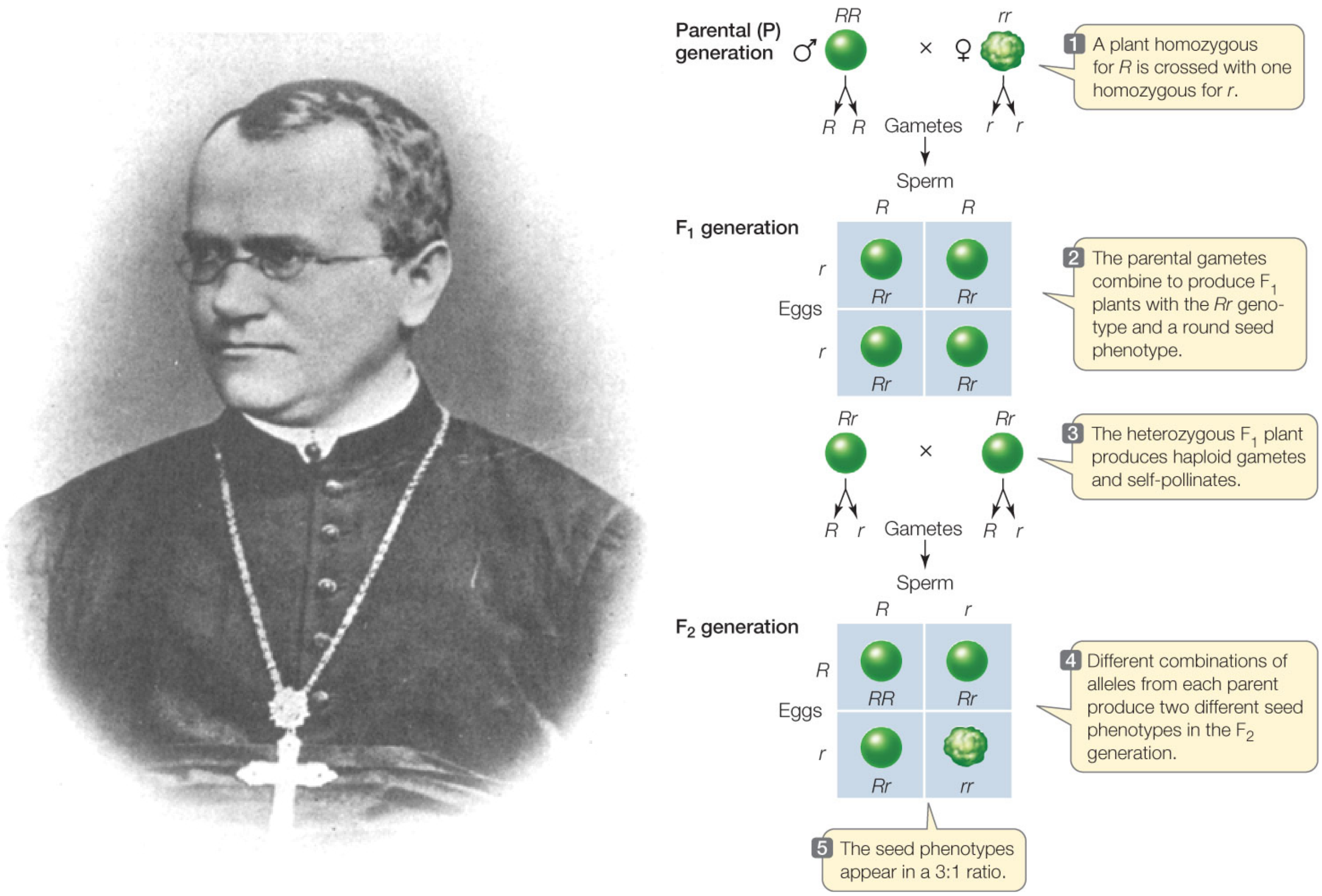
Just as organisms with the same genes may have different phenotypes, individuals with similar phenotypes may have different combinations of alleles. The nineteenth-century Austrian monk Gregor Mendel was the first person to understand genetic variation within and among individuals. Mendel studied pea plants with two different phenotypes for various traits, such as red flowers and white flowers or smooth peas and wrinkled peas. When he crossed smooth pea plants with wrinkled pea plants, all the offspring (new plants) had smooth peas. However, when he crossed this second generation of smooth pea plants with each other, the result was a mix of smooth and wrinkled peas.

FIGURE 21



Gregor Mendel and his pea-plant experiment.

Source: Khan Academy

What is the explanation for this? Mendel proposed that there was a hereditary factor (what we now call a gene) that transmitted traits such as pea surface from generation to generation. The plants he used carried genes with two alleles for each trait, such as pea surface. If a plant inherited one smooth allele and one wrinkled allele, the smooth allele would dominate, masking the effect of the wrinkled allele, which would not show up in the phenotype. The allele for wrinkled peas would create the wrinkled pea phenotype only when the plant inherited two copies of it, one from each parent.

If two smooth pea plants or two wrinkled pea plants were crossed, they would always produce one phenotype—either all smooth or all wrinkled. However, crosses among the genetically varied plants would always produce a mixture of smooth and wrinkled peas. In other words, increased genetic variation within individuals will result in an increase in phenotypic variation in offspring. Mendel's results with pea surface were replicated with many

Mutualism

The third major type of population interaction is **mutualism**. Mutualistic interactions are those that increase the survival probability or reproduction of both species. Though the term mutualism may lead some people to imagine species helping each other in a cooperative sense, ecologists see it more as "reciprocal exploitation" since each species is using the other to benefit itself. If the self-benefit to one population becomes too low, the interaction will no longer be of value and will no longer provide an adaptive advantage to either species.

A hummingbird drinking nectar from a flower while also serving as a pollinator is an example of mutualism.

The most common type of mutualism involves interaction between plants and animals. Probably the single most important type of mutualistic interaction is the relationship between plants and their pollinators, such as birds and insects, since many plant species depend upon pollination for their reproduction and survival. Some pollinators pollinate many different species of plants, and many plant species are pollinated by many different species of animals. In these cases, the mutualistic interaction between any particular pair of plant and animal species is weak. In symbiotic mutualism, by contrast, one animal species pollinates only one plant species, and the plant is pollinated only by that one animal species. For example, there are about nine hundred species of fig trees, and almost every one is pollinated by one particular species of fig wasp. These types of mutualistic interactions are most likely due to resource partitioning in the evolutionary past.

ECOLOGICAL COMMUNITIES

So far, we have seen how the interaction between two populations affects the survival and growth of each individual population. However, many of the most important ecological processes occur at a level of organization higher than the population (or two interacting populations)—the ecological community. A **community** is any assemblage of populations in a particular area or habitat. Community ecology studies groups of populations living in the same area.

Food Webs

A **food web** summarizes the species that make up a community and the ways they are linked by various predator-prey interactions to form pathways of energy flow. Food webs operate like food chains, but since they include all the species in a feeding relationship, they are much more complex, as you can see in Figure 38, which shows the Greater Yellowstone ecosystem food web. In an aquatic food web, the photosynthesizers are primarily multicellular algae and single-celled phytoplankton. Single-celled animals (zooplankton) feed on the phytoplankton, and herbivorous fish eat the algae. Carnivorous fish prey upon zooplankton, insects, and herbivorous fish and are, in turn, eaten by the secondary carnivores—tarpons (the largest fish species in the lake) and several bird species.

As we have seen, interspecific competition will limit the species found at any one **trophic level**. In addition, individual- and population-level processes will limit both the presence and abundance of a particular species. In most cases, the extinction of one species is not critical to the long-term health of a community. The remaining species at that trophic level, or species from adjacent areas, can provide the necessary links for energy to flow. However, the loss of one species in a community can lead to the damage or extinction of the entire community.

Fertility

We can consider the human population as a system comprising a pool of 8 billion people with births as inputs and deaths as outputs. In any given time period, the number of births in a population is dependent on the number of individuals in the population and the birth rate, and the number of deaths is dependent on the number of individuals in the population and the death rate.

Infant mortality, the number of deaths of infants (children under age one) per one thousand live births, together with life expectancy, can provide an accurate representation of health care in a given country.

In the United States, the total fertility rate (an estimate of the average number of children that will be born to each woman in the population throughout her child-bearing years) today is 1.84, which means that, on average, each woman of child-bearing age will have a little less than two children. As you would expect, the growth rate of a population and the total fertility rate correlate with one another; when we compare a number of countries, those with higher growth rates usually have higher total fertility rates.

The **replacement fertility rate** is the number of children each woman must have on average to replace the current population. Replacement level fertility is usually 2.1: a total of 2.1 children, on average, are needed to replace two parents because some children never reproduce. Therefore, the United States is below replacement level fertility. Based on that statistic alone, we would expect the population in the United States to decrease over time. However, we must also consider immigration (remember the equation at the beginning of this section), which is projected to add almost one million people per year to the population of the United States as well as the individuals in the population that are not yet reproductively mature who will soon begin to contribute to the birth rate.

Life Expectancy and Infant Mortality

Life expectancy is the average number of years that an infant born in a given year can be expected to live, given the current average lifespan and the death rate. Life expectancy is often reported for the overall population of a country and for males and females within the population. In almost every situation, the life expectancy for men is shorter than that for women, reflecting greater hardships and dangers generally experienced by men in the workplace and different lifestyle choices. The gap between life expectancy for men and women is decreasing as more and more women enter the workforce. *Infant mortality* is the number of deaths of infants (children under age one) per one thousand live births.

Life expectancy and infant mortality together usually provide an accurate representation of the level of health care in a given country. If life expectancy is fairly high and infant mortality is fairly low, it is likely that the country has a relatively high level of health care. Note that crude death rate is *not* a good indicator of health care. Even with a high life expectancy and a low infant mortality, a country could have a high crude death rate because it has a large number of older individuals. For example, the United States has a higher crude death rate (9) than Mexico (5), which is a reflection of an older population in the U.S. than in Mexico.

Over a dozen developed countries have lower infant mortality rates than the United States, including Canada, Finland, Iceland, Ireland, Japan, Sweden, and France. What accounts for a U.S. infant mortality rate that is one to two deaths per thousand greater than other comparable countries, many of which spend less per capita on health care? Universal health care and more generous allowances for time off during the later stages of pregnancy are two reasons. The large disparity in the level of health care provided to Black Americans, Hispanics, Native Americans. and other minorities in the United States relative to whites is also a factor. The infant mortality rate for the entire

Six other essential elements—nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur—are considered macronutrients because they are required in relatively large amounts, usually greater than 0.1 percent of an organism's dry weight. The remaining seven plant-essential elements—manganese, iron, copper, zinc, molybdenum, chloride, and boron—are required in very small quantities and so are called micronutrients. Plants require the sixteen plant-essential elements in slightly varying proportions depending on the individual species. While the atmosphere and rocks are the original sources of the nutrient elements, the soil is an important intermediate source for most plants.

The "dust bowls" of the 1920s and 1930s in the western part of the United States were the source of large amounts of calcium and magnesium that were carried by the prevailing westerly winds and deposited in the central and eastern states.

In order to obtain the nutrients they need, plants take up elements in ionic form. All plant-essential elements (and many other elements as well) have an *aqueous phase*; in other words, they have one chemical form that is soluble in water. *Soil water*, the water in the pore spaces between soil particles, facilitates the exchange of dissolved elements (elements in their aqueous phase) between soil and plant roots.

In addition to moving water itself, the hydrologic cycle (see Section II) is instrumental in the movement of chemical elements. **Weathering** (physical or chemical breakdown) degrades mineral rock so that the elements are released, while **erosion** transports the elements via water and wind. In their aqueous phase, elements are then mobilized by the hydrologic cycle and carried to the oceans or taken up by plants and animals on land. Weathering of rock can be accomplished by water, wind, acid rain, other chemicals, and even the roots of growing plants.

The Cycles of Calcium, Magnesium, Potassium, and Sulfur

Calcium, magnesium, and potassium are derived primarily from rocks and decomposed vegetation. Calcium and magnesium can occur in very high concentrations in limestone, dolomitic limestone, and marble. Calcium and magnesium are often quite abundant in ecosystems overlying limestone and some other rock types. Calcium and magnesium are also a large component of terrestrial dust, so airborne dust deposition often translocates large amounts of these elements. The "dust bowls" of the 1920s and 1930s in the western part of the United States were the source of large amounts of calcium and magnesium that were carried by the prevailing westerly winds and deposited in the central and eastern states. Heat, drought, and wind, coupled with poor agricultural practices and other human land use that caused the destruction of the natural topsoil were the causes of the dustbowl. Calcium and magnesium combine with organic compounds and do not leach easily. However, potassium is susceptible to leaching from plant tissue and soils, so it may be more easily lost from systems than tightly held elements like phosphorus.

The sulfur cycle is similar to the nitrogen cycle in a number of ways. Sulfur has a gaseous component to its cycle, sulfur dioxide (SO_2). Plants take up sulfur from the soil primarily as the sulfate anion (SO_4^{2-}). Anthropogenic deposition of sulfur is even greater than the deposition of nitrogen, although clean air regulations have lowered sulfur deposition significantly in the United States since 1995, as we will see in Section IV. Sulfate is the second ion, along with nitrate, that comprises acid rain. Sulfate is also easily leached from soils and ecosystems. One major difference between the sulfur and nitrogen cycles is that there is a pool of sulfur in rocks and minerals. Volcanic emissions are a natural atmospheric source of sulfur.

SOIL

What Is Soil?

The various soils on Earth form a dynamic membrane that covers much of the land surface, connecting the overlying biology to the underlying geology. They also serve a number of functions that benefit animals, plants,