Lesson 3
The Diversity of Life

Gro Torsethaugen, PhD

Penn State Biology - BISC 003: Environmental Science
Over millions of years, life has evolved to the tremendous diversity we see today. Approximately 1.2 million eukaryotic species have been named and described to date + another 700,000 or so described but yet not added to the central databases.

Estimates of the actual number of species on earth range from 5-30 million (Encyclopedia of Life, www.eoearth.org), a recent study pinpoint the number to 8.7 give or take 1.3 million (http://www.sciencedaily.com/releases/2011/08/110823180459.htm)

Biodiversity can be defined as the variety of living organisms in the world or in a particular habitat or ecosystem, including variation within and between species.
With so many species, it is critical to have a working classification system. Taxonomy is the science of naming and classifying things. Taxonomy can be a dry topic, although knowing scientific names for organisms is one of the quickest ways to impress non-scientists.

In 1758 Swedish botanist Carl Linnaeus created and published the system still used to formally name and describe species today, the binomial classification system. In this system each species is given a two-part name; the genus and the species name. One example is *Odocoileus virginianus*, or what most of you know as the white tailed deer. *Odocoileus* is the genus name and *virginianus* is the species name. All deer species share the common genus name, while each species of deer have their own unique species name.

But why bother devoting so much time and energy to naming and classifying living organisms? There is basically a three-fold rationale behind taxonomy, what we can call the three Cs of taxonomy; convenience, communication, and comprehension. It is easier to find what you need if you know where it is. Categorizing things with common features is a natural human tendency. In traditional and modern classification systems, similar organisms are grouped together. Like in our example; all deer are closely related and they are grouped in the same genus.

Standardized names make communication easier. One species typically have a different name in each language around the world, and even within the same country or region people have through times
given different names to the same species. Through the binomial classification system each species is given one Latin or binomial name that is used by scientists and others around the world.

The comprehension side of taxonomy relates back to the basic human desire to understand how the world works. Though initially developed for convenience and communication, the focus of modern taxonomy is to classify organisms in a way that reflects the evolution of those organisms. This is called a phylogenetic classification system.

**Taxonomy**

- Science of naming and classifying things
- Carl Linnaeus – father of taxonomy, came up with the binomial classification system
- Binomial names: genus and species epithet
  Example: *Odocoileus virginianus* (white tail deer)

**The three Cs of taxonomy**

*Convenience*: easier to find and store information about species  
*Communication*: same language around the world  
*Comprehension*: evolutionary relationships, phylogenetic classification system

This is an example of a phylogenetic tree, one that show the three domains and six kingdoms used to organize all species on earth. Taxonomy is not static. As new knowledge about species is gathered, changes to the classification system are made and scientists do not always agree. This makes it challenging to get a handle on how organisms are classified. Until the dust settles, we will use the basic and generally accepted system shown here. Species are grouped into three domains: the true bacteria (those you are the most familiar with, including *E. coli* and salmonella), the archae or ancient bacteria, and the eukaryotes. The domains are traditionally divided into six kingdoms. These include the prokaryotic kingdoms of the archae and true bacteria, and the eukaryotic kingdoms of the protists, the plants, the fungi and the animals.

Species within these kingdoms differ in many ways, including how they obtain nutrients. As you may remember from lesson 2, plants use photosynthesis, animals consume plants or other animals and fungi
secret enzymes into their surroundings that break down organic material and then absorb those nutrients.

A phylogenetic tree showing all 1.2 million known species on earth would obviously be very large so scientists typically design phylogenetic trees with just a small subset of species, orders or classes. This is an example from the animal kingdom. Within this kingdom there are many different phyla, including the Arthropoda phylum, and within this phylum there are many different classes, including the insect class. And within the class of Insecta we find the order of Diptera, or true flies.

The Diptera order is one of the most species rich orders, making up around 12% of all the known animal species on earth. An estimated 125,000 species of Diptera have been described.

Within the order of Diptera we find several suborders and families, and not show in this figure, within each of those families you will find many different genus and within each of those, many different species.

This is just an example to illustrate how species are organized and also a small glimpse into the amazing diversity of life on earth.
So why are there so many different species?

The biodiversity we see on earth today is the product of evolution. In the simplest terms, evolution is the change in the genetic makeup of a population over time. A couple of things you should remember about evolution is that evolution is a population event. A population is a group of individuals of the same species. A population can be small or large. You can talk about the population of humans in your hometown or the population of humans in the world. You and I as individuals do not evolve, but the human population is evolving. You should also realize that evolution is a long-term process over many, many generations and thousands of years.

Take a look at the first page in chapter 3 to learn more about Charles Darwin and how his discoveries at the Galapagos Islands lead to the scientific theory of evolution. He was the first to explain how natural selection leads to evolution and increased biodiversity.

There is one final type of heterotroph; those that feed on living hosts. Pathogens and parasites are found in all the kingdoms of life—there are parasitic plants, animals and fungi as well as pathogenic bacteria. In general, parasites are multicellular organisms that feed on a living host, and pathogens are single celled organisms that cause disease.
Natural selection is the process by which individuals more likely to survive are more likely to reproduce and therefore more likely to pass their genes, and corresponding traits, on to future generations. Natural selection is the driving force behind evolution and helps explain why the genetic makeup of a population can and will change over time in response to various environmental factors. The beginning premise of natural selection is that in nature, there is an overproduction of young. Regardless of an organism’s life history strategy, there are always more young produced than can survive. In addition, there is variability in most natural populations. Variation within a species is a result of random mutations (changes in DNA) and sexual reproduction. So, in a naturally occurring population, more young are produced than the environment can support and these young are not genetically identical. As they grow and develop, they will compete for limited resources such as food, shelter and mates. Individual organisms will also be more or less well adapted to the current environmental conditions. Any factor that influences the evolution of a population is called selection pressure. Selection pressure can be environmental factors or other organisms in the same ecosystem.

Competition between members of the same species goes on every day right under your nose; think about spring with the return of migratory birds that fill the air with their song. That song is not for you, it is to attract a mate and to declare a territory. In this case, the limited resource may be suitable nesting sites or a good mate. This brings us to the final step in natural selection: The better competitor is more
likely to survive to reproductive age and thus more likely to reproduce. Natural selection and evolution is not simply about “survival of the fittest,” it is about reproductive success. In the case of the songbirds, those individuals that through their song are able to secure a good territory and attract a mate are more likely to reproduce, passing their “good song genes” on to the next generation. In this example being able to sing well is the adaptive trait, and the limited availability of nesting sites as well as the mate’s preference for song are selection pressures, or the factors that affect the evolution of the song bird population.

**Natural Selection**

The process by which individuals more likely to survive are more likely to reproduce and therefore more likely to pass their genes, and corresponding traits, on to future generations.

- Overproduction of young
- Genetic variations: beneficial mutations (traits) and sexual reproduction
- Competition for resources
- Adapted to current environmental conditions, adaptive traits
- Selection pressure
- Reproductive success
- Differential reproduction

There are several factors that determine what sort of organism lives where. To understand which factors determine who lives where, it is helpful to introduce the concepts of habitat and niche.

**Habitat** is the term used to indicate the address or location where an organism can live—the physical, chemical, and other abiotic conditions that are suitable for that particular organism. Habitat also includes the vegetation of a given area, as vegetation not only provides food for animals; but also shelter and a place to live.

The ecological niche of an organism is a more complex concept. **Niche** is the functional role of an organism—how it fits in a particular ecosystem. Niche includes habitat, feeding and nesting habits, relationships with other organisms, and all the factors that go together to describe how an organism fits
in a particular community and ecosystem. The number of available niches relates to the diversity of the habitat- the more diverse the habitat, the more diverse the community and the more niches. The same holds true for food sources - the more diverse the food sources, the more diverse the community. This is something to keep in mind when reading about **biodiversity hotspots** – areas with a large number of species.

### Habitat and Niche

#### Habitat
- address or location of a species
- abiotic factors and vegetation (food and shelter) that are suitable for an organism

#### Niche
- functional role of species
- includes habitat, feeding and nesting habits, relationships with other organisms

Now let’s consider the types of organisms you see on a daily basis. Environmental conditions like temperature, nutrients, moisture and light determine where each species is able to live, this is called tolerance range.

Some organisms have a very wide **tolerance range** and can survive in a number of different habitats. Such species are **generalists** and tend to adapt and fare well when they come in contact with humans. Contrast this with organisms that have narrower niche requirements, whether it be a specialized diets or specific nesting needs. Such species are called **specialists** and tend to fare poorly when they come in contact with humans.

As an example we can compare the opossum, a generalist with the porcupine, a specialist. The opossum is an omnivore with a territory determined by food availability: the more abundant the food supply, the denser the population. Opossums are common residents of even urban settlements and thrive in contact with humans.
A similar sized mammal, the porcupine is an herbivore, eating the tender bark of trees, vegetation and fruit. They are found only in areas with sufficient tracts of forest. Unlike the opossum, porcupines are highly territorial, especially in the summer. Porcupines are much less common than opossums in human-dominated areas.

From the plant kingdom we can compare the dandelion that can live anywhere, including cracks in a parking lot to orchids, most of which are very specific in their needs. Most wild orchid species will die if removed from their original location—unless similar temperature, light, humidity and nutrient requirements are provided.

### Generalists and Specialists

**Tolerance range:** the environmental conditions (temperature, nutrients, moisture, light etc) that one particular species can survive within

**Generalist**
- wide tolerance range
- typically do well around humans

**Specialist**
- narrow niche requirements;
  specialized diet or specific nesting needs
- typically do poorly around humans

The interaction of the opossum and porcupine could be categorized as a neutral interaction in that they do not normally directly interact with each other. A more direct interaction occurs between the opossum and its prey such as the earthworm. **Predation** is a necessary fact of life for most consumers, even herbivores. You may not perceive a rabbit or cow as a fierce predator but to a grass plant, they absolutely are. Predators and prey have coevolved an impressive arsenal of offensive and defensive weaponry. Consider that plants cannot run away—they are still not defenseless against herbivores. A host of nasty poisonous compounds that plants produce is evidence of their sophisticated defenses. Plants can also camouflage themselves. Several different species of desert plants mimic stones, thus protecting themselves from predation.
As we already discussed competition between members of the same species is a driving force behind natural selection, this is called intraspecific competition. Competition between members of different species is called interspecific competition.

Not all interactions between organisms are detrimental. One example is the relationship between legumes and nitrogen fixing bacteria that is beneficial to both organisms; the bacteria helps the plant absorb nitrogen and the bacteria get nutrients from the plant in return. This is an example of a symbiotic relationship called mutualism. Another type is a commensalistic relationship; one organism benefits where the other is unaffected. An example is a bird living in a tree, beneficial for the bird while the tree probably doesn’t care one way or the other. And finally, parasitism is a relationship where the parasite benefits but the host is negatively affected.

Species Interactions

- Predation
  - Coevolution of prey and predators
  - Toxins and camouflage in plants
- Competition
  - Intraspecific
  - Interspecific
- Symbiosis
  - Mutualism
  - Commensalism
- Parasitism

To describe a population we may include information such as plain total numbers, gender and age distribution. However, the size of the population does not tell the whole story, as a population does not remain constant. Population dynamics describe how the size of the population changes over time. Consider a small generalist species and how its population changes through the course of a growing season. Early in the growing season, the population can experience exponential growth. The population grows not just in total numbers but at an ever-increasing rate. Such a growth spurt cannot be maintained. Ultimately, the population will hit some sort of environmental resistance. This limitation to population growth is referred to as the carrying capacity of an environment. Some populations
overshoot their carrying capacity and go through cycles of boom and bust. Others experience a more measured increase or logistic growth. Though the population initially grows exponentially, it feels the impact of environmental resistance long before it reaches the carrying capacity for the population. This is something to keep in mind when you study the human population in the next lesson.

**Population Growth**

*Population dynamics*: how population size changes over time

![Graphs showing exponential and logistic growth](image)

**Carrying Capacity**: limitation to population growth, environmental resistance

This difference between exponential and logistic growth sets us up to discuss different life history strategies of organisms. Some species are r-adapted or opportunistic species, whereas others are K-adapted. The dandelion is a classic r-adapted species. It is small, has a short life span, and invests its energy into producing lots of young with little parental care. Contrast this with a coconut. A coconut is a single seed, probably the biggest seed you are likely to see. K-adapted species are typically large, have long life spans and invests their energy into caring for only a few young. As is typical in biology, not all species fit neatly into these categories. The bullfrog, for example, produces a huge number of young but does invest some energy in protecting those young even after they hatch.
We can now start to put the pieces together and examine how ecologists describe communities. A community is the populations of all species that live within an area, while an ecosystem is the community plus all the abiotic or non-living things in an area, like rocks and soil.

How would you go about describing a community? Just as for a population, the logical thing would be to count the total number of individuals; this will not necessarily tell you much about the community itself though. You might first want to take a look at how productive that community is. The producers determine Productivity. The most productive ecosystems are those where the producers are the most abundant, such as the tropical regions of the world and the coastal regions, including coral reefs. Desert ecosystems do in comparison have a relatively low productivity. It is also important to examine the diversity of an ecosystem, which is the number of different species. Though it may seem like ecologists spend a large amount of time making lists of species in a given ecosystem, this information is important, especially considering the current extinction rate, which we will get back to.

The complexity of an ecosystem relates to the number of trophic levels and connections between species.

The resilience describes an ecosystem’s ability to recover from a disturbance and the stability it’s resistance to change over time.
In this lesson’s case study assignment you will pick one ecosystem that you find interesting and evaluate its productivity, diversity, complexity and its resilience in response to a disturbance.

Communities and Ecosystems

**Community**- all species within an area  
**Ecosystem** – community + abiotic factors

- Productivity- energy and biomass produced  
- Diversity– number of species  
- Complexity – number of trophic levels and interactions  
- Resilience – rate of recovery  
- Stability – resistance to change

By understanding how communities respond to disturbances, we can gain useful information about how human activities can impact ecosystems. Disturbances can have natural causes like wild fires, grazing, floods and hurricanes while human caused, or anthropogenic disturbances include deforestation, overfishing, building of roads and houses, just to name a few.

For general patterns of response to disturbances, ecologists examine the change in a community over time or the process of succession. Succession may be primary, where life is established in a lifeless soil-less area like a shoreline, lava flow or retreating glacier. Secondary succession is when life reinvades a disturbed area like an abandoned field or homestead, recovery after a flood or fire, or even as small as filling in a gap where a tree fell in the forest. Both processes begin with pioneer species. In the case of primary succession, the pioneer species are responsible for forming soil and are primarily lichens. Over time, soil begins to form and more sophisticated plant life can invade. This process takes hundreds to thousands of years. The pioneer species in secondary succession are weedy herbaceous plants. The process is still not fast, typically taking tens to hundreds of years, but is much faster than primary succession, in large part due to the presence of soil.
When ecology was in its infancy, the idea of succession ending in a stable, predictable climax community was the rule of thumb. This hypothesis provided some of the scientific fuel behind suppressing forest fires. Reality and nature are never quite as simple as humans try to make them. Though some ecosystems have relatively stable, somewhat predictable communities such as boreal and tropical forests, other ecosystems, such as grasslands and chaparral and even some forests rely on regular disturbance by fire. Some of the plants in these ecosystems are adapted to only reproduce after a fire. For example, the cones of giant sequoias do not release their seeds unless they are burned. I took these pictures after a fire in Sequoia National Park.
Climax community?

Grasslands, chaparrals and some forests rely on fire.

Some plants only reproduce after fire, example: Giant Sequoia

Sequoia National Park  
Sequoia Cone  
Young Sequoia