to ZPG, because it represents the average number of daughters that a woman is expected to produce in her lifetime. ZPG is attained when NRR equals one; every woman is exactly replacing herself. (It is not necessary to consider males, from a demographic point of view, since only women bear children.) If $NRR > 1$, a population will increase and if $NRR < 1$, a population will decrease. A value of $NRR = 1$ corresponds to an intrinsic growth rate of zero. ZPG is investigated in the following exercises.

1. Simulate each country's population growth for 300 years and look at the time series plot of the population size. **Form a hypothesis about which countries are closest to ZPG (that is, $NRR = 1$). Compare the NRRs of the seven countries. How well did you do with your hypothesis?**
2. Choose a country with a high population growth rate (for example, Nigeria) and modify its fertility rates until you get as close as possible to ZPG.

What types of changes to fertility rates were necessary to attain ZPG? Reset fertility rates back to their default values and change female mortality rates until you get as close as possible to ZPG.

What types of changes to female mortality rates were necessary to attain ZPG? Do the same changes to male mortality rates achieve ZPG? Why or why not? Given the types of changes necessary to achieve ZPG, what realistic options are open to a nation to reach ZPG?

Assignment 5: Demographic Momentum

Even though a country may have fertility and mortality rates that give a zero or negative growth rate, population size may increase for many years before leveling off or decreasing. Demographers call this demographic momentum. The following exercises illustrate this phenomenon.

1. Simulate population growth in China for 100 years.

How long does it take for the population size of China to begin decreasing? Does any other country exhibit a similar phenomenon?

2. **Choosing a country with a negative growth rate, try modifying its 1998 population structure so it will exhibit demographic momentum.**
3. **Propose a hypothesis about what causes demographic momentum. Test your hypothesis by altering the default values of any country and simulating it in DemographyLab. Design an experiment to illustrate negative demographic momentum (a decrease in population size followed by a long-term increase).**

Assignment 6: Dependency Ratios

From a social and economic point of view, human demographers are concerned about the proportion (ratio) of workers in a population to those who are economically dependent on these workers, either directly or through taxes such as Social Security. The following formula, called the dependency ratio, is used as a summary statistic.

$$\text{Dep. Ratio} = 100 [(no. \text{ children under } 15) + (no. \text{ elderly over } 65)] / [no. \text{ persons } 15 - 64]$$

We look at the dependency ratio in the following exercises.

1. **Referring to the Tabular Data view of DemographyLab, compute the 1998 dependency ratio for each of the seven countries. Compare and contrast each nation. Which component, children under 15 or elderly over 65, is most important for determining the dependency ratio for different nations?**
2. **Compute the dependency ratio for the USA for the years 1998, 2003, 2008, 2038. What happens to the dependency ratio as the USA enters the next century? Which component, children under 15 or elderly over 65, is most**

important for determining the changes in the dependency ratio? What are possible social or economic implications of these changes?

- 3. What do you think will happen to the dependency ratio for a country over the long term if vital rates remain constant? Test your hypothesis using DemographyLab.**

Assignment 7: Sex Ratios and the Marriage Squeeze

The sex ratio for a population or age group is the ratio of the number of males to females. A related concept is what demographers call the marriage squeeze. On average, husbands tend to be a few years older than their wives, so the ratio of men in one age group to women in the next younger age group is an indication of whether or not there is a balance in the number of potential spouses for either sex. The following exercises illustrate these concepts.

1. Choose any nation and compute the 1998 sex ratio for each age group.

How does the sex ratio change with age? At what age does the sex ratio become close to 1? Repeat the computation for a second country. Are the trends similar?

2. **Propose a hypothesis to explain differences in sex ratio with age. Test your hypothesis by altering the vital rates of a country and looking at the sex ratio of different age groups after 100 years of population change.**
3. Using the Tabular Data view for the USA for 1998, compute the ratio of men 20–24 to women 15–29 to women 20–24 and so on, until you reach the last age group.

At what ages is the marriage squeeze most pronounced? Compute the USA 1998 sex ratios for each group. Would the marriage squeeze be less of a problem if, on average, spouses were of the same age?

4. Choose and country and modify the fertility rates so that population growth is a large positive value, a large negative value, and ZPG. For each case, simulate 100 years of population growth and examine the sex ratio and marriage squeeze at the end of the 100 years.

Is there an effect of population growth rate on sex ratios? Is there an effect of population growth rate on the marriage squeeze? Can you explain these results?

Assignment 8: Exponential Population Growth and Decline

If vital rates remain constant, what will happen to population numbers over time? This question is investigated in the following exercises. Keep in mind that although we are working with a human population model, the same principles will apply for any population of plants or animals.

1. Set the number of years to 300 and simulate the population growth of each of the seven nations. Examine the Time Series graphs on both the linear and logarithmic scales.

What happens to each population over the long-term? These simulations assume that current fertility and mortality rates remain unchanged. Is this possible? Why or why not?

2. *Exponential growth is described by the following exponential equation:*

$$\underline{N}(t) = \underline{N}(0)\exp^{rt} \quad \text{equation (1)}$$

where $\underline{N}(0)$ is the total population size at some arbitrary initial time, $\underline{N}(t)$ is the population size t years in the future, and r is the intrinsic growth rate of the population.

What will happen if r is a positive value? What will happen if r is negative? How do the Time Series plots compare with the Growth Rate parameter listed in the summary Stats? Do the populations seem to follow this equation over the long term?

If we take the logarithm of both sides of the exponential growth equation, we get:

$$\log \underline{N}(t) = \log \underline{N}(0) + rt \quad \text{equation (2)}$$

What would you expect from a plot of the logarithm of population size over time? How the case for $r > 0$ differ from $r < 0$? Examine the Time Series plots of population size versus time for each of the seven nations with the Logarithmic Scale option selected. Do the logarithmic plots of the long-term population values agree with your predictions?

3. *Let's use equation (1) to predict population size. Choose any nation and simulate population growth for 300 years. Using the Intrinsic Growth Rate parameter, try predicting the 2298 population size using the population sizes for 1998, 2098, and 2198. (Set r equal to the intrinsic growth rate, set $\underline{N}(0)$ to the population size for 1998, 2098, or 2198, and use $t = 100, 200, \text{ or } 300$ years.) Since the intrinsic rate is displayed to three significant figures, your predictions will be limited to three significant figures of precision.*

How well does the exponential growth model do with the three predictions? Which predictions are most accurate? Can you explain why this might be the case? Try another nation to see if you get similar results.

4. *Another measure of population growth is the doubling time, if $r > 0$ or half-life, if $r < 0$. The doubling time is the number of years it takes the population to double in numbers. The half-life is the amount of time it takes the population to decrease by 50%. The doubling time or half-life is given by the equation:*

$$T = 0.6931/|r| \quad \text{equation (3)}$$

where $|r|$ refers to the absolute value of the intrinsic growth rate. If $r > 0$, T is a doubling time; if $r < 0$, T is a half-life.

Compute the doubling times or half-lives for each of the seven nations. What are the political and social implications of these values?

5. Choose any country, alter its 1998 population size, and simulate the population for 300 years.
What effect, if any, does this have on the long-term population growth rates? Repeat the procedure for alterations in the population structure, fertility rates, and female and male mortality rates. Come up with a hypothesis for how changes in each of these factors affect the long-term population growth rates. Design and carry out simulations to test your hypotheses.
6. **Try deriving equation (3) from equation (1). [Hint: Set $N(t)$ equal to $2N(0)$ or $N(0)/2$.]**

Assignment 9: Group Assignment

Given your observations on the differences in the demographic variables considered in the previous assignments, work in groups of four or five students to develop a hypothesis to consider which nations will exhibit positive long-term growth rates and which ones will have negative long-term growth rates. For each nation, click the Run button to simulate 100 years of population change and look at the Stats view of the output. The last three statistics are all measures of long-term population growth rates. How well do your rankings agree with the rankings of the actual measures of growth rate? Compare and contrast the summary statistics for the different nations.

Pick one of the nations that exhibits a positive long-term growth rate and discuss the following:

1. **Should this nation take measures to limit its population size? If so what should those measures be? For example, should a nation limit immigration?**
2. **Should this nation use either voluntary or mandatory contraceptive programs to limit population size?**

3. **Identify environmental, health, and other quality-of-life issues that may arise as a result of long-term population growth.**
4. **Prepare a plan that could be used reduce population growth. If you were the leader of this country, how would you justify your plan to the citizens of your country?**

Once you have discussed these topics within your group, compare your responses to those of other groups of students who evaluated the same country.