

An Introduction to Population Growth

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Why do scientists study population growth? What are the basic processes of population growth?



Why Study Population Growth?

Population ecology is the study of how populations — of plants, animals, and other organisms — change over time and space and interact with their environment. Populations are groups of organisms of the same species living in the same area at the same time. They are described by characteristics that include:

1. **population size:** the number of individuals in the population
2. **population density:** how many individuals are in a particular area
3. **population growth:** how the size of the population is changing over time.

If population growth is just one of many population characteristics, what makes studying it so important?

First, studying how and why populations grow (or shrink!) helps scientists make better predictions about future changes in population sizes and growth rates. This is essential for answering questions in areas such as **biodiversity** conservation (e.g., the polar bear population is declining, but how quickly, and when will it be so small that the population is at risk for extinction?) and human population growth (e.g., how fast will the human population grow, and what does that mean for climate change, resource use, and biodiversity?).

Studying population growth also helps scientists understand what causes changes in population sizes and growth rates. For example, fisheries scientists know that some salmon populations are declining, but do not necessarily know why. Are salmon populations declining because they have been overfished by humans? Has salmon habitat disappeared? Have ocean temperatures changed causing fewer salmon to survive to maturity? Or, maybe even more likely, is it a combination of these things? If scientists do not understand what is causing the declines, it is much more difficult for them to do anything about it. And remember, learning what is probably not affecting a population can be as informative as learning what is.

Finally, studying population growth gives scientists insight into how organisms interact with each other and with

their environments. This is especially meaningful when considering the potential impacts of climate change and other changes in environmental factors (how will populations respond to changing temperatures? To drought? Will one population prosper after another declines?).

Ok, studying population growth is important...where should we start?

Population Growth Basics and the American Bison

The American Plains bison (*Bison bison*) is an iconic symbol of the American West. It is estimated that the plains region of the United States originally supported a population of 15 to 100 million bison (Dary 1989, Shaw 1995). Throughout the 1800's, hunters aided by advancements in transportation and weaponry decimated the wild bison populations, and by 1889, only about one thousand bison remained (Hornaday 1889).

The US government, along with private landowners, began attempts to save the American bison from extinction by establishing protected herds in the late 1800's and early 1900's. The herds started small, but with plentiful resources and few predators, they grew quickly. The bison population in northern Yellowstone National Park (YNP) increased from 21 bison in 1902 to 250 in only 13 years (Figure 1, Gates *et al.* 2010).

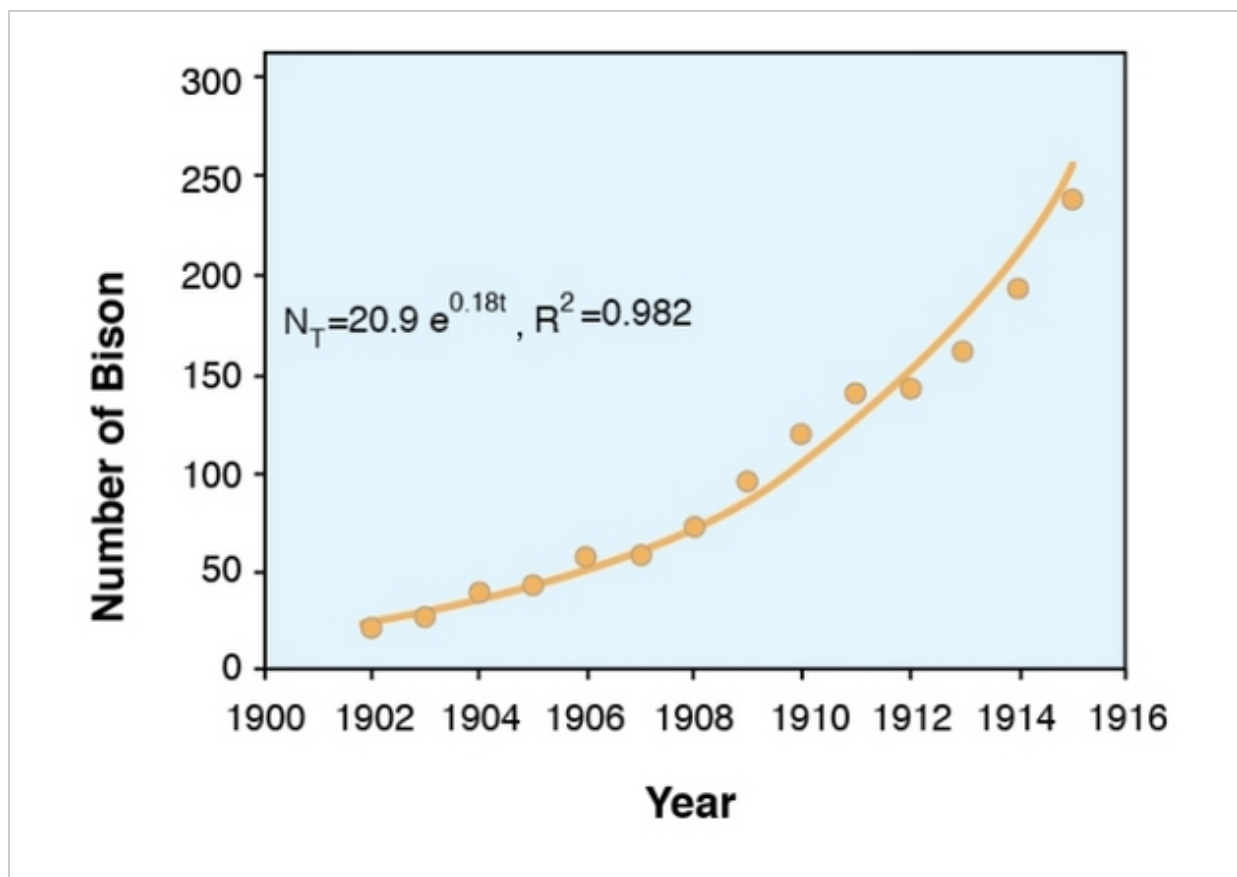


Figure 1: The American bison population in northern Yellowstone National Park grew exponentially between 1902 and 1915.

After being driven nearly to extinction in the 1800s, the population began growing again due to conservation efforts implemented by governments and private landowners in the early 1900s.

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The yearly increase in the northern YNP bison population between 1902 and 1915 can be described as **exponential growth**. A population that grows exponentially adds increasingly more individuals as the population size increases. The original adult bison mate and have calves, those calves grow into adults who have calves, and so on. This generates much faster growth than, say, adding a constant number of individuals to the population each year.

Exponential growth works by leveraging increases in population size, and does not require increases in population growth rates. The northern YNP bison herd grew at a relatively constant rate of 18% per year between 1902 and 1915 (Gates *et al.* 2010). This meant that the herd only added between 4 and 9 individuals in the first couple of years, but added closer to 50 individuals by 1914 when the population was larger and more individuals were reproducing. Speaking of reproduction, how often a species reproduces can affect how scientists describe population growth (see Figure 2 to learn more).



Figure 2: Bison young are born once a year — how does periodic reproduction affect how we describe population growth?

The female bison in the YNP herd all have calves around the same time each year — in spring from April through the beginning of June (Jones *et al.* 2010) — so the population size does not increase gradually, but jumps up at calving time. This type of periodic reproduction is common in nature, and very different from animals like humans, who have babies throughout the year. When scientists want to describe the growth of populations that reproduce periodically, they use geometric growth. Geometric growth is similar to exponential growth because increases in the size of the population depend on the population size (more individuals having more offspring means faster growth!), but under geometric growth timing is important: geometric growth depends on the number of individuals in the population at the beginning of each breeding season. Exponential growth and geometric growth are similar enough that over longer periods of time, exponential growth can accurately describe changes in populations that reproduce periodically (like bison) as well as those that reproduce more constantly (like humans).

Photo courtesy of Guimir via Wikimedia Commons.

The power of exponential growth is worth a closer look. If you started with a single bacterium that could double every hour, exponential growth would give you 281,474,977,000,000 bacteria in just 48 hours! The YNP bison population reached a maximum of 5000 animals in 2005 (Plumb *et al.* 2009), but if it had continued to grow exponentially as it did between 1902 and 1915 (18% growth rate), there would be over 1.3 billion (1,300,000,000) bison in the YNP herd today. That's more than thirteen times larger than the largest population ever thought to have roamed the entire plains region!

The potential results may seem fantastic, but exponential growth appears regularly in nature. When organisms enter novel habitats and have abundant resources, as is the case for invading agricultural pests, **introduced species**, or during carefully managed recoveries like the American bison, their populations often experience periods of exponential growth. In the case of introduced species or agricultural pests, exponential population growth can lead to dramatic environmental degradation and significant expenditures to control pest species (Figure 3).

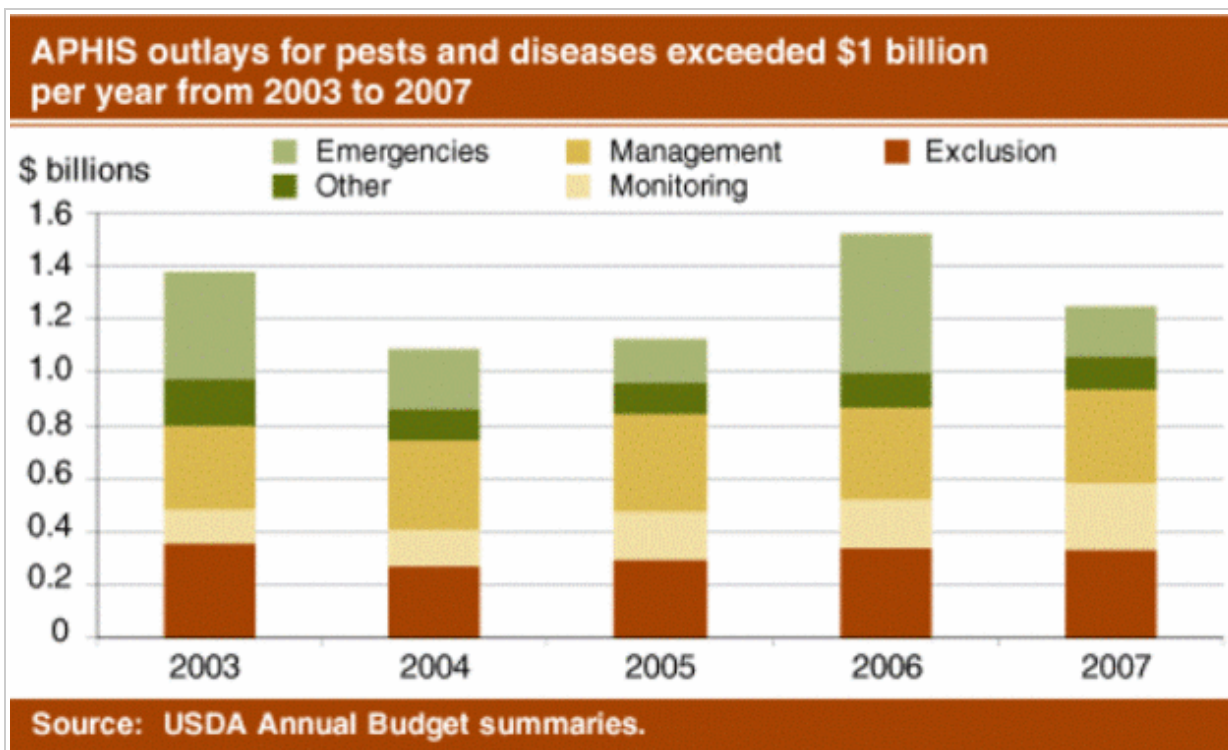


Figure 3: If this much money is being spent on something, it must be important!

Understanding population growth is important for predicting, managing, monitoring, and eradicating pest and disease outbreaks. Many introduced species, including agricultural pests and infectious diseases, grow exponentially as they invade new areas, and billions of dollars are spent predicting and managing the population growth and dispersal of species that have the potential to destroy crops, harm the health of humans, wildlife, and livestock, and affect native species and natural ecosystem functioning. APHIS is the Animal and Plant Health Inspection Service and is part of the United States Department of Agriculture.

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After the Boom: Limits to Growing Out of Control

For every organism — whether plant, animal, virus, or bacterium — there is an ideal set of circumstances that would allow a population of that organism to grow, uninhibited, at the highest possible rate. Even if they temporarily achieve maximal rates of uninhibited growth, populations in the natural world eventually fall short of this ideal. For example, the northern Yellowstone National Park bison herd did not grow to 1.3 billion...why not? Let's think about the conditions that allowed the bison population to grow between 1902 and 1915. The total number of bison in the YNP herd could have changed because of births, deaths, immigration and emigration (immigration is individuals coming in from outside the population, emigration is individuals leaving to go elsewhere). The population was isolated, so no immigration or emigration occurred, meaning only births and deaths changed the size of the population. Because the population grew, there must have been more births than deaths, right? Right, but that is a simple way of telling a more complicated story. Births exceeded deaths in the northern YNP bison herd between 1902 and 1915, allowing the population to grow, but other factors such as the **age structure** of the population, characteristics of the species such as **lifespan** and **fecundity**, and favorable environmental conditions, determined how much and how fast.

Changes in the factors that once allowed a population to grow can explain why growth slows or even stops. Figure 4 shows periods of growth, as well as periods of decline, in the number of YNP bison between 1901 and 2008. Growth of the northern YNP bison herd has been limited by disease and predation, habitat loss and fragmentation, human intervention, and harsh winters (Gates *et al.* 2010, Plumb *et al.* 2009), resulting in a current population that typically falls between 2500 and 5000, well below the 1.3 billion bison that continued exponential growth could have generated.

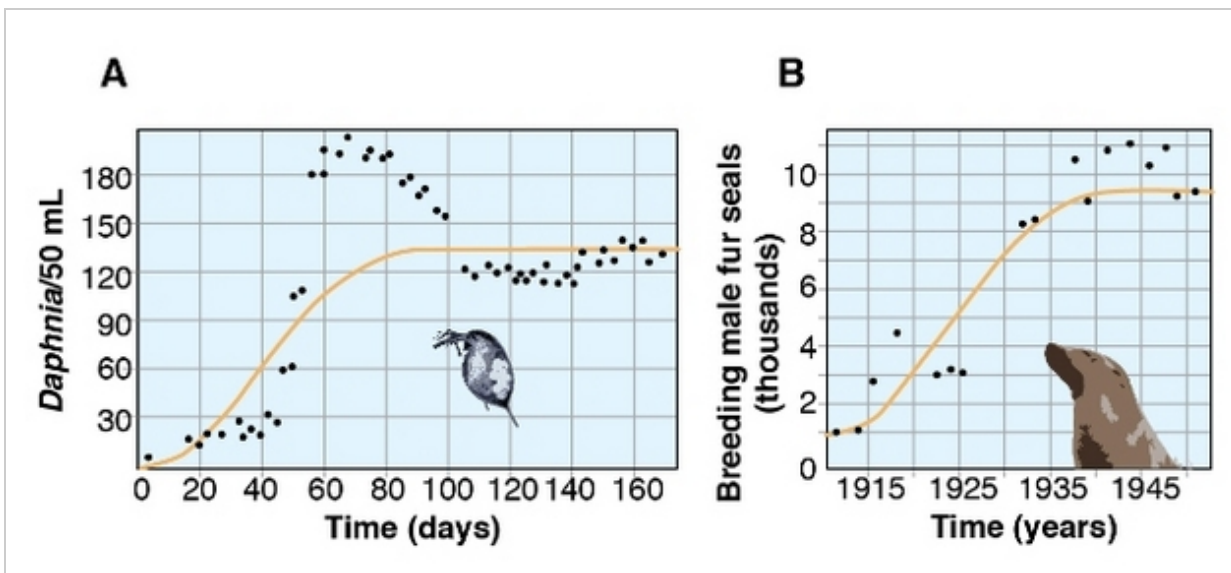


Figure 4: The YNP bison population has increased and decreased in size over the past century in response to factors such as disease, predation, habitat loss, human intervention, and environmental conditions.

Scientists with the National Park Service and Colorado State University recently published these data showing both the number of bison counted in YNP on an annual basis (blue dots) and the number of bison removed from the population (grey columns) for the purposes of herd management. Management of the bison population in YNP has been fairly controversial — to learn more about this controversy check out Plumb *et al.* 2009.

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Factors that enhance or limit population growth can be divided into two categories based on how each factor is affected by the number of individuals occupying a given area — or the population's **density**. As population size approaches the **carrying capacity** of the environment, the intensity of density-dependent factors increases. For example, competition for resources, predation, and rates of infection increase with population density and can eventually limit population size. Other factors, like pollution, seasonal weather extremes, and natural disasters — hurricanes, fires, droughts, floods, and volcanic eruptions — affect populations irrespective of their density, and can limit population growth simply by severely reducing the number of individuals in the population.

The idea that uninhibited exponential growth would eventually be limited was formalized in 1838 by mathematician Pierre-Francois Verhulst. While studying how resource availability might affect human population growth, Verhulst published an equation that limits exponential growth as the size of the population increases. Verhulst's equation is commonly referred to as the **logistic equation**, and was rediscovered and popularized in 1920 when Pearl and Reed used it to predict population growth in the United States. Figure 5 illustrates logistic growth: the population grows exponentially under certain conditions, as the northern YNP bison herd did between 1902 and 1915, but is limited as the population increases toward the **carrying capacity** of its environment. Check out the article by J. Vandermeer (2010) for a more detailed explanation of the equations that describe exponential and logistic growth.

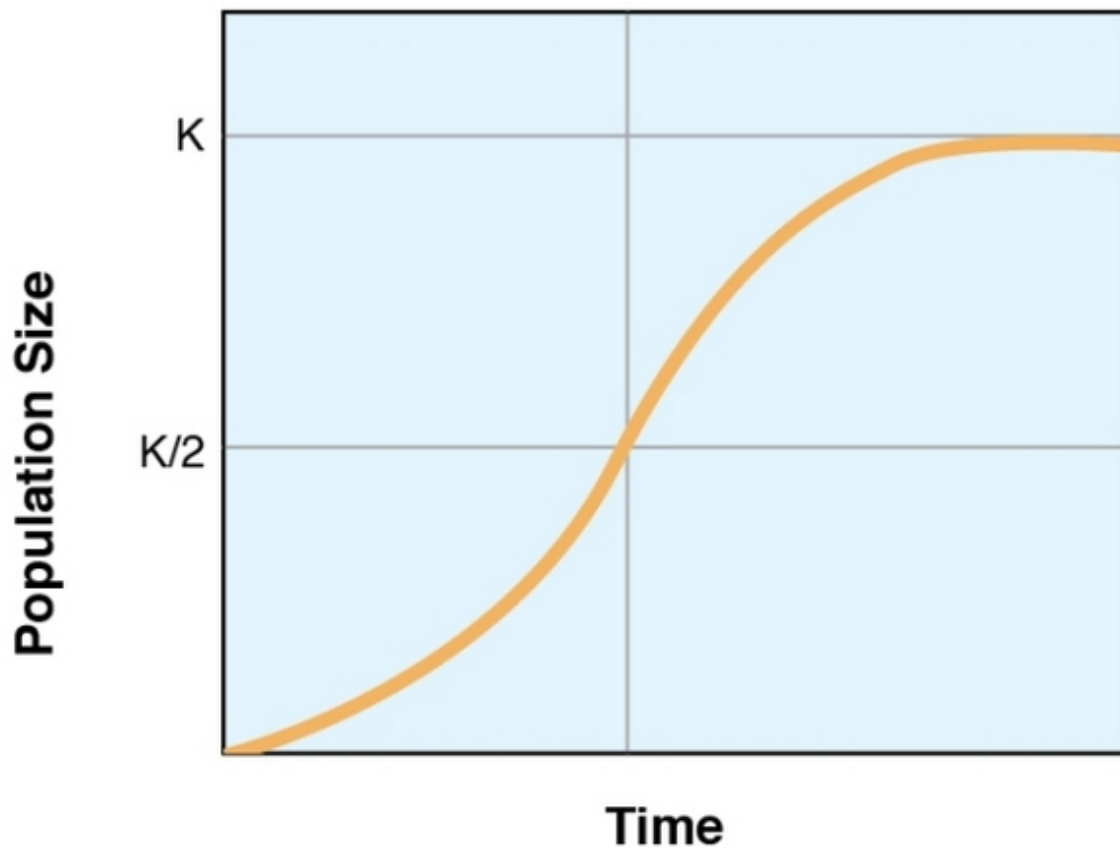


Figure 5: This curve describes logistic growth.

The population size grows exponentially for a while (like the bison in Figure 1), but then it slows down and levels off when it approaches the carrying capacity (K).

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Logistic growth is commonly observed in nature as well as in the laboratory (Figure 6), but ecologists have observed that the size of many populations fluctuates over time rather than remaining constant as logistic growth predicts. Fluctuating populations generally exhibit a period of population growth followed a period of population decline, followed by another period of population growth, followed by...you get the picture.

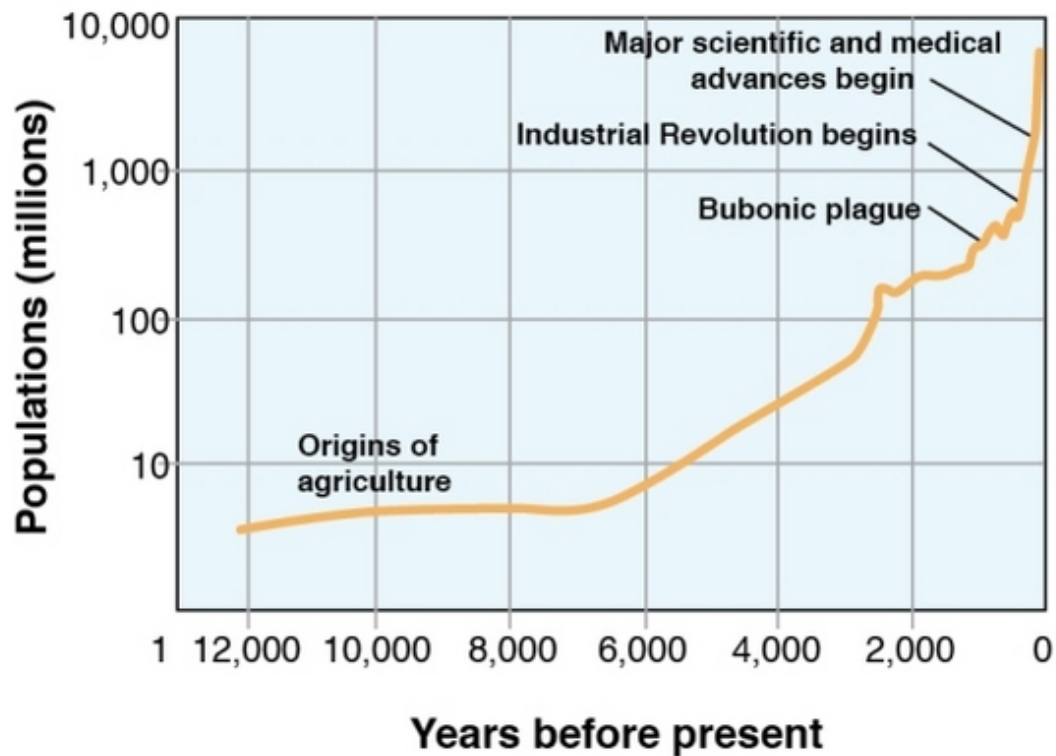


Figure 6: Logistic growth curves as seen in real populations.

Populations growing according to logistic growth are observed in laboratory populations (*Paramecium* and *Daphnia*) as well as in nature (fur seals). In the *Daphnia* example, it appears that the population size grew to more than 180 individuals and then declined, leveling off at around 130–150 individuals. What factors might have caused this pattern?

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Populations can fluctuate because of seasonal or other regular environmental cycles (e.g., daily, lunar cycles), and will also sometimes fluctuate in response to density-dependent population growth factors. For example, Elton (1924) observed that snowshoe hare and lynx populations in Canadian boreal forests fluctuated over time in a fairly regular cycle (Figure 7). More importantly, they fluctuated, one after the other, in a predictable way: when the snowshoe hare population increased, the lynx population tended to rise (plentiful food for the lynx!); when the lynx population increased, the snowshoe hare population tended to fall (lots of predation on the hare!); when the snowshoe hare... (and the cycle continues).

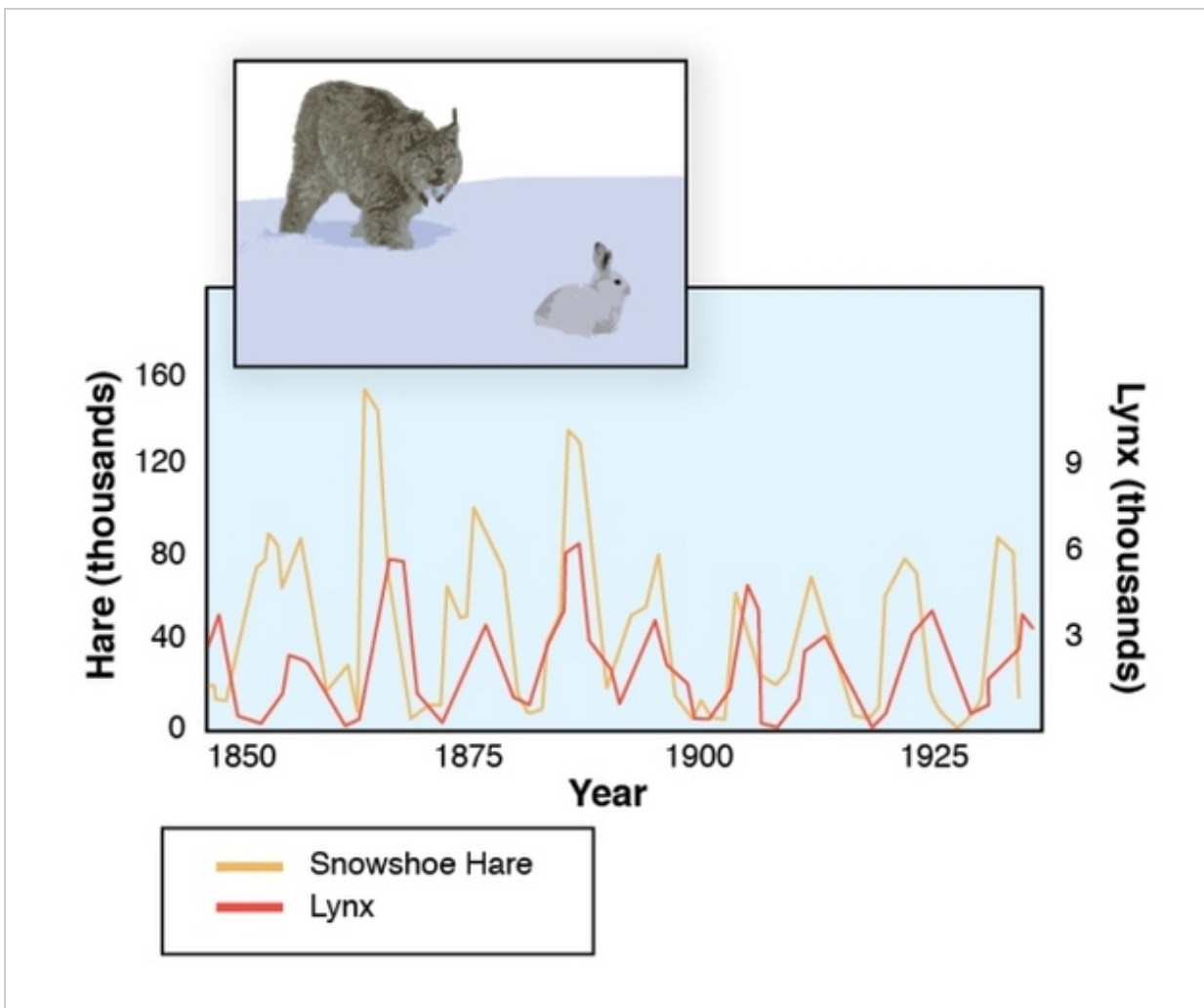


Figure 7: Typically populations don't just reach a carrying capacity and stay there—instead, they fluctuate.

Many populations, over time, exhibit periods of growth and decline. Cyclic changes in population growth can be caused by seasonal, or other environmental changes, or can be driven by density-dependent processes, such as predation, like the snow shoe hare and lynx example depicted here.

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It is also possible for populations to decline to extinction if changing conditions cause death rates to exceed birth rates by a large enough margin or for a long enough period of time. **Native species** are currently declining at unprecedented rates — one important reason why scientists study population ecology. On the other hand, as seen in the YNP bison population, if new habitats or resources are made available, a population that has been declining or relatively stable over a long period of time can experience a new phase of rapid, long-term growth.

What about Human Population Growth?

One of the most challenging applications of population growth research is to predict human population growth. The human population surpassed six billion people in 1999, and is expected reach nine billion before 2050. It is somewhat surprising to realize that it took all of human history for the human population to reach one billion people — which happened around 1800 — then a little over 100 years to double to two million, and just 40 years to double from three to six billion! The recent explosive (think exponential!) growth has been facilitated by advances in agriculture, science, and medicine, which have enabled more people to survive and have longer lifespans (Figure 8).

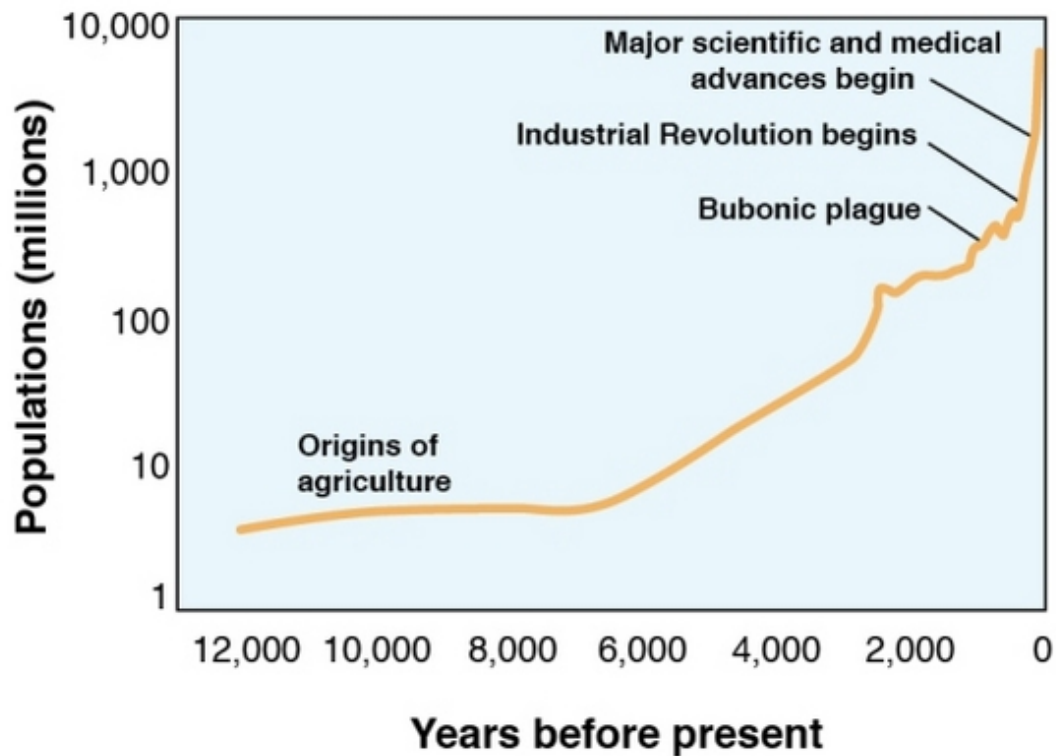


Figure 8: Does it surprise you that human population size is growing exponentially?

This graph shows the explosion of human population over the last 10,000 years along with some relevant historical events.

Think about the ways that each of these events might have affected birth and death rates of the human population. Note that the x-axis represents years before the present (i.e., 0=present day).

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The growth of the global human population shown in Figure 8 appears exponential, but viewing population growth in different geographic regions shows that the human population is not growing the same everywhere. Some countries, particularly those in the developing world, are growing rapidly, but in other countries the human population is growing very slowly, or even contracting (Figure 9). Studying the characteristics of populations experiencing different rates of growth helps provide scientists and **demographers** with insight into the factors important for predicting future human population growth, but it is a complicated task: in addition to the density dependent and independent factors we discussed for the northern Yellowstone National Park bison and other organisms, human population growth is affected by cultural, economic, and social factors that determine not only how the population grows, but also the potential carrying capacity of the Earth.

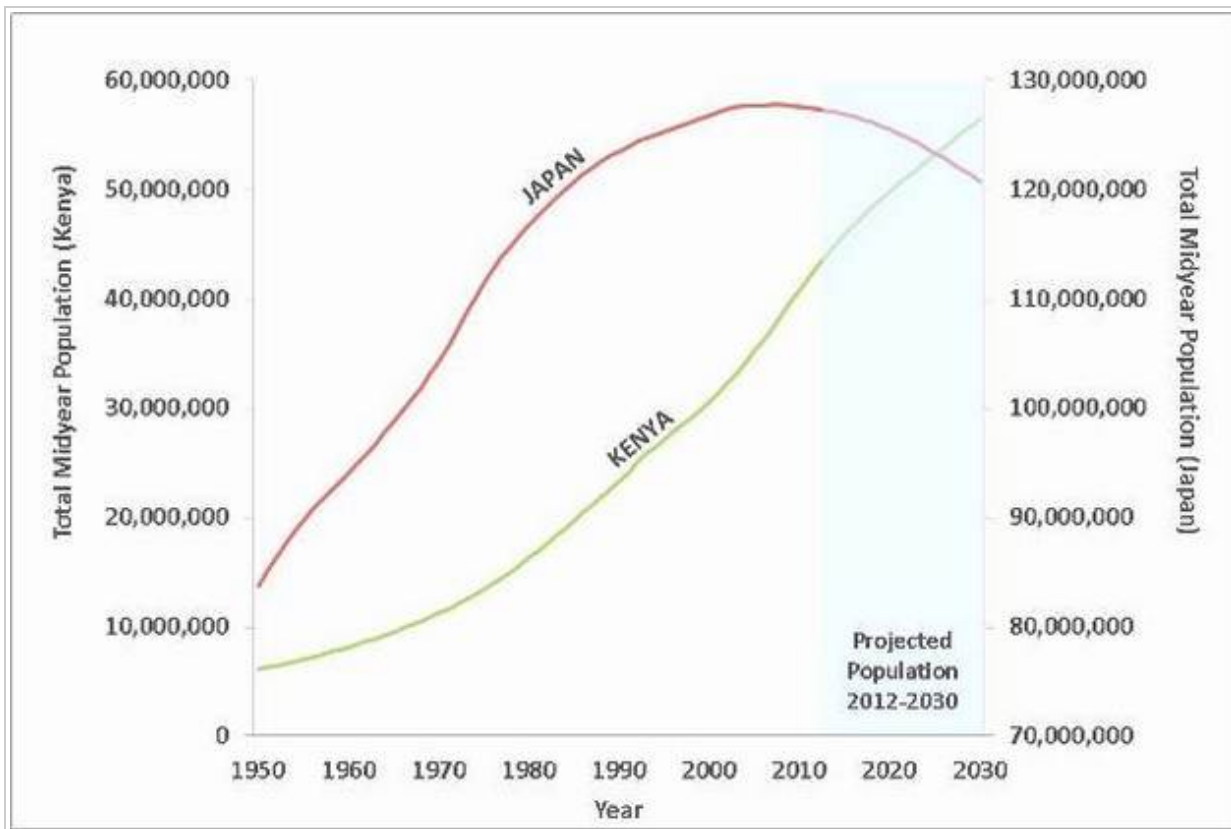


Figure 9: Global population growth is growing exponentially

Based on data from the US Census Bureau's International Database, this figure shows human population growth in Kenya and Japan from 1950–2025 (projected). Human populations in Kenya are growing exponentially, but human populations in Japan have slowed, and may even be declining. What pattern do you expect for human population growth in the United States? In China? Go to <http://www.census.gov/ipc/www/idb/> to get the data for any country that interests you, and make your own graph like the one above.

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The idea that the human population might experience limits to growth was posed in 1798 in Thomas Malthus's "An Essay on the Principle of Population Growth" and has generated debate for over 200 years. Today, questions about the limits to human population growth remain unanswered. Will the same factors that have already begun to limit growth in the world's more developed countries — declining birth rates, for example — slow global human population growth? Or will growth continue on an exponential path? If rapid growth continues, will the human population eventually approach the carrying capacity of the Earth, and be limited by increased disease and competition for resources? Scientists continue to study the processes of population growth and demography to gain insights into these important questions.

Glossary

biodiversity: The variety of types of organisms, habitats, and ecosystems on Earth or in a particular place.

exponential growth: Continuous increase or decrease in a population in which the rate of change is proportional to the number of individuals at any given time.

age structure: The distribution of individuals among age classes within a population.

lifespan: How long an individual lives, or how long individuals of a given species live on average.

fecundity: The rate at which an individual produces offspring.

density: Referring to a population, the number of individuals per unit area or volume; referring to a substance, the weight per unit volume.

carrying capacity: The number of individuals in a population that the resources of a habitat can support; the asymptote, or plateau, of the logistic and other sigmoid equations for population growth.

logistic equation: The mathematical expression for a particular sigmoid growth curve in which the percentage rate of increase decreases in linear fashion as the population size increases.

native species: A species that occurs in a particular region or ecosystem by natural processes, rather than by accidental or deliberate introduction by humans.

introduced species: A species that originated in a different region that becomes established in a new region, often due to deliberate or accidental release by humans.

demographers: Demography is the study of the age structure and growth rate of populations.

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