Many processes—predator-prey, host-parasite, environmental stress, adaptation and specialization—help to maintain balance and stability within an ecosystem. Natural forces bring about disturbances and changes, and species have to react. In fact, it’s change and adaptation or else extinction. At all levels, biological diversity is an important factor.

We’ll also see the impact of human pressure. Compared to Earth, the record of human existence is a very recent phenomenon, and human history after the agricultural and industrial revolution is even shorter. However, we have manipulated and exploited our resources and few things that we do fall in line with sensible ecological principles. A message from the study of biodiversity is that by destroying natural habitats, we are also eliminating genetic resources, which are the culmination of thousands and millions of years of adaptation. Since evolutionary succession is affected by climatic changes, human activities which lead to environmental changes on a global scale may have dire results.

The population of a species is the dynamic balance between its biotic potential and environmental resistance. This is nature’s system of checks and balances.

Population growth is due to a higher birth rate than death rate. In ecology, recruitment, the growth and maturation of newborn into the adult breeding population, is considered a more important gauge of potential population growth. The success of recruitment and the rate of population growth, of course, are dependent on how well the species is adapted to the current environmental conditions—factors that we call biotic potential and environmental resistance.

Biotic potential is a measure of how well a species has adapted to survive, for example, by defense mechanisms, resistance to adverse conditions, migration, and seed dispersion. On the other hand, environmental resistance is adverse biotic and abiotic factors like predators, parasites, unfavorable temperature, and lack of water. These adverse environmental factors raise the death rate of a population. Environmental resistance is more effective (i.e. more damaging) on the young (the recruitment phase). The combination of biotic and abiotic factors determines the carrying capacity of an ecosystem—the maximum population of a species that can be supported. If the population approaches or exceeds the carrying capacity (or the optimal population density), competition sets in to limit the population.

Population balance between biotic potential and environmental resistance is dynamic since environmental factors rarely remain the same over time. For the same reason, population explosion is not common as all conditions are seldom favorable for an extended period of time.

Examples of environmental resistance and biotic potential.

To use slightly different words, biotic potential consists of factors that help population growth, while environmental resistance consists of factors that tend to decrease population growth. These factors control population or ecosystem balance. Here are some examples:
<table>
<thead>
<tr>
<th>Biotic Potential</th>
<th>Environmental Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biotic Factors</strong></td>
<td><strong>Predators</strong></td>
</tr>
<tr>
<td>• High reproductive rate</td>
<td>• Diseases</td>
</tr>
<tr>
<td>• Ability to migrate or disperse</td>
<td>• Parasites</td>
</tr>
<tr>
<td>• Ability to invade other habitats</td>
<td>• Competitors (including invasive species)</td>
</tr>
<tr>
<td>• Ability to compete or find food</td>
<td>• Lack of food (or nutrients)</td>
</tr>
<tr>
<td>• Ability to hide or run</td>
<td></td>
</tr>
<tr>
<td>• Special defense mechanisms</td>
<td></td>
</tr>
<tr>
<td>• Ability to cope with adverse conditions</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Abiotic Factors</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Favorable weather, lots of sun and water</td>
<td>• Lack of water</td>
</tr>
<tr>
<td>Think Hawaii!</td>
<td>• Lack of light</td>
</tr>
<tr>
<td></td>
<td>• Unfavorable weather conditions</td>
</tr>
<tr>
<td></td>
<td>• Human induced pollutants or destruction</td>
</tr>
</tbody>
</table>

Nature is not very predictable. Many events, especially environmental resistance, happen by chance.

There are other ways to categorize environmental stress. Because of the unpredictability of nature, one approach is to group environmental resistance into categories that may happen by chance. These probabilistic events are:

1. **Demographic fluctuations**, which account for accidental variations in birth rate, death rate, and the ratio of the sexes.

2. **Environmental fluctuations**, which account for variations in weather, in food supply, and in the population levels of predators, competitors, parasites and disease. They in turn will affect population fluctuations in birth and death rates.

3. **Natural disturbances**, which include hurricanes, floods, droughts, and unusually harsh winter.

4. **Genetic fluctuations**, which account for random chance that undesirable genetic traits become more common, irrespective of natural selection. This phenomenon is also called a genetic drift.

The probability of genetic drift increases with a small, isolated population. The effects of demographic fluctuations are also more conspicuous in a small population; in a large population, unfortunate coincidences of individuals tend to cancel each other out. On the other hand, environmental fluctuations and natural disturbances cover a wider geographical range and affect all population sizes.
Examples of adaptation and specialization

Traits that organisms acquire are usually specialized, serving to support the survival and reproduction of the species. Among different species, there are a large variety of features that accomplish the same task. The ability to adapt is also another way to talk about the biotic potential of a species. Here are just a few specific examples.

<table>
<thead>
<tr>
<th>Animals</th>
<th>Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Reproductive traits</td>
<td>Having a large number of eggs; finding or attracting mates—antler of deer, exotic plumage of peacock, sex attractants of insects, mating dance of grebes</td>
</tr>
<tr>
<td>• Migration or seed dispersal</td>
<td>Terns, trumpeter swans, ducks, Monarch butterflies</td>
</tr>
<tr>
<td>• Obtaining or competing for food or nutrients and water; also light with plants</td>
<td>The long neck of giraffe, the tongue of frogs, the web of spiders</td>
</tr>
<tr>
<td>• Escaping predators</td>
<td>The quill of porcupine, stench of skunk, cryptic coloration of many birds and insects, running ability of, say, rabbits</td>
</tr>
<tr>
<td>• Coping with severe physical factors such as cold</td>
<td>Heavy fur or blubber; hibernation or migration</td>
</tr>
</tbody>
</table>

As a result of adaptation and specialization, each species occupies a specific ecological niche in an ecosystem.

We have learned in Chapter 2a that each species is specialized to exist within some ranges of environmental conditions. We also know that they play a specific role within a food web. In a way, after continual adaptation and specialization over a long duration, each species has established its own ecological niche, or niche in the environment.

An ecological niche describes how a species has established in a biological community. A niche encompasses all the physical, chemical, and biological factors that a species needs to survive. More specifically, the habitat niche refers to where a species lives. The food niche refers to what it eats and how it feeds itself. The reproductive niche refers to how and when it reproduces. We can consider physical and chemical niches to describe the adaptation to temperature, moisture, shade, resistance to toxins, and so on. The fact that each species tends to have its own ecological niche has important implications in ecosystem stability.

By and large, each species is confined to a particular habitat or a restricted range of habitats. Of course there are exceptions. Some habitats (e.g. the tropical forest) provide more niches, and some species may have broader niches than others. Migratory birds, for example,
have wintering and summer spawning grounds easily thousands of miles apart. Top carnivores, like wolves and eagles, cover a range over hundreds of miles. In contrast to the tropics, the harsh Arctic and desert habitats (near the limits of tolerance) have less diversity. Most of the hardy species that can survive in these regions are highly specialized to adapt to the hostile environment.

Within a given habitat, all plants and animals make their living in a wide variety of different ways, that is, in different ecological niches. Niche partitioning is the utilization of different resources by different species. This is how they assure continued coexistence, even though they may still be competing against each other in some way. For example, different predators may have their own food niche by feeding on different things or at different times or locations, and, consequently, minimizing competition. An extension of this idea is the competitive exclusion principle—two different species that have identical requirements cannot coexist in the same ecosystem. Over time, different species have learnt to coexist within the same habitat by exploiting different ecological niches.

In nature, every generation of every species is subjected to natural selection. The changes are reflected in the gene pool.

We have just mentioned that a species must continually undergo adaptation and specialization to counter environmental resistance. Under environmental stress, an individual that is better equipped to overcome obstacles to survival will also have a better chance to reproduce. The environmental pressure affects which specific trait is desirable for adaptation.

If environmental resistance persists over time, progenies that have inherited traits that better fit them to the environment will out-compete others (of the same species). They will reproduce and be better represented by descendants in future generations. Gradually, individuals bearing the same successful traits become abundant in the population. This phenomenon is called differential reproduction—individuals with adaptive genetic traits producing more surviving offspring than others without such traits.

Eventually, the beneficial trait is spread to all members of a population. We can define natural selection as the differential reproduction of genetic types in such a way that a new trait is acquired by a population. The persistent environmental resistance is referred to as the selective pressure (or evolutionary pressure). This is one fancy, but more proper, way to say survival of the fittest.

Genetic diversity can be explained, of course, on the basis of genetics. A trait, in simple terms, can be represented by a gene. The possible variations of the same gene in a species (e.g. the gene that controls eye colors) are called alleles. The gene pool of a species is the collection of all the different alleles of each gene in a population. Genetic variation in different individuals arises from sexual reproduction and random mutation. Natural selection serves to retain desirable traits in the gene pool of a species. Through adaptation and specialization, there is a concomitant modification of the gene pool with time.

If natural selection is allowed to proceed over a long enough period, a new species may evolve from the original. Speciation is the term used to describe when the population of a species separates geographically and, through prolonged exposure to selective pressure, gradually develops into a distinct species. Generally speaking, evolution is the gradual, generational change in inherited characteristics of a population; it can lead to new species, but it can also lead to extinction of a species naturally.

On the whole, no species is assured of perpetual survival. Fossil records are filled with examples of new species emerging and others fading into extinction. One important factor that determines the survival of a species is its ability to maintain a stable balance with all other species in an ecosystem. Once a species has established a niche for itself, the adaptation
is in relation to both the physical environment (abiotic factors) and all the other species in the ecosystem (both predator and prey). Changes in the ecosystem depend on what is present. Once an organism dies, its traits are lost from the gene pool for good. Once a species is extinct, it cannot be recreated. (At least not without cloning techniques.)

Human-induced disturbances may select for undesirable traits in a species.

Overexploitation can exert selective pressure unwittingly in a way that selects for traits that may jeopardize the fitness of a population in the wild. Unlike genetic drift, human influence is not random.

One example is a snow lotus that has become smaller. This particular snow lotus inhabits rocky slopes high in the Himalayas and has been picked heavily for two reasons—it is valued in traditional Chinese and Tibetan medicine for treatment of headaches, high blood pressure and menstrual problems. It is also desired by tourists. In both cases, people collect the large flowering plants that are prettier and thought to be more potent and efficacious. Over close to a century, this harvesting pattern inadvertently selects for smaller plants. By evolving to become smaller, they are less attractive to pickers, and they also go to seed younger before they get picked. Plants in protected areas and other species of snow lotus retain their size over the same period.

The Atlantic cod faced a similar fate. Under heavy overfishing, the population that reaches sexual maturity has shifted toward younger and smaller fish. That is because all the fish genetically wired to breed at older ages and larger sizes were all caught. The fitness benefits of being bigger or more competitive, to have more mates, and more eggs disappeared. The result under overfishing selection pressure is a population of smaller fish that breed sooner. In another example, the age structure of the elephants in Zambia has become younger and with a large fraction of the population without tusks because poaching has reduced their numbers by some 90%.

The selection against slower maturity may jeopardize a species already at low population density. The age-truncation effect can make the population subject to wider fluctuations. With less eggs and lower seed yield, the risk of extinction increases. Indeed, the population of Atlantic cod collapsed and it has become commercially extinct—the population is so small that we cannot harvest it anymore. And in Zambia, the decimation of the elephant population also has destroyed the family unit, where young females learn about maternal behavior and survival skills. Instead, there has been a sharp rise of adolescent mothers without guidance and without protection from a social group.

The concept of biological diversity encompasses genetic diversity, species diversity, and ecological diversity.

**Biological diversity**, or more commonly just **biodiversity**, is loosely associated with the number of species on Earth. In more comprehensive terms, biodiversity can be considered at three different levels. We will define them here and do the explanation in the following sections.

- **Genetic diversity** is the variability in the genetic make up of a given species (i.e., variability in the gene pool). It is important for the survival of a species.
- **Species diversity** refers to the variety of species and their relative abundance. Species diversity can be used either in the context of a given ecosystem, or more broadly speaking, all the species on Earth. Species diversity is important for the stability of an ecosystem.
- **Habitat diversity** (or community diversity) is the variety of habitats in a given ecosystem. The area of an ecosystem is not the sole determining factor on the number species. A higher
habitat diversity provides more ecological niches for different species to exploit and the possibility for more species to coexist. Rain forests and wetlands are especially rich in habitat diversity.

We often find habitat diversity being equated to ecological (or ecosystem) diversity in a larger context. We may recall that biological communities are open; natural biota in them interact with each other. Different ecosystems also interact with one another through physical forces and altogether, ecosystems recycle nutrients and replenish soils, purify water, and regulate climate and the composition of the atmosphere. Ecological diversity affects the general health of the biosphere. (We cannot possibly have only condos and golf courses everywhere!)

**Survival of a species depends on maintaining its genetic diversity and on minimizing changes.**

Genetic diversity in the gene pool is an important factor which helps a species to counter environmental changes, and which in turn helps to prevent the extinction of the species. With a large variation in genetic types, there is a higher probability that some individuals may be better equipped to counter changes in the environment. Genetic diversity can be boosted by a wide geographic distribution and high reproductive capacity of a species. Of course, the extent of change (biotic or abiotic) is also a factor; the smaller the change, the easier the adaptation.

Variability in the genetic makeup arises naturally during sexual reproduction as an offspring inherits its parents’ genes. Changes may also be due to mutation—infrequent mistakes introduced during DNA replication. Mutations occur naturally, and their effects are observable easily in microorganisms such as viruses and bacteria. Mutagenic agents such as radiation or certain toxic chemicals can accelerate the frequency and extent of mutation. Genetic changes are not always favorable. A mutation can be lethal to a progeny. Nevertheless, in rare circumstances, the change may lead to a trait that allows the progeny to be better adapted than its parents or its siblings. The progeny may produce more offspring—the process of differential reproduction and natural selection.

**Species diversity provides ecosystem stability.**

Species diversity refers to the number of different species and their relative abundance. In a natural habitat, population balance among different species is maintained by complex feeding predator-prey or host-parasite relationships in the food web.

Only a relatively small number of animals is so specialized that they prey on one single species. A predator can insure against scarcity of food and increase its chance of survival if it feeds along different food chains within a habitat. When the population of one particular prey is low, the animal feeds on something else.

In this sense, predators help to foster diversity at the lower levels of the food web by consuming the most abundant prey and even out the competition among the preys themselves. Likewise, herbivores also help to promote diversity of plants by feeding upon the buds and seedlings of the most abundant species.

When we look at an individual species, its population fluctuates in an ecosystem according to biotic or abiotic environmental stresses that predominate during a given period. However, feeding relationships within a complex food web can help to reduce drastic “bust and boom” fluctuations and the chance that a species may become extinct.

In physics, stability is the ability of an object to withstand disturbance and to return to the original position after someone pushes it. With something as complex as an ecosystem, it
would be an oversimplification if we use only one metric to define its stability. Nonetheless, we often have to resort to choose one quantity that may reflect the stability of an ecosystem in a general way. In this respect, the stability of an ecosystem can be measured in terms of the total biomass of all the species and defined as how it may recover after a disturbance. Even as populations of various species fluctuate, the biological community can be stabilized if there is a large enough number of different species. With a complex food web, there is a good chance that different species will establish in wider ranging ecological niches. When a disturbance imposes an environmental resistance, it may harm some species, but unharmed competitors may thrive and maintain the total community biomass. Hence, a diverse community with species diversity is considered to be more stable.

On a broader perspective, stability also depends on the ability of the ecosystem to recycle and retain nutrients. The total biomass of all the species again can be used as a measure of ecosystem productivity. With more species present to take advantage of various ecological niches, the result is an ecosystem that can more effectively recycle and utilize nutrients and other natural resources—in other words, more productive. Indeed, it is well established that the primary productivity of many ecosystems increases with the number of plant species.

We can take a simple grassland as example. With a mix of grasses with different root systems and with leguminous members, the grassland ecosystem as a whole can more effectively recycle and absorb nitrogen, and reduce the amount that may leach away. The reward of better plant growth (the producers) will permeate up the food chain, helping to sustain a larger animal population.

Indicator species are like a coal mine canary. They reflect the general health of an ecosystem.

In conservation projects, we may come across the use of two identifications: indicator and keystone species. There is no strict measure to define what characteristics would qualify a species to be defined as an indicator or a keystone (in the next section). Furthermore, the importance of a species may change in time or in location. The two terms are just a general conceptual reference.

An indicator species (also called sentinel species) tends to be highly specialized and its well-being is a general indication of the status of the ecosystem where it inhabits. When its population drops, an indicator species serves as early warning that an ecosystem is being degraded.

Amphibians like frogs and salamanders are notable examples of an indicator. They live at the interface of land and water, and their thin, permeable skin makes them vulnerable to pollutants and environmental changes. With their dependence on a wide range of habitats between north and south and along the flyway, migratory birds can also be considered as an indicator species.

An important indicator of the aquatic ecosystem is freshwater mussels, particularly in the streams of Southeastern United States. Freshwater mussels work like a biological water filter and can be harmed by poor water quality. They have a unique life cycle that after hatching from an egg, a larva attaches itself to the gills or fins of a host fish. But dams on the river prevent fish from swimming upstream to help the mussels mature and disperse. As a result, many freshwater mussel species are on the endangered list.

Keystone species can regulate the population dynamics of other species.

Keystone species have a marked influence on ecosystems out of proportion to their relative abundance. They may carry out essential functions not performed by other species. Their
impact may be on species diversity or in changing energy flow. A common keystone example is the beaver. By building dams on a stream, they make ponds and marshes that in turn harbor many other species in a riparian habitat.

Often, predators at the top of a food web (the apex species) play the role of a keystone; they feed on and consequently regulate the populations of other species. Their removal changes the structure of the biological community. Examples are the wolf and the mountain lion in most parts of North America. Their removal or decrease in population has led to the population explosion of deer and elk. The increase in deer and elk in turn exerts a heavy pressure on young plants.

In the prairies, both the huge bison and the tiny prairie dogs are considered keystone species important for healthy grasslands. Bison apply grazing pressure on the grass species. The burrows and grazing of the prairie dogs help to maintain good soil properties, not to mention that they are the major prey of the black-footed ferret.

The keystone concept can encompass much smaller species such as pollinators. One example is the small seed-eating kangaroo rats in the Southwestern deserts in the United States. Many plants, insects and vertebrates rely on disturbance, shelter or stored food provided by their mounds. Their diet indirectly regulates the plant community, which in turn affects the bird populations.

Because of their influence, keystone species are a major focus of conservation policies. Habitat protection by itself is not enough; we need the proper population balance and dynamics. The loss of a keystone species in an ecosystem may lead to cascading losses of species as the effects work their way through the food web. The sequence of population disruptions that passes from one level of the food chain to another is referred to as a trophic cascade (it's like an ecological domino effect). In dire circumstances, the cascading disruption can lead to species extinction.

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**Invasive species are nonnative species that cause environmental or economic problems.**

When a nonnative (also referred to as introduced, alien, or exotic) species is introduced, it will disappear if it fails to establish an ecological niche. Occasionally, the introduced species will thrive if it is better adapted to the local environment or if there are no natural predators, and it becomes invasive. The invasive species may compete for available resources, or it may prey on the native species. They may be so competitive that they drive the indigenous species to extinction. In many cases, these invasive species can cause significant ecological disruption and economic damage.

Endemic species of ocean islands such as Hawaii are particularly vulnerable. These islands generally did not have large animals, and most species in time discarded defensive evolutionary adaptations that deal with predators. They suffered from the first wave of assault from Polynesians, who decimated the bird population and introduced rats that came along as hideaways. Then came the Europeans with their many plants and animals, including goats, pigs, and rabbits. Today, Hawaii has the largest number of endangered species in the United States, and by one account, more than one half Hawaii's free-living plant and animal species are introduced. Even leis are made from nonnative flowers.

The list of introduced species in the U.S. is long; it includes even the house cat. More common examples of nonnative species include the Norway rat, tumbleweed, yellow star thistle, and eucalyptus whose existence we have taken for granted. Other notable examples are goats, wild pigs, wild burros, Japanese beetle, and the gypsy moth. Less known examples are earthworms and European honeybees. Moreover, we can count blight (a fungus) that infects chestnut, carp in rivers and lakes, water hyacinth in Florida waterways, the zebra mussel in the Great Lakes, and brown tree snake in Guam.
Many nonnative species are introduced as stowaways on cargo ships, especially in ballast water. To balance the weight of an empty ship, we fill the ballast with water. (Stones and soil were used in the old days.) When the ship arrives in a new port to load its cargo, it dumps the ballast water, together with any living organisms from the original port. Because we import and export goods, nonnative species are introduced in both directions of any international commerce.

Ecosystems undergo continual disturbance and recovery. Successional changes are the different stages of development in a biological community.

Because a population is the result of dynamic balance, it comes as no surprise that biological communities exist in a continual state of flux. When an environmental factor is altered or when a habitat is disturbed, the ecosystem slowly recovers or rebuilds. The sequence of changes initiated by natural disturbances is called succession. A common observation is that a species is being displaced by others over time. Disturbances commonly are restricted to a small region. Thus, over a larger region, an ecosystem is made up of a mosaic of various successional stages.

Primary succession refers to the development of plant communities in newly formed habitats previously without vegetation (sand dune, lava flow, bare rock after erosion or exposure by a glacier) and their subsequent changes. The gradual fill-in of bogs is considered as primary succession.

Secondary succession is the return of an area to its natural vegetation after a major disturbance (e.g., forest fire or clearing, flooding, hurricanes and tornados). The various stages of changes are called seres. The very early stages are made of relatively simple pioneer communities. The final stage where a biological community reaches equilibrium with its surroundings is the climax. Successional changes are found in all kinds of habitats and each stage has its characteristic biological community. The richness of the community generally increases with time until the final climax. Major ecological regions such as prairie, tundra, scrubland, and different kinds of forests are climax communities.

Many processes and factors govern the course of succession. The pioneer communities are dominated by species which have short life cycles and strong dispersal power, helping them to establish themselves quickly. In many circumstances, they create a development stage that facilitates subsequent seres by modifying and improving the microenvironment (nutrients, soil property). The most prominent example is legumes that harbor nitrogen-fixing bacteria in their root nodules. Another example is the shading by pines of the seedlings of subsequent hardwoods like oak, beech, and maple.

The early invaders eventually give way to species that can exploit resources more effectively (e.g., trees with deep and extensive root systems). Species in the climax community are considered superior competitors, but they grow more slowly and do not express their dominance in the habitat until others have grown up (see Figure 1).

Relatively speaking, changes are rapid at first. Successional progression becomes slower as the vegetation type reaches the tallest growth form that the environment can support. Eventually, the climax biomass dimensions are limited by physical (climatic) factors.
Until we can draw them, we need to imagine that some little trees and some big trees will be grown in this spot.

| Grasess | Shrubs, seedlings of shade intolerant species | Saplings | Young forest | Mature forest | Old growth forest |

**Figure 1.** Secondary succession in a coniferous forest. [Adapted from Anderson et al., Fig. 9.4, without the drawings]

**Succession is a very slow process.**

It should come as no surprise that succession is slow. Succession results from variations in the ability of organisms to colonize disturbed habitats (i.e., adaptation) and from changes in the environment following the establishment of new species in a habitat.

The time for succession varies with environmental factors (regional and local climate), but is generally long. It takes 25-30 years to reestablish a pine forest from cleared fields, and it takes about 150 years for a mature oak forest to develop in North Carolina. Even reaching the climax stage of western grasslands may take 20 to 40 years. Primary succession may take even longer, over a thousand years from sand dunes to a birch-maple climax forest in Michigan.

The process can be faster in the tropics if the soil has not been eroded. But after farming and prolonged exposure to sun and rain, the succession process from eroded landscapes may take centuries.

**Survival of many species in nature depends on disturbances.**

In nature, occurrences of disturbances and even catastrophes are inevitable. Many species have adapted to specific changes in the environment. The well-being of an ecosystem may even depend on periodic natural disturbances.

Hurricanes can help wipe out invading trees that shove aside native ones. Open spaces that hurricanes make in a forest canopy let in sunlight and allow wildflowers and other “gap species” flourish. The best food supplies for Northern California’s steelhead trout are in streams that are scoured by heavy floods.

Prairie grass species in the Midwest are well adapted to disturbances, which include grazing by animals and many of them can thrive only in the wake of major fires. Scientists now realize that eliminating grazing is not entirely desirable because cattle have replaced bison that once romped the plains and provided the disturbance required for prairie plants to prosper. *

Another prime example is the Colorado River. Before we built the dams, especially the Glen Canyon Dam 15 miles above the Grand Canyon in 1963, spring and summer floods were a fact of life. The plants and animals of the river and the Grand Canyon shores have evolved with the floods and are superbly adapted to them.

* Of course, we may want to replace cattle by bison, but the political and economic climate is against us.
The flood used to help stir up sediments of nutrients in form of decaying vegetation and other organic matter. The liberated nutrients fed algae at the bottom of the food web and re-nourished native streamside plants like honey mesquite and coyote willow. Floods also scoured sand from the river bottom, pushed boulders out into the river, and in the process created and refurbished habitats such as sandy beaches, eddies and backwater behind sandbars for native fish.

Without the floods, nutrients remain inaccessible, and sandbars and beaches eroded. Native fish and plants are also being crowded out by invading species such as catfish, carp, and the tamarisk.

Human beings have worked hard to eliminate the negative (economic) impacts of natural disasters. As a result, species that depend on fires and flood have suffered because of firefighting and dams. An entire ecosystem may be affected by dikes and channels as in the case of the Everglades. Sometimes, these efforts have unexpected consequences. The dikes along the Mississippi River, built to control flooding, eliminated the flood plain, aided the erosion of the delta, and actually exacerbated flooding.

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Fire—a very important abiotic factor that regulates population.

The dynamics of ecosystems and the regulation of biological communities are affected by many factors. One of these factors that has received much attention is fire. Periodic fire, mostly started by lightning, is a natural abiotic factor that helps to maintain population balance in many ecosystems.

Different plants have different adaptations, which can be resistance to fire or capabilities to re-establish after a fire. In the prairies, fire kills woody species and weeds, but grass with buds protected in the ground readily survives and regrows. In a pine forest, ground fire removes excess fuel (deadwood) and kills competing species. Pines, with their growing buds protected in the needles, are more resistant to fire than broad-leaf trees, and lodge-pole pine cones will not release their seeds until they have been scorched by fire. In dry ecosystems, fire is important in releasing nutrients from dead organic matter. (Without moisture, decomposition is slow.)

After a century of fire suppression in U.S. forests, low-lying brush and saplings have continued to grow. Once a fire breaks out, the younger trees offer ladders for the spreading fire to climb, while the accumulated deadwood on the forest floor provides additional fuel. When fires reach the canopy 150 to 200 feet above ground, “crown fires” can grow so hot and spread so quickly that they become out-of-control infernos.

Forest fires caught the attention of the general public when over 700,000 acres were burned in the Yellowstone National Park during the summer of 1988. For years, all fires were suppressed in national parks, and it was not until the 1960s that ecologists began to understand the dynamic nature of ecosystems and to question the value of fire suppression. In 1972, an experimental program which allowed natural fires ignited by lightning to burn was implemented at Yellowstone and the decision was made an official policy in 1976. The “let burn” policy was extended to other national parks and was considered successful until the huge fire in 1988. Despite the criticism of those who questioned the fire policy, Yellowstone has shown tremendous resilience and its recovery (succession) after the fire is now a textbook example in succession.
The study of succession provides a revealing perspective on modern agriculture, and more specifically monoculture in which a huge industrial farm grows nothing but one single crop. The farm as an ecosystem is akin to a pioneer community. Some of its characteristic features in contrast to a matured community is summarized in the table below:

<table>
<thead>
<tr>
<th>Pioneer Community</th>
<th>Climax Community</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Immature</td>
<td>• Mature</td>
</tr>
<tr>
<td>• Small plant size</td>
<td>• Large plant size</td>
</tr>
<tr>
<td>• Low trophic structure (predominantly producers and decomposers)</td>
<td>• Complete trophic structure (producers, consumers and the detritus community)</td>
</tr>
<tr>
<td>• Simple food chains</td>
<td>• Complex food web</td>
</tr>
<tr>
<td>• Species have generalized niches</td>
<td>• Species have specialized niches</td>
</tr>
<tr>
<td>• Low efficiency in recycling nutrients</td>
<td>• Nutrients recycled efficiently</td>
</tr>
<tr>
<td>• Low stability</td>
<td>• High stability</td>
</tr>
</tbody>
</table>

*Example: modern agriculture (monoculture)  Example: nature (natural habitats)*

A pioneer community or young ecosystem is populated with mainly large numbers of fast growing species. The ecosystem is specialized in growth. On the other hand, a matured ecosystem is stable, and while it does not play a significant role in production, it provides us with crucial ecological functions and services (Chapter 2a).

Monoculture can be very productive, but with a simple biotic structure, it is inherently unstable. It comes as no surprise that the agriculture industry has to rely so heavily on fertilizers and pesticides to sustain productivity. From a pragmatic perspective, we need both types of ecosystems: young ones for the production of food, and mature ones for ecological services and stability. Over a reasonably large region, nature itself is a mosaic of biological communities at various stages of succession. Any debate is on the fact that modern agricultural corporations have become so enormous that they have tipped the proper ecological balance. Of course, we can reintroduce biodiversity back into our agricultural practices, and this idea is reinforced in scattered places in Chapters 4 and 5.

Modern agriculture is threatened by declining biological diversity.

We just mentioned in the last section that modern agriculture that is predominated by monoculture runs counter to biological diversity. Over 80% of our food staple is based on just five plants: wheat, corn, rice, soybean, and sugar cane. Under natural selective pressures, wild populations exhibit “genetic vigor,” not only harboring numerous traits to compete or to resist pests, but to adapt to changing conditions. On the other hand, cultivated crops are bred for their excellent production capabilities, but they have a minimum of genetic variation. Needless to say, these highly selected strains are more susceptible to climatic condition changes.

To maintain vigor in cultivated vegetation, we have to continually crossbreed high yield strains with related species in the wild which carry desired traits. Hence, natural biota function as a gene bank. Preservation of a healthy diversified natural biota is important for the long-term viability of our food production.
Similar reasoning applies to forestry products and medicine. A large number of our fruits originate from the rain forest. A commonly cited figure (mentioned also in Chapter 2a) is that about one quarter of our medicines contain compounds that were originally derived from rain forest species.

Many human factors have led to the erosion of biological diversity.

The world faces an unprecedented mass extinction. While the extinction rates may be debatable, many reasons for species extinction are obvious. We have touched upon some of the reasons in the Introduction chapter. Here is a summary of the major factors that contribute to species extinction:

- **Habitat loss.** This is a consequence of agricultural and urban development, and the more insidious suburban sprawl. The effects due to human development may be indirect. The population of winter-run Chinook salmon on the West Coast is decimated because of all the dams and diversions built on rivers. The dams form barriers to salmon swimming upstream to their spawning grounds, and the huge reservoirs impede the fingerlings' return to the ocean.

- **Habitat fragmentation.** Breaking up habitats into isolated, small islands restricts the movement of wildlife and can have deleterious demographic and genetic effects (for example, through inbreeding). Fragmentation also exposes the edges of the habitat islands to climate changes and even upsetting the balance of predator and prey. The edges also make it easier for humans to collect firewood, forage livestock, and hunt for bushmeat. In the Amazon, when edge effects are included, the total area affected by deforestation is almost three times larger than the area shorn of trees.

- **Overexploitation.** A classic tragedy of the commons. There are abundant examples such as hunting, poaching, predator control, overfishing, and whaling.

- **Invasive species.** A disruptive introduced species can out-compete and drive indigenous, and especially endemic, species to extinction.

- **Pollution.** The use of DDT (a pesticide) is responsible for the demise of many bird populations, including the bald eagle. In the future, climate change due to global warming may have catastrophic effects.

A main reason for the degradation of the natural environment is population pressure, but there are other cultural factors that have compounded the problem. Here is a summary of the human factors that contribute to biotic degradation:

- **Population growth.** The continuous increase in human population exerts population pressure on many ecological and evolutionary processes and functions. (This essentially is a review of Chapter 1.)

- **Poverty.** Problems due to population pressure are compounded by poverty and hunger, the reasons for deforestation, poaching, trade in rare and endangered species, and failure of grass root support.

- **Overconsumption.** Significant population pressure arises from the affluent lifestyle of the rich too.

- **Cultural transitions.** Most of the world's people are in a transitional demographic phase (recall Chapter 1). When a population is colonizing uninhabited territory and undergoing rapid social change, little value is placed on resource management and the protection of nature.

- **Misperception.** Benefits of conservation projects can only be measured on a long time span—easily decades and longer. On the other hand, governments often want immediate
results, and tend to overreact to sudden events of lesser long-term impact, while denying long-term failures. Our general concerns are utilitarian and human-centered (anthropocentric)—most of the humanitarian aid money goes to religious organizations, followed by medical, cultural, and social welfare causes. We need more “biocentric” economic policies.

• **Economics.** The demands from the industrialized countries for so-called cash crops like coffee, sugar cane and banana, and other products like hard wood, beef, and shrimp are responsible for the destruction of many habitats in developing countries. Similarly, governments worldwide have largely subsidized the mechanized fishing industry.

• **Policy implementation.** Most poor developing countries lack the financial resources to preserve nature. The problems are exacerbated by social and civil disruption, corruption, and failure of law enforcement.

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**Some characteristics of endangered or threatened species.**

Many endangered species have narrow ecological niches or are specialists. Now that we know more about factors that lead to loss of biodiversity, we can be more specific about the characteristics that may be associated with endangered and threatened species. In many ways, this is a review.

First, let’s recall that a reference to ecological niches is general. The specific niche can be the habitat niche, the food niche, the reproduction niche and so on. Secondly, we should clarify that an *endangered* species is one that has such a small population that it could become extinct over its natural habitat. A *threatened* species is one that still has a relatively large population but its numbers is declining and is likely to become endangered. Under current federal regulation, the habitats of both endangered and threatened species are similarly protected. Now finally some characteristics of species prone to become endangered:

- Species that have very specialized nesting or breeding areas (i.e., narrow habitat niches or geographic ranges) are especially sensitive to habitat loss. Examples are the least tern which only makes nests on sandy beaches, and the California gnatcatcher which needs the coastal California sage.
  
  Under some circumstances, the habitat is tied into specialized feeding habits (food niche). Examples are panda feeding only on bamboo, koala feeding on certain eucalyptus leaves, and the black-footed ferret preys on only the prairie dogs.

- Species that require extremely large territories. One example is the California condor, which needs hundreds of square miles. Another example is migratory birds. They need wintering grounds like tropical forests in the south and summer spawning grounds as far north as the Arctic, and wetlands along the migratory route (the flyway).

- Species with low reproductive rates or very specialized reproductive niches. Examples are sharks, the giant panda, and sea turtles.

- **Endemic island species** which are very specialized, and have evolved in isolation and in absence of competitors and predators. Numerous examples of threatened endemic birds and plants can be found in Hawaii.

- **Top predators** that may prey on livestock or people. The gray wolf, grizzly bear, mountain lion, crocodile, and so on have all been mercilessly poached or exterminated to protect human interests.

At the other opposite extreme to these examples are generalists or opportunists. A prime example is cockroach, a prolific breeder and generalist feeder. Other good examples are sea gulls and coyotes, both show an unsurpassed display of adaptability.
Why do we want to preserve natural biota and habitats? A summary of the important points.

1. Utilitarian reasons—the argument that natural biota and habitats are useful to human society. (Recall ecological services in Chapter 2a.)
   - Resource for agriculture, forestry, and medicine. This is the most common utilitarian justification. Natural biota are equivalent to a gene bank that is vital to the long-term viability of our food crops, medicine—and human needs. Production of food crops depends on continued introduction of fresh genetic characteristics by crossbreeding with wild strains to create new hybrids (also called cultivars). Many undiscovered species in the rainforests may be important medicinal drugs.
   - Tourism and commercial interests. While it may not be agreeable to land developers, natural biota support a fairly large economy based on tourism and recreational activities, and thus have commercial value. Ecotourism to observe wildlife within protected areas is a major and growing source of income for many developing countries.
   - Pollution cleanup. Certain plants and bacteria can remove toxic chemicals from the environment. Because different species have different capabilities, a diversity of species can provide more effective pollution clean up.

2. Ecological reasons—the argument that a species is necessary to maintain the functions of ecosystems, which in turn provide their natural services.
   - Conserve ecosystems. Species interact with one another, and each plays a role such as pollination, dispersal of seeds, nutrient cycling, or simply as part of a food web to help maintain a stable and functional ecosystem.
   - Conserve ecological functions. Forests, wetlands, and even the lowly soil biota function like the lung and kidney of the earth in helping to clean up air and water and recycle nutrients. Preservation of habitats and conservation of natural biota are important to keep our natural resources renewable. It is important to note that we cannot emphasize saving species alone; we must look at the broader perspective of saving functional ecosystems.

3. Aesthetic and cultural reasons—arguments based on the belief that all species have a moral right to exist, independent of our need for them. Or how big or small. And regardless of whether they are charismatic. In addition, many indigenous people still rely on nature to provide food and shelter.

Better management through conservation biology?

We have attempted to explain that nature has its own delicate mechanisms of regulation and population control in a community. All organisms are subjected to limiting factors or environmental resistance. Humans, on the other hand, have overcome the natural constraints—natural feedback control mechanisms no longer work, recruitment increases, and the human population explodes.

An extension of studying community biology is conservation biology. Its aim is to understand how to sustain the viability of natural biota or an ecosystem. We want to answer questions like what is the minimum viable population of a threatened species? In practice, we want to know how to manage or regulate the use of natural resources, or in even simpler terms, how much can we take? Obvious issues include cattle ranching and grazing, and limits on logging, hunting, and fishing. Other useful applications are in the design of nature reserves, habitat restoration, and reintroduction programs.
Most biological resources have an upper limit on how much we can exploit. If our harvest exceeds this limit, we will decrease the population so much that it undercuts the long-term productivity of the system. Hence, from a management perspective, there is a **maximum sustainable yield**. If we exceed this upper limit, the harvest will eventually decrease because of a lower population. If we harvest below the maximum sustainable yield, we may be losing “products” to natural competition. Of course, the maximum sustainable yield varies with species, ecosystem, and time. Determining the maximum sustainable yield is a difficult task that is subject to the whims of politicians.