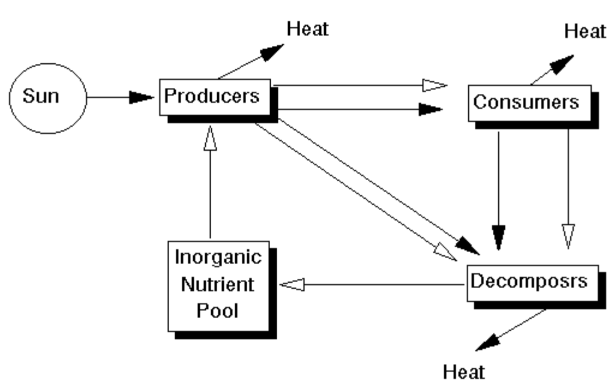
Trophic Levels

The second law of thermodynamics states that systems have a tendency towards disorder - that is, that over time, they should become less complex (or more random). Given enough time, the entire universe will gradually 'run down'.

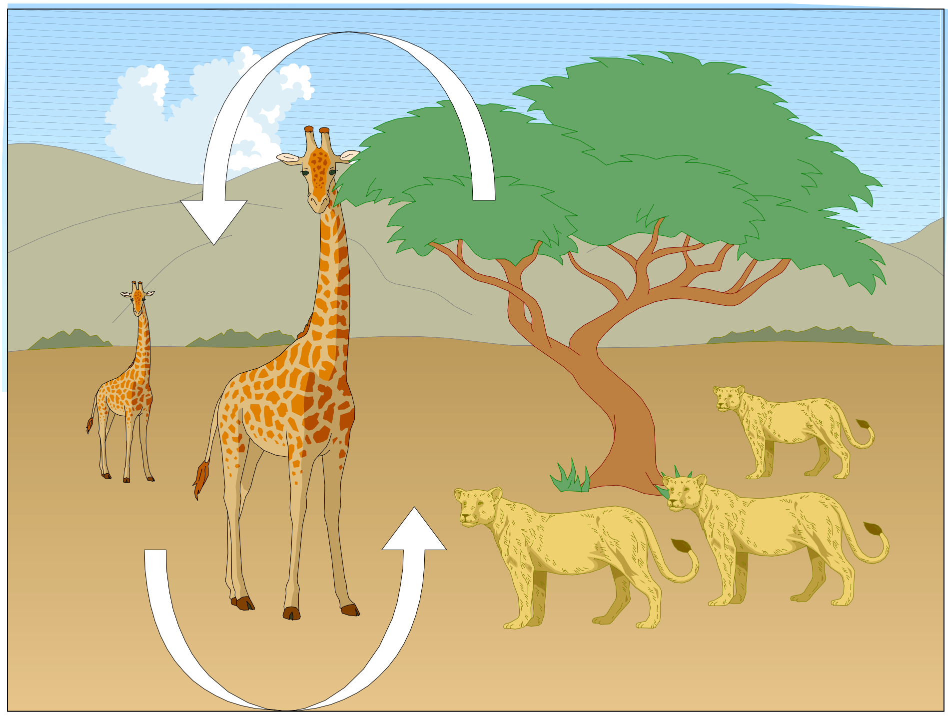
How then can we explain living systems, with their incredible complexity, apparently thriving despite the second law and its implications? Fortunately, the universe is not a uniform place, and universal concepts of time dwarf our own perspectives. In the process of running down, our sun will convert trillions and trillions of tons of energetic material into less energetic material, and in the process radiate energy out into space. The Earth lies in the path of this extravagance of energy, and thus is in the enviable position of gaining more energy than it loses to the surrounding state.

Energy from the sun is absorbed by plants and incorporated into the carbohydrates. As the plants are eaten by animals (consumers), the energy is transferred as well. Likewise, when plants and animals die and decompose, the energy in their carbohydrates is used by the decomposers. At all levels, the organisms use some of the energy for their own activities; once used, this energy is lost from the system as heat. At the same time the energy is moving through the system as carbohydrates, other nutrients and minerals such as nitrogen and phosphorous are also passed along. The crucial difference is that these nutrients are never lost from the system; instead, they are able to be used by the plants and reincorporated into living tissue:



This crucial difference will become the basis for our discussion of trophic levels.

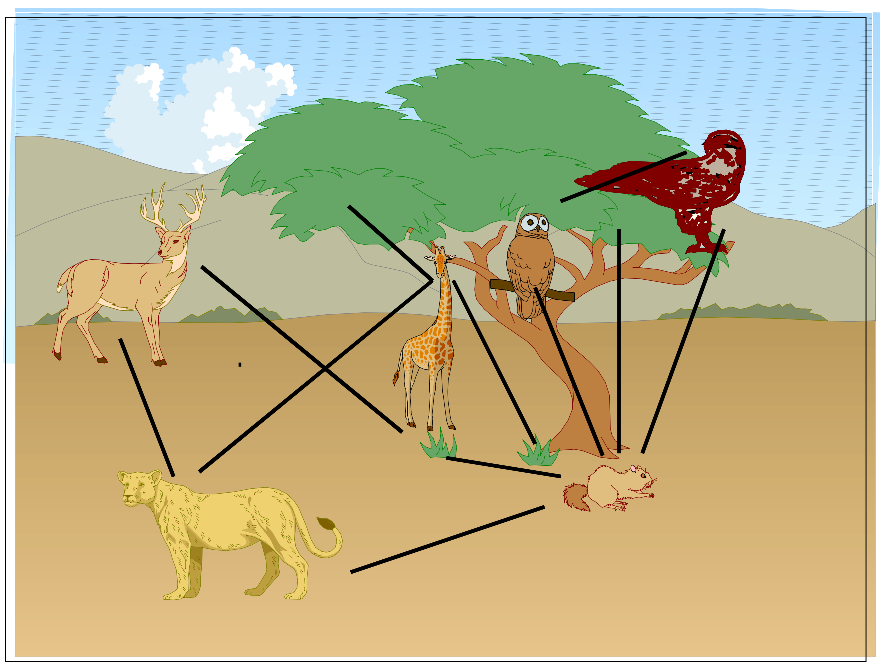
So here we are. **Trophic levels** are assigned based on what eats what. Before going into the details, let's look at a typical **food chain:**



This short food chain has only three levels. The tree takes energy from the sun, and is therefore called a **producer** or an **autotroph**. The giraffes feed on the tree; they are known as **heterotrophs** since the get their food (trophy) from a different (hetero) source. An autotroph can feed itself, just as an automobile can move itself. Since the giraffes are the first organisms in the food chain to feed on the producers, we call them **primary consumers**; another word you are used to is **herbivore**. The lions shown (this picture isn't sexist, it is the lioness which does most of the hunting) are **secondary consumers** or **carnivores** (chili con carne is chili with meat; a carnivore devours meat). If anything would try to hunt down and kill the lion for food, it would be a **tertiary consumer**, a **carnivore**, and a fool. Since the lions are getting their food from another source, they are also heterotrophs. Not shown in this food chain are **omnivores** which eat both plants and animals, and **detritivores** which eat dead organisms (**detritus**); detritivores are also known as **scavengers** or **decomposers**. The food chain pictured is often called a **grazing food chain** since it is based on animals feeding on plants. Although we are most familiar with grazing food chains, in nature they are probably outnumbered by **detrital food chains** based on decaying organic material. In some ecosystems, such as a cave or the ocean floor, *all* of the food chains are based on detritus.

Why all the terms for the same thing? It all depends on the questions you are asking. Each of the sets of terms forms a vocabulary specially suited to different types of questions. For instance, if you are studying energy flow in an ecosystem, it is better to use the producer » primary consumer » secondary consumer » tertiary consumer scheme. If you are interested in diet or behavior, the herbivore, carnivore, omnivore, detritivore schema may be more insightful. Further, the producer » primary consumer » secondary consumer » tertiary consumer scheme arranges the ecosystem into what we term trophic levels.

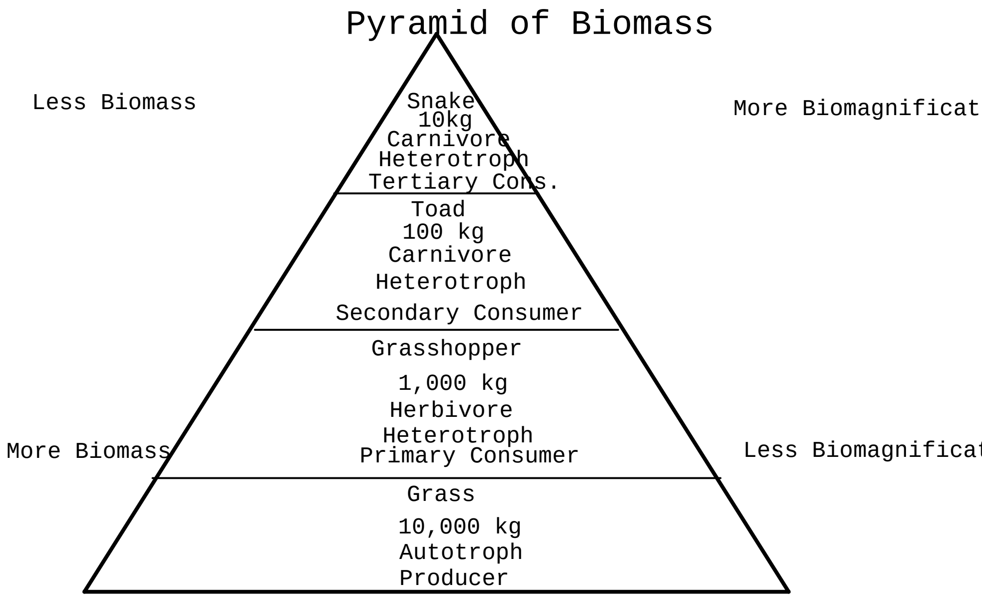
Simple food chains are largely a human invention. The real world is often much more complicated; in real life **food webs** predominate:



In this *very simple* food web, the tree and grass are the producers, providing food to the squirrel, the deer, and the giraffe. The lion acts a a carnivore or secondary consumer in feeding on the squirrel, deer, or giraffe. The owl is also a secondary consumer, focusing on squirrels. The eagle may act as a secondary consumer when it feeds on squirrels, or as a tertiary consumer when it eats owls.

Now, you know energy doesn't cycle as it moves through the ecosystem. Every time one organism eats another, a chain of events begins, and energy is lost at each link in this chain. For instance, suppose there are 100 units of energy in a kilogram of grain eaten by a deer. Some of the grain will pass through the deer undigested; this energy will not be available to the deer. The deer will use some of the energy to move around; a predator eating the deer would not get that energy. If a predator, say a wolf, ate the deer, there would be portions of the deer that would be indigestible. All in all, of the 100 units of energy available in the grain, on average, only about 10 (or 10%) would reach the next trophic level (the deer) and only about 10% of that would reach the wolf. So, in the long run, 1% of the energy in the grain would reach the wolf.

The relationship shown above has a number of consequences. If you add up the combined weight of all the organisms at a given trophic level, they will weigh about 1/10 as much as the organisms on the level below them. This sets up what is known as a **pyramid of biomass**:



The figure above shows that biomass decreases as you move up the pyramid. Note that the weight of individual organisms does not necessarily follow this relationship. For instance, an individual bison, acting as a primary consumer, would weigh more than the grass plant it feeds on. Of course, there are many more grass plants than there are bison; and if you add up the weight of all the bison it would total less than the total weight of all the grass plants.

For humans, there is an important practical point to all this. Given a limited amount of land, it is more efficient to feed humans grain than it is to feed them meat. For instance, if you have an acre of land in Washington County, you could raise up to 130 bushels of corn on an acre of land[1]. That is about 9100 lbs. of corn. According to the principles outlined above, you could get roughly

[1]According to Soil Survey of Washington County, Ohio. United States Department of Agriculture. The county soil surveys contain a wealth of information of great use to environmentalists. They can be obtained free from the Soil Conservation Service, or found in any public library. One of their most attractive features is a set of soil maps based on aerial photographs; it's like having your own spy satellite (although the data is old).

910 pounds of cattle by feeding them the corn. If you fed the 910 pounds of beef to people, you would get 91 pounds of human. On the other hand, if you fed the corn directly to the people, you would get 910 pounds of people - enough for a little-league team. Don't confuse this ecological efficiency with individual efficiency though. From an individual's standpoint, it is better to eat the meat as 1 pound of meat will be more digestible and have more energy than 1 pound of corn. It's on a worldwide scale that we see, however, that it just isn't feasible for us all to eat this way.

You may notice the word biomagnification on the preceding figure. In opposition to the decrease in energy with each succeeding trophic level, we sometimes see an increase in the concentration of certain pollutants. This phenomenon is known as **biomagnification**; the best-known example of which is the case of DDT. DDT is a persistent (long-lasting) chemical. It is not particularly toxic to mammals; we can eat the stuff without being seriously harmed[2]. It is not fatally toxic to birds, either, but it does interfere with calcium deposition in their egg shells. Birds with appreciable amounts of DDT lay thin-shelled eggs which crack upon laying or brooding. DDT is, of course, toxic to most insects, its original target.

In the environment, insects would encounter DDT and absorb some of it into their bodies. Often, they would receive a sub-lethal dose, enough to impair them but perhaps not kill them. In any event, it stands to reason that insects either dying or merely slowed down by pesticide intake would become easy targets for birds. Upon ingestion, the DDT in the insect bodies is released and makes its way into the tissues of the bird's body, particularly the fat deposits. Because an individual bird eats many insects, and because the DDT does not leave the bird's body, and because DDT resists breaking down (either in the environment or the body), it accumulates to higher levels in the bird's tissues. In other words, the DDT that was spread out over, say 1,000 crickets will be concentrated in one bird. This process is biomagnification.

In some cases of biomagnification, certain organisms actively take up the poison. Plants often take up heavy metals in large amounts; these metals may serve esoteric biochemical functions. Because these metals are often in short supply, plants have adapted to take them up whenever they become available. This may serve as the first step in biomagnification. In addition, the concentration of naturally occurring toxic chemicals in one's body is not an unusual tactic; witness the monarch butterfly which consumes the toxins in the milkweed plant as a larva. We should not be surprised that artificial toxins are utilized for protection as well.

Toxins accumulated in the body tend to concentrate in certain tissues. Many concentrate in fat, particularly those that are soluble in fat (water-soluble

[2]Needless to say, don't try this at home (or anywhere else).

toxins often pass out of the body in urine). DDT accumulates in fat; you may have read of DDT being found in human breast milk. This makes sense since the breasts are fatty tissue (and breast milk is more easily sampled than other sorts of fat, although I'm sure the researchers could get a long list of people who would volunteer to have, say, 10lbs of fat removed from their bodies [in certain places, and all in the name of science, of course!]). Another toxic hot spot in the body is the liver (in chordates; other organisms have similar organs, for example the green gland of crayfish and lobsters). The liver (or its analog) is responsible for detoxifying chemicals in the blood. The liver normally does a good job of this, but the liver may not be able to deal with certain novel artificial chemicals; these will simply be stored.

Actually, this topic of biomagnification foreshadows our next topic, pollutants.

You should be able to:

Give a specific example of a food chain and a food web.
Label the example by trophic level, diet, etc.
Given biomass for one trophic level, calculate biomass for
the other levels in the food chain.
Tie your own shoes.
Trace the flow of energy, carbon, and nitrogen through a food chain.
Describe biomagnification.
Explain why it is more efficient to eat grain rather than meat.
Draw, label, and understand a pyramid of biomass.