Chapter 12

Population

Chapter Objectives:

1. Describe the historical change in population and its expected growth in the future.
2. Describe the philosophies of Thomas Malthus regarding population.
3. Define exponential growth and doubling time.
4. Discuss the relationship between growth rate, birth rate, and death rate.
5. Define life expectancy and discuss its relationship to gender.
6. Discuss factors that affect the ability to predict human population growth.
7. Describe how industrialization affects the population growth of a country.
8. Describe how the demographic profile of a country affects its future population growth.
9. Describe measures that can be taken to stabilize the world's population, including family planning and birth control.

Introduction

On October 31, 2011, Earth welcomed a newborn child that brought our planet's population up to the 7 billion mark, according to the U.N. Population Fund. While this is an astoundingly large number of people to have on Earth, what makes this figure even more remarkable is that as recent as 1960, there were only a little over 3 billion people on the planet. For the last century, we have been averaging a rate of increase in the world's population that would double it about every 50 years. If this continues, it means that we will have close to 12 billion people on the planet by the middle of this century. By some people's estimates, this would amount to complete environmental devastation if it were to happen.

While the world's population has been growing at a staggering pace, it has not been a homogenous, global growth. Some areas of the world are not experiencing any growth at all. In fact, some areas of Europe are actually experiencing a decline in their population. Other areas of the world offset these declines by growing at a rapid clip. Both of these situations bring about their own unique set of problems. In this chapter, we will look at the factors that affect population and discuss how global population might change over the coming century. Before we do that, we need to define a few terms and formulae that are important to this discussion.

Demographic Basics

Demography is the study of populations, whether they be human, plant, or animal. Human demography is that sub-discipline that looks specifically at humans, and it relies very heavily on statistics, geography, psychology, and sociology. Like any area of study, it has its own unique terms that, while they exist in everyday language, describe something very specific that might be different from their everyday definitions. For example, demographers have several terms that they use to describe how a population can change. The terms that they use are birth rate, death rate, natural growth rate, growth rate, replacement-level fertility, and total fertility rate. The first two of these are quite simple and are what you would expect.

Birth rate - Commonly used as the crude birth rate, this is the number of births per 1,000 people within a certain population.

Death rate - Commonly used as the crude death rate, this is the number of deaths per 1,000 people within a certain population.

The formulae for determining crude birth rate and crude death rate for a given time interval, such as a year, are as follows:

$$\frac{\text{total births in a population}}{\text{total population}} \times 1{,}000 = \textbf{crude birth rate}$$

$$\frac{\text{total deaths in a population}}{\text{total population}} \times 1{,}000 = \textbf{crude death rate}$$

The next two terms are not quite as obvious, but are easily explained. The **natural growth rate** is just the crude birth rate minus the crude death rate, i.e. the number of people who are born minus the number that died per 1,000 people. Many people who read this think "Well, that is obvious. The growth is just how many new babies are born minus the number of people who die." However, this neglects the effect of immigration and emigration, and it is why this term is called the natural growth rate. The term **growth rate** includes the effects of immigration (people entering a country) and emigration (people leaving a country) and is defined as the natural growth rate plus the migration rate (immigration minus emigration).

To explain this another way, let us look at an example. Suppose that a country of 100,000 people has 15,000 births in a year in which 10,000 people die. At the same time, 540 people move into the country to settle and 780 leave the country to live in the Arctic tundra of Canada. With these values, the terms we have defined so far are:

birth rate = (15,000/100,000) x 1,000 = 150

death rate = (10,000/100,000) x 1,000 = 100

natural growth rate = 150 - 100 = 50

migration rate = (540 - 780/100,000) x 1,000 = -2.4

growth rate = natural growth rate + migration rate

growth rate = 50 + (-2.4) = 47.6

Thus, this country has a total growth rate of 47.6 people for every 1,000 citizens that it has. At this rate of growth, it would take 21 years for the population to double, as 47.6 people per year times 21 years is equal to 1,000 people (actually, 999.6 people, but there is no such thing as .6 of a person).

We must recognize that this way of expressing the growth is a little different than some other ways of expressing it. In some instances, we express the growth as a percentage of the population. It is easy to convert between the two, as all one needs to do is to divide the crude growth rate by 1,000 people and then multiply by 100%. In our example, this is

percentage growth = (47.6 people/1,000 people) x 100%

percentage growth = 4.76%

We need to note, though, that if the population continues to grow at this percentage, then the amount of time to double will not be 21 years; it will be less. The reason for this is quite simple, as growth at a fixed percentage means that each year sees greater overall growth than the year before. In our example, growth at 4.76% means that 4,760 people are added to the country the first year. The next year, the number of people who are added will be 4.76% of 104,760, or 4,762. While this is only 2 people more, this will continue to grow in succeeding years, which means that doubling will be reached sooner, as we will show below.

Replacement-level fertility: This is the average number of births that couples in a population must have in order to keep the population stable. At first glance, one might think that this number is 2.0, as it is a simple matter of each member of a couple replacing himself or herself. However, not all children will survive until they reach puberty when they could legitimately take part in producing the next generation of children. For this reason, replacement-level fertility (RLF) is higher than 2.0 and depends greatly upon the infant and childhood mortality rates of a country. In more developed countries, this number is approximately 2.1, while in developing countries with poor medical care, the number can be as high as about 2.3.

Total fertility rate: This is the average number of children a woman in a population has in her lifetime. Excluding immigration and emigration from the equation, if the total fertility rate exceeds the replacement-level fertility in a population, then the population is growing. If the total fertility rate is below the replacement-level fertility, then the population is reducing. Germany in 2014, for example, had a total fertility rate of 1.4, which is well below the RLF. With this rate, the population of Germany should be shrinking fairly rapidly; yet, it is almost stable with a very small decline. The reason for this is in two parts. First of all, Germany is experiencing a net immigration influx of 1 person per 1,000 people, which is causing a small increase to offset the low TFR. The second reason is due to population inertia, which a country experiences even as it is goes below RLF. This can happen for a number of reasons, but is usually due to the large number of kids who were born when the TFR was greater than the RLF getting older and maturing past the age of childrearing. It can take a country up to 30-40 years past the date at which TFR goes below RLF before its population actually begins to level off and decline because of this.

An excellent website for finding statistics related to population: http://www.geographyiq.com

Doubling Time and the Rule of 70

As we stated above, there is a difference between growth at a constant amount and growth at a constant percentage rate. The constant amount growth always adds the same number of people each year, while the constant percentage rate growth increases the number of people that are added each year. This growth at a constant percentage rate is called exponential growth because it is exactly explained by an exponential function. Because of this relationship, we can very accurately define how long it will take a population to double in size by performing some simple mathematics (which we will not do here, but will leave either to your professor or to a good economics textbook to explain). It turns out that the doubling time is approximately 70 years divided by the percentage growth in a given years.

> Example: Ougadougastan has a population of 20 million people that is growing at 2.0% per year. If it continues to grow at this same rate every year, how many years would it take for the population to reach 40 million?
>
> 70/2.0 = 35 years

As you can see, this is much shorter than the projected 50 years it would take if the population only grew at 400,000 each year, which is 2.0% of the original 20 million.

Growth Factors: John Eli Miller vs. Jules Francis Pratte

What causes growth in a population? There are numerous factors that affect growth, some of which limit it and some of which cause it to increase. One can divide most of these factors into two categories: basic necessities for life and sociological/psychological factors of life. An example of the first of these is the availability of food and water. If there is not enough of these two things, the population will starve or die of thirst, which will cause the total number of people to decrease. If there is more than enough of these two, then the population can grow, although it does not have to do so. Another example would be the availability of clothing and shelter, without which people will be left to the elements and possibly die of exposure. While the basic necessities for life often set upper bounds on the population, they do not necessarily cause a population to grow, as we can see from the following example.

After the basic necessities are met, there are numerous factors that will cause a population to grow, be stable, or shrink. For instance, take the example of the John Eli Miller family. Miller was a farmer born in the mid 1800's who had 5 children, 61 grandchildren, and 338 great-grandchildren alive when he died. Some environmental textbooks use this example to show that a population can bloom quickly, i.e. it can experience exponential growth.

Some of these textbooks forget, though, to illuminate into what type of society John Eli Miller and his progeny were born when discussing this growth. Miller and his descendants were farmers that were raised in an agrarian community in a developing country (the U.S. was not a fully developed country in the 1800s). His example is not like one would find from an industrialized community in a fully developed country like America, Europe, and

Japan today or even a semi-industrialized community like that found in a developing country.

As a contrary example, let us look at the Jules Francis Pratte family. Jules was born in the late 1800's in a small town near St. Louis. Like John Eli Miller, he had a fairly large brood of children (7, with 6 surviving childhood). However, Pratte's six adult children only produced 14 grandchildren, many fewer than the 63 of Miller. These 14 grandchildren only produced 21 great-grandchildren, which is a far cry from the 341 great-grandchildren of Miller. As Figure 1 shows, while Miller's family growth is exponential (increase by same percentage), Pratte's is an example of linear growth (increase by same amount).

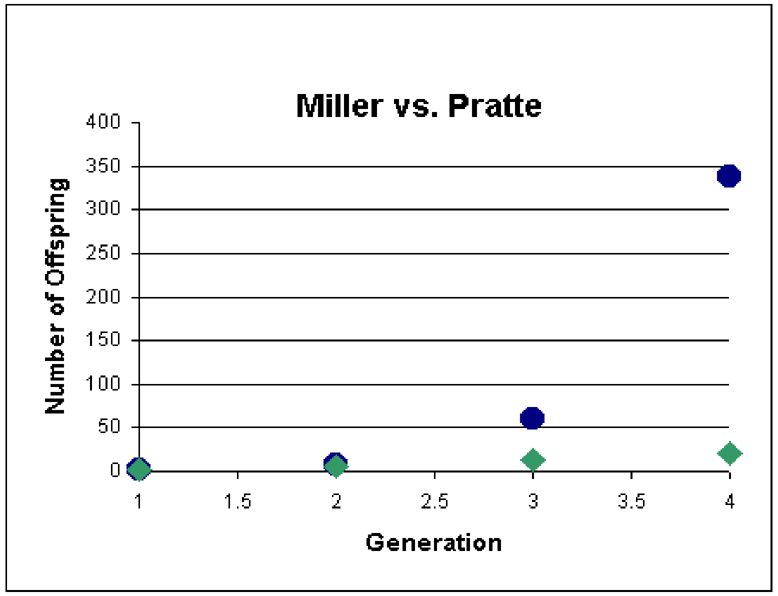

Fig. 1: Miller (circles) versus Pratte (diamonds)

The difference is that all members of Pratte's family have had occupations in the industrial or professional sector of the American economy. This makes a profound difference in the population's growth rate. In an agrarian society, especially one without modern fossil-fuel driven machinery, every child you have is another free field hand. Children usually start working on the farm at an early age, and will be responsible for producing more food than they eat. This results in a net income for the family. In an industrial society with strict child labor laws, every child you have is another mouth that you have to feed that does not bring in any additional income. In a very real sense, every child you have will be a serious drain on your financial resources. This societal difference accounts for a large portion of the difference that you will find in the population growth rates in the two different kinds of cultures even though most industrialized societies have a longer life span.

Other Growth Factors

While the exact reason a person has a child will vary, it usually falls into one of several categories. The most obvious reason is a biological imperative to procreate, i.e. an innate desire to have children. This is a very strong reason, and it should not be neglected. However, there are additional reasons that people have children that go beyond this base desire, and can cause growth even when other factors to stop having children become strong. For example, some people have babies for societal reasons such as to carry on the family name. Anybody who has ever had their mother or father ask them when they are going to get married, settle down, and have kids knows this reason very well. This drive to carry on the family name is very strong and can often overcome drastic measures not to have children. China's "One Baby Policy" in which couples pay fines and lose health benefits if they have more than one child in urban environments has resulted in a disparity in the number of males and females. Some families have resorted to abortion or giving their child up for adoption if they find out it is a female in order for them to have a male child to carry on the family name. This has led to a situation where there are almost 10% more males under the age of 30 than there are females. Even with the shorter lifespans of males, this ratio might never reverse, and could be a tremendous societal problem for China in the future.

Some people have children for religious reasons. For some faiths, it is a matter of not doing anything to prevent having children. For instance, the Roman Catholic faith believes that it is immoral to use artificial means to prevent conception. For other faiths, there are actual dictates to have more children, as the more children there are, the more souls there will be available to go to a good place in the afterlife. These reasons tend to spawn larger families than are needed to exceed RLF.

These two reasons, along with the basic instinct to procreate, are the three strongest reasons for growth in the U.S. and some other developed countries. In developing countries where growth rates are the largest, there are often many other very important reasons. For instance, a lack of education and economic opportunity for women has been very strongly correlated to increased birth rates. Women in these situations generally do not have information about birth control. The lack of economic opportunities further compounds the problem as their only "job" is to be married and have children. This is a double-edged sword. If they are able to find employment, then there is pressure not to have more children, as each child means that they will have to be away from work, and thus, decrease the earnings for the family. If there are no economic opportunities available, then the only way for women to provide for themselves later in life is to have children who will take care of them as they age. Hence, if there are economic opportunities, there is pressure to decrease family size while a lack of them causes pressure to increase it.

Another very important factor in determining growth is the age at which women get married. The average woman has about 30 years in which she can have children. If she starts having children at an early age, then she is much more likely to have a lot of children. This factor is also tied to economic opportunities and education, as these two things often delay the age at women get married.

Developed Countries and Immigration

When George Washington started the first Presidency of the United States of America, he was governing less than 4 million people who occupied an area of 2,300,000 square kilometers[1]. It was an agrarian society, with 95% of the population living on farms and only 5% in cities or towns of more than 2,500[2]. There was plenty of land, and a vast array of natural resources, just waiting to be tapped.

Today, we live in a country of over 300 million people[3]. While we are one of the major food producers in the world, it is no longer due to us being an agrarian society. Today, most people live in towns and cities, with less than 25% of the population living in rural areas. And even though we have grown to a physical size of over 9.8 million square kilometers, our population density has increased from the 2 people per square kilometer of Washington's day to almost 30 people per square kilometer today.

From where did all of these people come? The increase in territory that occurred over that time did increase the number of people in the U.S. from the simple fact that there were already people living there. We have also expanded by immigration, with wave after wave of people entering this country to find new life and new opportunity. Neither of these, though, accounts for the largest segment of growth. Both put together still account for less than 80 million people.[4] The largest sector of the population is here due to birth.

This same thing is true of most countries. Immigration is often a small factor to the overall growth of the country. However, it can have a powerful effect on the growth of a country, as the birthrate can be greatly affected by it. In the early days of the U.S., the growth from births came from all sectors of society. However, as the case study at the end of this chapter shows, the growth of a developed country can come mostly from the descendants of immigrants.

Predicting the Future

For all of its futuristic stylings, the television show Star Trek (the original series, not the recent travesties wrought by J.J. Abrams) was, like most science fiction, a commentary on the state of society at the time it was written (late 1960's). One of the more famous episodes of that series was the one entitled The Mark of Gideon, which dealt with a planet that was so overpopulated that people did not have anywhere to sit down. At the time of the show, the Earth's population was at about 3.5 billion, and was increasing at an incredible rate. The effects of such a large population on the environment were beginning to become abundantly clear, and people had begun to wonder just how many more people the Earth could hold. This Star Trek episode is just an example of the times, as there were a number of television shows, movies, and books at that time (ex. Soylent Green) that foretold of an ominous future if we did not begin to do something about curtailing the world's population.

All of these shows were predicated on predictions made by demographers at the time of what the world's population would be at some point in the future. This was nothing new, as each generation has done this, sometimes with startling accuracy, and sometimes missing the mark completely. For example, in 1798,

Thomas Malthus, an English demographer and economist, predicted that the world's population would one day outstrip mankind's ability to feed itself, and that this would be reached when the population was 1 billion people. Of course, Malthus could not foresee the introduction of the internal combustion engine and the production of artificial fertilizers that have increase our capacity to feed. However, his basic premise of the factors that stop a population from growing is called Malthusian catastrophe.

We now have more than 7.2 billion occupants of Earth, and we are continuing to grow. As previously stated, at current rates of growth, we will reach 12 billion by the year 2050. However, this prediction is most assuredly wrong, as it relies on everything going along just as it is. As Malthus shows us, one cannot assume this. In order to make a more sophisticated prediction, we need to look deeper at the data to see what it is telling us. One tool that aids in that regard is the age structure diagram, also known as the population pyramid.

Demographic Profiles

While it is sometimes called a population pyramid, an age structure diagram does not have to have a pyramid shape. What this diagram actually shows is the distribution by ages of females and males within a certain population in graphic form. Figure 2 shows a bar graph for the United States population arranged so that populations are grouped by sex in 5-year increments. The length of each bar from the vertical line represents the population total for that particular group. The centerline separates the females on the right from the males on the left. This particular diagram shows that we have nearly the same number of people in each age group up to about 50 years old, where it begins to decrease. This is an example of an almost stable population.

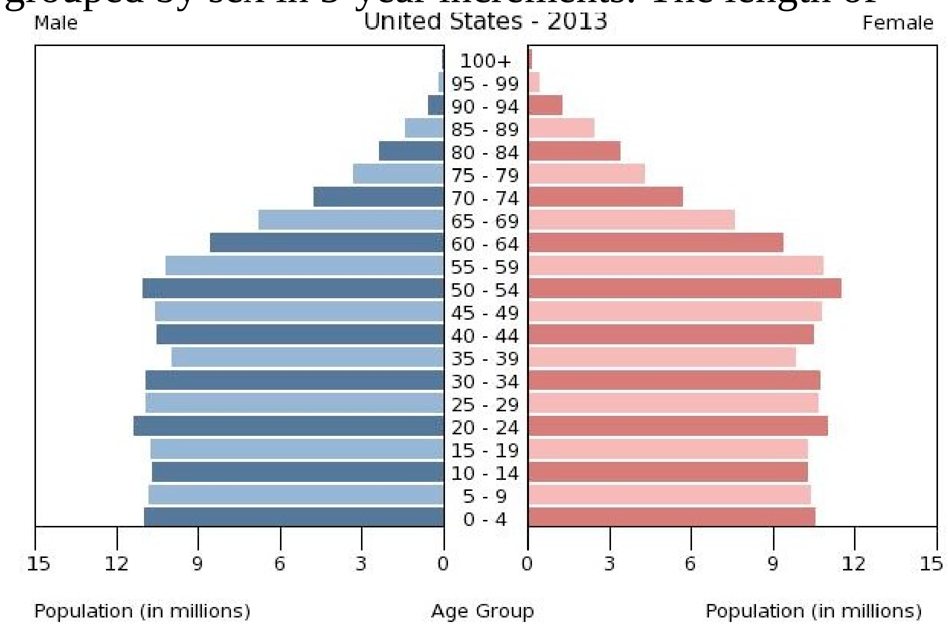

Fig. 2: age structure diagram for the U.S.

Age and Sex Distribution

By looking closely at the age structure diagram, one will notice slightly more boys in the younger age groups than girls (nature actually produces 2.1 males for every 2.0 female babies in humans); however, the ratio tends to reverse in the upper age groups, as females tend to outlive males. Many countries have a female majority at older ages as a result of the longer life expectancy for females. In the United States, this ratio change is clearly shown in the table below showing age and sex distribution in the census year 2000. Notice that at about age 35-40, the majority changes.

AGE	NUMBER		
	BOTH SEXES	MALE	FEMALE
TOTAL POPULATION	316,668,567	156,051,262	160,617,305
UNDER 18 YEARS	75,765,736	38,697,386	37,068,350
18-64 YEARS	197,005,926	98,231,023	98,774,903
18-24 YEARS	30,824,312	15,728,949	15,095,363
25-44 YEARS	83,702,009	42,254,081	41,447,928
45-64 YEARS	82,479,605	40,247,993	42,231,612
65+ YEARS	43,896,905	19,122,853	24,774,052
MEDIAN AGE (YEARS)	37.2	35.9	38.5

As stated before, in China, the age and sex distribution is a cause for alarm. Efforts there to reduce the birth rate have apparently contributed to a prominent male majority. Since the early 1980's, policies by the government to reduce population growth in the most populous country in the world has resulted in many parents actively trying to have a male child if they are to have only one child. Cultural traditions there tend to cause parents to see a male child as more beneficial to the family than a female child; therefore, a striking imbalance has resulted between the numbers of males and females. There are concerns that the imbalance could lead to instabilities as these boys mature into men and find that there are not enough women to marry.

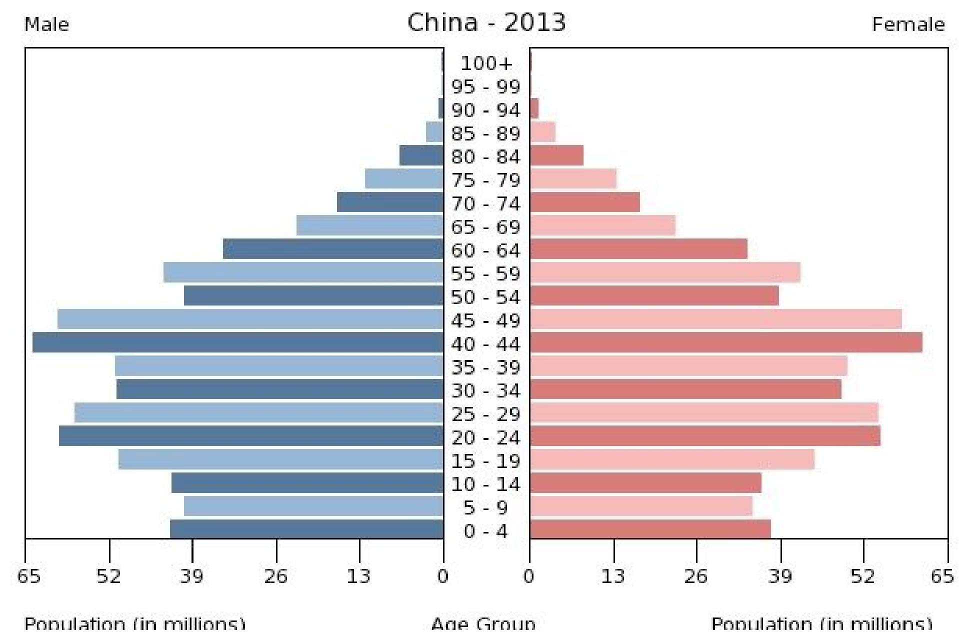

Fig. 3: age structure diagram for China

Constructing and Interpreting an Age Structure Diagram

With age and sex distribution data from a certain population (you can retrieve this for any country using the U.S. Census Bureau's International Database), it is easy to construct an age structure diagram. All one has to do is to plot each value for the number of males or females in a given age bracket as a horizontal bar, with older brackets being found higher on the diagram. The reason for doing this is that this diagram gives a very visual representation of what is likely to occur to a country in the future barring a major catastrophe. This can be interpreted just from the shape of the diagram. For example, if the diagram shows a pyramidal shape, then one can expect a rapid rise in population. If the diagram shows a generally straight up and down shape except for the older age groups, a stable population is thus revealed. If the diagram shows a top-heavy shape, then a decline is forecast for that population.

Why is this? Figure 4 shows the age structure diagrams for Mexico, Iceland, and Japan from the year 2000. The different shapes seen in the diagrams reflect different population characteristics. The diagram for Mexico shows the unmistakable pyramidal shape that will cause ever-increasing numbers of births. This is because there are much larger numbers of children in the 0-4 age bracket than there are in the 20-24 one. Barring a major catastrophe, most of these children will make it to the 20-24 year range, meaning that there will be many more people of childrearing age 20 years from now than there are today. Unless they drastically cut back on the total fertility rate, this means that there will be even more children in the 0-4 age bracket 20 years from now than there are today. Thus, the total population of the country will grow, as all age brackets will have more people in them then than today.

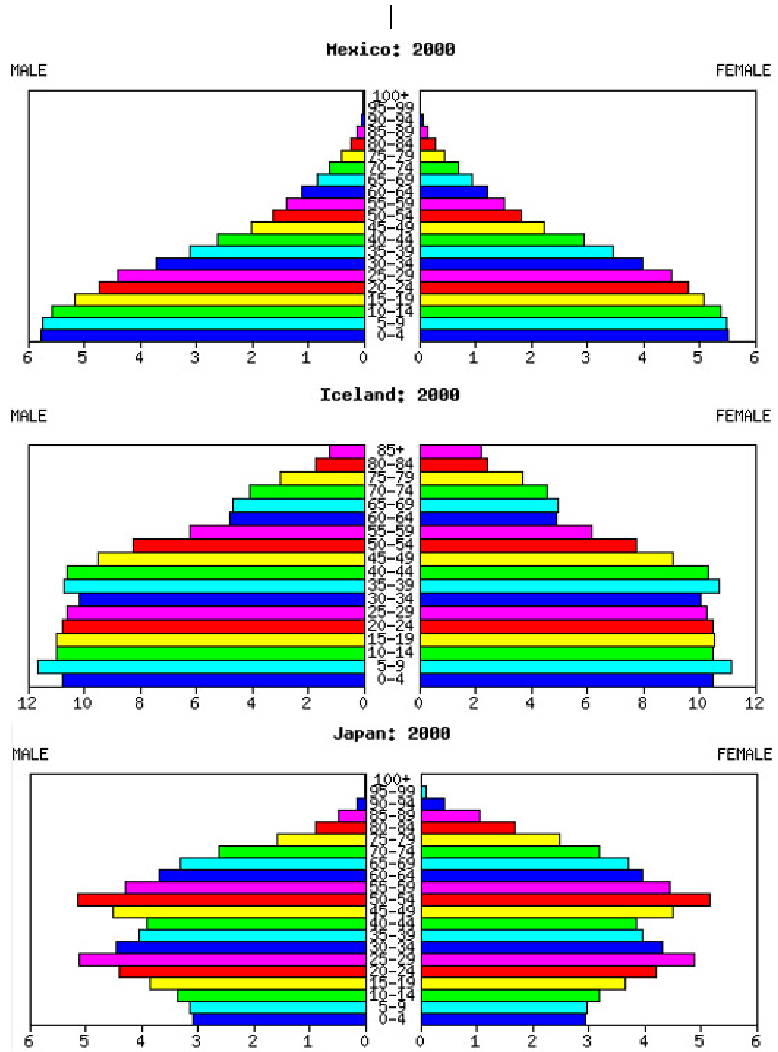

Fig. 4: Age structure diagrams for Mexico, Iceland, and Japan (U.S. Census Bureau)

Japan’s diagram shows the opposite of this. In it, you should note how pre-reproductive age groups (0 - 14 years) have smaller populations than the reproductive age groups (15 - 44 years). Thus, unless the total fertility rate increases there, Japan will have even fewer kids in the 0-14 age group 20 years from now than there are today, which means that the population will decrease. Of course, this will present different problems for Japan, as a shrinking younger age group means that there will be fewer and fewer younger workers to support the elderly. One way to rectify this is to increase immigration at the lower age groups, which will bring more workers into the country. While this will provide the necessary workers to take care of the elderly, it can be problematic to implement in a homogenous population like that found in Japan or Italy, another country that has this same problem.

Iceland, on the other hand, shows a more stable population. Except for the post-reproductive groups (45+ years), the populations for the age groups extend generally the same lengths. There is a slight bulge outward, but if you account for infant and childhood mortality, the number of children in the 0-4 age range that make it to the 20-24 age range should be just about the same as the number of adults in that age range today. This means that there should be little to no growth, with the possible exception of people living longer and increasing the raw numbers by essentially extending the diagram upwards.

Which of these growth trends is best? That all depends upon on a variety of factors such as the total population of the country, how much land it has, how much food it can grow to support it, how much energy it uses, and how big of a footprint the average citizen has. In an ideal situation, the population would only be as big as the amount of land and resources it has to sustainably support it. Currently, from a global perspective, we do not have this, as our modern lifestyle is not sustainable. We use far greater resources than what we create in most countries. In developed countries, this is because we use many more resources per capita (cars, electricity, food, etc.) even though we have relatively small populations. In developing countries, it is because of the relatively large populations even though each citizen uses very few resources.

If we are going to survive past the end of this century, this will have to change. Worldwide, we currently produce enough food to feed about 7.5 billion people. As we stated at the beginning of this chapter, Earth has over 7.2 billion now, and we are increasing at a rate of slightly less than 100 million per year. If we are not able to continue to increase the amount of food that can be produced, we will begin to run into food crises within this decade. While much of the media attention is on the environmental damage we are doing to the planet, this issue receives very little press in the U.S., although it does get press outside of America. Soon, though, the confluence of a lack of food and a greatly changing climate that limits our ability to produce food might change this.

Discussion Questions

1. How many people are on Earth right now? How long will it take for this number to increase by 1 billion at the current growth rate?

2. The Total Fertility Rate for the U.S. is below 2.0. Why is the population still increasing?

3. Go to the U.S. International Database site and pull up the data for China. Do you notice anything unusual about it?

4. Go to the U.S. International Database site and pull up the data for South Africa. Do you notice anything unusual about it?

5. How does increasing the employment opportunities for women in a country decrease its birth rate?

References

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3. http://www.census.gov/main/www/popclock.html, October 16, 2004.
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Case Study

Karen’s Story by Matt Laposata

It had been a bad day for Karen Christini. After enduring paralyzing rush-hour traffic following a miserable day at work, she was ready for some hard-earned relaxation. But no such opportunity availed itself, for tonight was decision night. While in college, Karen had joined the Sierra Club, a national organization dedicated to environmental preservation, with her boyfriend Andrew. Andrew lasted less than a semester, but her Sierra Club membership was still going strong as she entered her mid-thirties. And on this chilly April night it was the Sierra Club that demanded her attention.

The Sierra Club's budget, political lobbying, policy stances, and preservation efforts are directed by a group of 15 elected board members. Board elections were typically not national news, but this election was anything but typical. For some time, the membership of the Sierra Club had been divided on the issue of U.S. immigration and its relationship to human population growth. In 1998, a movement within the organization put forth a proposal to replace the Sierra Club's historic "no position" stance on U.S. immigration with one that advocated reductions in the number of immigrants admitted to the United States to reduce environmental impacts associated with growing populations. Sixty percent of members rejected the proposal and the Sierra Club continued advocating controls on global human population growth with a neutral policy towards U.S. immigration.

In the following years, however, three members that advocated a stance towards reduced immigration were elected to the board. There were five open seats this year, so the election of five reduced-immigration candidates would give the group a majority on the board and the power to steer the organization. Karen had not come to a decision on her votes and the ballot had to be in the mail tomorrow. As she had done many times over the past few weeks, she sat at the kitchen table hunched over her Sierra Club ballot and began running her fingers through her hair, trying to use the rhythmic motions to force a decision from her head. She reviewed the major points of view one last time, hoping yet another analysis would yield a conclusion.

On the one hand, she thought, the advocates of reduced immigration had a point. The United States absorbs around one million legal immigrants and several hundred thousand illegal immigrants a year, and these immigrants have average birth rates about double that of U.S.-born citizens. Unlike most industrialized nations, the population of the United States is expected to grow from around 292 million (in 2003) to about 422 million in 2050 - and up to 70% of this growth is attributable to immigration. Given the high consumption lifestyle in modern America, this population growth will lead to increased impacts on the local and global environment, exactly the things the Sierra Club aims to reduce. Proponents of immigration reduction also argue that international immigration causes talented and educated citizens of developing nations to leave for industrialized countries, slowing the industrialization that leads to lower birth rates. They further contend that immigration has economic costs when wages earned in the United States are sent home by immigrant workers.

But, she thought, those that support current immigration policies make several convincing arguments. They argue that while international immigration increases the U.S. population, it slows the growth of the global human population as the children of immigrants have birth rates like that of other U.S. born citizens - rates likely far lower than those in the immigrant's native country. Immigration proponents also claim that immigration improves cultural awareness in the United States, thereby promoting environmental sustainability in these countries through foreign aid initiatives.

Immigration advocates say that the United States should always be a "safe harbor" for victims of human rights abuses or armed conflict around the world. They also claim that immigrants infuse skills and labor into the workforce and improve the economy of the host country. Karen's family was a classic example. Her grandparents emigrated from Sicily to the vibrant Italian-American community in New Haven, Connecticut, in the early 1900s and prospered in subsequent generations through a dedication to education and hard work.

Karen sat back in the chair and sighed heavily. The epiphany, the tiebreaker, or the revelation she sought had once again eluded her. This wasn't going to be easy. She sat forward, propped her elbows on the table, stared at her ballot, and began running her fingers through her hair.

Appendix A

The following tables are from General Geology of the Western United States - A Laboratory Manual by Bassett and O-Dunn, pp. 6-18, Peek Publications, Palo Alto, CA, 1980.

MINERALS WITH METALLIC LUSTER				
Name & Composition	Hardness	Color	Streak	Features
Graphite C	1	silver-gray	black	marks paper, greasy feel, light in weight, one perfect cleavage
Molybdenite MoS2	1 - 1 1/2	bluish-gray	greenish-gray	soft, flexible, shiny plates (one perfect cleavage); often with hexagonal outline, marks paper
Galena PbS	2 1/2	silver-gray	black	cube or octahedron cystals, cubic cleavage, bright luster, heavy
Native Copper Cu	2 1/2 - 3	copper-rose	copper-rose	greenish-gray surface film where altered; heavy and malleable; rare crystals, usually in compact masses, often has a pale green surface coating of malachite
Native Gold Au	2 1/2 - 3	gold, white-gold, rose	gold, white-gold, rose	color varies with impurities; extremely heavy; may be gouged or sliced with a knife; dissolves in aqua regia; rare small crystals and dendrites, nuggets in sedimentary deposits
Native Silver Ag	2 1/2 - 3	silver-white	silver-white	tarnishes dark gray or black; irregular fracture; very heavy; sectile; may occur as dendrites (see Gold) and wires in calcite and other minerals
Bornite Cu5FeS	3	rose to brown	gray-black	iridescent alteration coating common; brittle conchoidal fracture; “peacock ore”
Chalcopyrite CuFeS2	3 1/2	brass-yellow	greenish-black	often tarnished iridescent or chalky greenish-blue; brittle, fairly soft; usually massive; conchoidal fracture
Pyrite FeS2	6	light brass-yellow	black	occurs in cubes with grooved faces, and pyritohedrons with 5-sided faces; called “fool’s gold”; much lighter than true gold; poor cleavage; fragile
Magnetite Fe3O4	6	black	black	magnetic, granular or octahedral crystals common; no cleavage
Specular Hematite Fe2O3	6	shiny steel-gray	dark red	glittering flakes or wavy sheets; streak is distinctive; tendency to flake obscures true hardness

MATERIALS WITH NON-METALLIC LUSTER				
Name & Composition	Hardness	Col	Streak	Description
Talc $Mg_3Si_4O_{10}(OH)_2$	1	white, pale	pearly	extremely soft, soapy feel; impurities may increase hardness; one perfect cleavage; often in scaly masses
Kaolinite	1 - 2 1/2	white, cream	earthy, dull	soft, powdery texture; smells earthy when damp; usually in clay-like masses with dull appearance
Native Sulfur S	1 1/2 - 2 1/2	yellow	resinous, greasy	low hardness; light in weight; detectable sulfur odor; often in well-developed blocky crystals, or as fine coating on volcanic rock
Gypsum $CaSO_4$ ~$2H_2O$	2	colorless, white, sometimes	vitreous to pearly	soft; one perfect cleavage; selenite is clear and may occur in large (1 m) sword-like crystals, or in bladed groups incorporating sand and known as “desert roses”, satin spar is fibrous, alabaster is massive
Borax $Na_2B_4O_7 \cdot 10H_2O$	2	white	vitreous	short, stubby crystals; conchoidal fracture; brittle, soft; also in earthy, massive forms
Chlorite	2	light to dark green	vitreous to earthy	micaceous habit; one good cleavage; flakes are not elastic like mica
Carnotite $K_2(UO_2)_2(VO_4)\ 3H_2O^2$	2	canary yellow	dull, earthy	usually a coating or powder in sandstone or other rock; imparts a strong yellow color; vary radioactive; hardness indeterminate
Cinnabar HgS	2 - 2 1/2	cinnamon red	adamantine to dull	color diagnostic; may appear almost metallic or in earthy, pinkish-red masses; scarlet streak; toxic
Biotite Mica $K(Mg,Fe)_3\ AlSi_3O_{10}\ (OH)_2$	2 1/2	dark brown,	vitreous	occurs in six-sided mica “books” and as scattered flakes; peels into flexible greenish-brown sheets along one perfect cleavage; black mica
Muscovite Mica $KAl_2(AlSi_3\ O_{10})\ (OH)_2$	2 1/2	colorless, pale	vitreous to pearly	occurs in six-sided mica “books” and as scattered flakes; peels into thin transparent sheets along one perfect cleavage; white mica
Lepidolite Mica $KLi_2(AlSi_4O_{10})\ (OH)_2$	2 1/2 - 4	colorless, lilac, yellow	vitreous to pearly	lilac color is diagnostic; often in granular masses of small mica “books”; lavender mica
Halite NaCl	2 1/2	colorless, salmon,	vitreous to greasy	easily dissolves in water; often has stepped-down “hopper” faces; cubic cleavage; crystal masses or coating on other material

MATERIALS WITH NON-METALLIC LUSTER				
Name & Composition	Hardne	Color	Streak	Descriptio
Asbestos Mg6Si4O10(OH)8	2 1/2 - 3	light green, light brown	silky	long, thread-like fibers with silky sheen; the commercial variety is fibrous serpentine
Calcite CaCO4	3	colorless, white (rarely pastel)	vitreous	effervesces freely in cold dilute hydrochloric acid; perfect rhombohedral cleavage; doubly refracting; frequently in rhombohedral crystals; hundreds of other forms known, may be fluorescent
Barite BaSO4	3	colorless, white, blue	vitreous	heavy for a non-metal; often occurs as tabular crystals; such crystals in circular arrangement form “barite roses”; perfect cleavage
Bauxite	3 - 3 1/2	white, usually stained with goethite	earthy	pea-sized round concretionary grains show color banding in cream, yellow, and brown; actually a rock made up of various hydrous aluminum oxides
Sphalerite ZnS	3 1/2	usually yellow-brown; also black, green, red	adamantine to metallic	light yellow streak in most colors varieties; heavy; perfect dodecahedral cleavage; cleavage chunks often triangular in shape; occurs as crystals, compact masses, and coatings
Azurite Cu3(CO3)2(OH)2 **Malachite** Cu2CO3(OH)2	3 1/2 - 4	azure blue bright green	dull velvety	colors and association distinctive; both effervesce in hydrochloric acid; azurite often in radiating masses; malachite frequently in curved masses exhibiting color banding in shades of greens
Dolomite CaMg (CO3)2	3 1/2 - 4	white, yellow, pink	vitreous to pearly	slowly effervesces in cold dilute acid when powdered; pale pink color is indicative; often associated with calcite; usually in rhombohedral crystals; perfect rhombohedral cleavage
Fluorite CaF2	4	colorless, all pastels; deep purple	vitreous	crystals often cubic or octahedral; color banding common; octahedral cleavage; usually fluorescent in ultraviolet light
Colemanite Ca2B6O11 ~5H2O	4 1/2	colorless, white	vitreous	may be in stubby glassy crystals, or in compact granular masses; perfect cleavage
Apatite Ca5(PO4)3F	5	white, blue, brown	vitreous	will not scratch glass; commonly in 6-sided prisms; green, blue, yellow; one poor cleavage

MATERIALS WITH NON-METALLIC LUSTER				
Name & Composition	Hardness	Color	Streak	Description
Scheelite $CaWO_4$	5	white, yellow, brown	vitreous	will not scratch glass; heavy; fluoresces; good cleavage; crystal faces may be grooved
Goethite $HFeO_2$	5 - 5 1/2	dark rusty brown, ochre yellow	dull, earthy	streak distinctive yellow-brown; often spongy, porous or earthy; bladed, fibrous; often occurs in cubes and pyritohedrons as an alteration or pyrite; also called limonite
Hematite (earthy) Fe_2O_3	5	dull brownish red to bright red	sub- metallic to earthy	characteristic red-brown streak; often earthy and too powdery for accurate hardness test; may be granular or oolitic; crystals rare; no cleavage
Rhondonite $MnSiO_3$	6	pink to deep rose	vitreous	massive, dense, or granular aggregates often have black veins; color and hardness diagnostic; blocky crystals; nearly 90° cleavage
Hornblende	5 1/2 - 6	greenish-black	vitreous	barely scratches glass; shiny on cleavage faces; opaque; often splintery at edges; usually massive, occasionally in chunky crystals; two directions of cleavage at 124° and 56°
Augite	6	dark green	vitreous to dull	stubby prismatic crystals; usually duller and greener than closely related horn blend; two cleavages at 87° and 93° and uneven fracture
Orthoclase Feldspar $KAlSi_3O_8$	6	white, pink	vitreous	two good cleavages; will scratch glass; wavy internal pattern and pink color distinguishes it from plagioclase when present; may be massive or in large, well-developed, coffin-shaped crystals
Plagloclase Feldspar $NaAlSi_3O_8$ $CaAl_2Si_2O_8$	6	white, gray	vitreous	two good cleavages; will scratch glass; “record grooves”; rectangular cleavage faces often seen in igneous rock
Spodumene $LiAlSi_2O_6$	6 1/2	colorless, white, lavender	vitreous	elongated prismatic crystals; associated with lepidolite, tourmaline, beryl; deep grooves often parallel long crystal faces; perfect prismatic cleavage
Olivine $(Mg,Fe)_2SiO_4$	6 1/2 - 7	olive green	vitreous	crystals often appear as glassy green beads, isolated or in masses; color distinctive; conchoidal fracture
Epidote $Ca_2(Al,Fe)_3$ SiO_{12} (OH)	6 1/2 - 7	light to dark green	vitreous	usually a dull avocado massive; crystals are dark green with striations and well developed cleavage

Appendix B

The following tables shows the composition of the atmosphere and the cumulative volume of each compound.

Sources:

1. *McGraw-Hill Encyclopedia of Science and Technology, 1987, McGraw-Hill, Inc.*
2. *Carbon Dioxide Information Analysis Center*

Full Name	**Formula**	**%Volume**	**# of Parts**	**Unit**	**Variable?**	**Cumulative Volume**
Nitrogen	N_2	78.1%	78 parts per	hundred		78.10%
Oxygen	O_2	20.9%	21 parts per	hundred		99.00%
Argon	Ar	0.934%	9 parts per	thousand		99.93%
Water Vapor	H_2O	0.04%	400 parts per	million	variable	99.97%
Carbon Dioxide	CO_2	0.0369%	370 parts per	million		99.99%
Neon	Ne	0.00182%	18 parts per	million		100.00%
Helium	He	0.000524%	5 parts per	million		100.00%
Methane	CH_4	0.0001842%	2 parts per	million		100.00%
Krypton	Kr	0.000114%	1 part per	million		100.00%
Hydrogen	H_2	0.0001%	1 part per	million	variable	100.00%
Nitrous Oxide	N_2O	0.0000315%	315 parts per	billion		100.00%
Carbon Monoxide	CO	0.00002%	200 parts per	billion	variable	100.00%
Xenon	Xe	0.0000087%	87 parts per	billion		100.00%
Ozone	O_3	0.000005%	34 parts per	billion	variable	100.00%
Sulfur Dioxide	SO_2	0.000002%	20 parts per	billion	variable	100.00%
Ammonia	NH_3	0.000002%	20 parts per	billion	variable	100.00%
Formaldehyde	CH_2O	0.000001%	10 parts per	billion	variable	100.00%
Nitrogen Dioxide	NO_2	0.0000003%	3 parts per	billion	variable	100.00%

Full Name	**Formula**	**%Volume**	**# of Parts**	**Unit**	**Variable?**	**Cumulative Volume**
Nitric Oxide	NO	0.0000003%	3 parts per	billion	variable	100.00%
Hydrogen Sulfide	N_2S	0.0000002%	2 parts per	billion	variable	100.00%
Hydrochloric Acid	HCl	0.00000015%	2 parts per	billion	variable	100.00%
Nitric Acid	HNO_3	0.0000001%	1 parts per	billion	variable	100.00%
Methyl Chloride	CH_3Cl	0.00000006%	600 parts per	trillion		100.00%
Freon-12	CF_2Cl_2	0.0000000544%	546 part per	trillion		100.00%
Carbonyl Sulfide	COS	0.00000005%	500 part per	trillion		100.00%
Freon-11	$CFCl_3F$	0.0000000263%	263 parts per	trillion		100.00%
Carbon Tetrachloride	CCl_4	0.000000098%	97 parts per	trillion		100.00%
Freon-113	$C_2F_3Cl_3$	0.000000082%	82 parts per	trillion		100.00%
Methyl Chloroform	CH_3CCl_3	0.000000056%	47 parts per	trillion		100.00%
HCFC-22	$CHClF_2$	0.0000001525%	153 parts per	trillion		100.00%
HFC-23	CHF_3	0.0000000011%	23 parts per	trillion		100.00%
Sulfur Hexaflouride	SF_6	0.000000004%	5 parts per	trillion		100.00%
Perfluoroethane	C_2F_6	0.000000004%	4 parts per	trillion		100.00%
Triflouromethyl Sulfur Pentaflouride	SF_5CF_3	0.00000000012%	0.12 parts per	trillion		100.00%