Food Webs
Content Background Document

Part 1. Introduction

Figure 1 is an illustration of how a scientist might organize terrestrial organisms into categories—producers, consumers, and decomposers—in a food web.

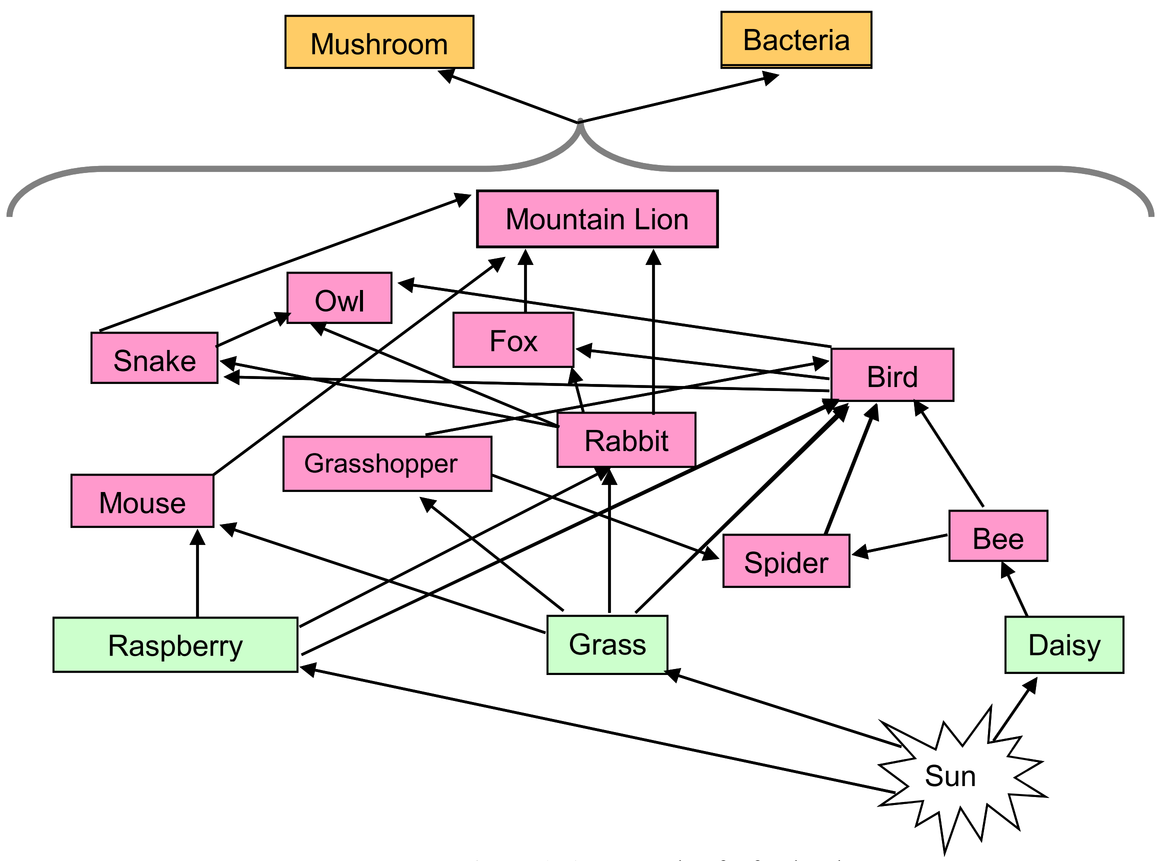


Figure 1. An example of a food web

What do you think the arrows in this food web represent? Students often label them "eats" or "is eaten by," but are these accurate descriptions? How would you label the arrows? Do they tell you anything about energy? Do they tell you anything about matter?

This figure gives a general picture of a food web, but it isn't complete. For example, you could draw additional arrows from the daisy to the mouse and from the mouse to the fox.

STOP AND THINK

Why is the Sun present in a food web? Does all the food end up in the mountain lion? Does all the food end up in the bacteria and the mushrooms?

Reflect on your answers to the Stop and Think questions as you read the background information and examine how students and scientists answer them. Consider how your understanding changes as you learn more about energy and matter in food webs, and how you will work with your students to align their understandings with those of the science community.

1.1 What Are Food Webs?

One way a food web may be described is as *a network of food chains that interlink within a biological community*. A food chain is a series of organisms that shows a pattern of consumption among individual organisms. For example, a cow eats grass; a wolf eats the cow; and bacteria consumes the wolf when it dies. The *linear path* from the grass to the bacteria is a food chain. There are typically numerous food chains within any food web. Look again at figure 1 and see if you can identify an example of a simple food chain.

Identifying food chains as "what eats what" is something many students understand quite early on. Many children learn the folk song about an old lady who swallowed a fly, which evokes a simple food chain:

I know an old lady who swallowed a cat.
Now fancy that, to swallow a cat!
She swallowed the cat to catch the bird.
She swallowed the bird to catch the spider.
That wiggled and jiggled and tickled inside her.
She swallowed the spider to catch the fly.
But I don't know why she swallowed the fly.
Perhaps she'll die. (Bonne, 1952)

When teaching about food webs, however, it is important to deepen students' understandings from a simple "cat eats the bird; bird eats the spider" definition to a more conceptual view of what is happening to matter and energy in the system. Although food webs do show what eats what, scientists use these diagrams to illustrate more important concepts: the movement and use of matter in an ecosystem, and the flow of energy between organisms. The arrows in the figure-1 food web represent the movement of energy from one organism to another. So why don't we call them *energy webs*? Why are they called *food webs*? For scientists, the word *food* has a very special meaning that involves the concepts of both energy and matter.

1.2 Is Food Considered Matter or Energy or Both?

First, we need to clarify the difference between matter and energy. *Matter* is physical "stuff," which scientists define more eloquently as "anything that takes up space and has mass." Anything that is made up of atoms or molecules is matter. Everything around you right now that can be weighed—including yourself and the air you're breathing—is matter. Students often think of things as "having or containing" matter rather than "being" matter. Another common student idea is that only solid things are matter. Students find it especially difficult to think of air (gases) as matter, but air is made up of various kinds of molecules (oxygen, carbon dioxide, water vapor, and nitrogen) that take up space and have mass. Your body, the chair you're sitting on, your food, the plants outside your school, the water you drink, and the air you breathe in are all matter.

Energy, on the other hand, is not a physical entity that has mass. We cannot touch it, hold it, or weigh it. We know it's there because we see evidence that things (matter) have undergone changes—they move and give off light, heat, or sound. Scientists define energy as "the ability to do work or to change matter." This definition doesn't usually have much meaning for young students, so it might be more helpful to engage them in looking for evidence of changes and motion as indicators of energy. For example, they can observe a bicycle racing down a hill or a fish swimming or a match burning or a light being turned on. Keep in mind that energy will be a much harder concept for students to understand than matter.

From the name, it's obvious that food webs have to do with *food*. Although this seems like a simple word that all your students will know, you'll find that they have a variety of ways of defining the word. For example, "Food is stuff you eat" (take into your body); "Food is what you chew" (not drink); "Food is what you need to live and grow"; or "Food is where you get energy." This last description comes closest to how a scientist would define food, and yet it isn't a complete scientific definition.

STOP AND THINK: What Is Food?

Write down how you would answer the question "What is food?" (Try to explain what it is without merely listing examples of the food you eat.)

Now look at the following chart. Which of these items is food by your definition?

After you've made your choices, read the scientific definition of *food* that follows.

What Is Food?	**Yes**	**No**
Is orange juice food?		
Is water food?		
Is sugar food?		
Are vitamins food?		
Is "plant food" (minerals) food for plants?		

A scientist would define food as "matter (building materials) that contains energy living things can use to live and grow." Food is the molecules (matter) that organisms use to build and repair their bodies, and these molecules also provide energy they can use to live and grow. Food can take the form of simple sugar molecules or more complex molecules, such as starches, proteins, and fats. In all of these "food" molecules, energy is stored in chemical bonds that hold the atoms in the molecules together. Energy is an especially tough concept because, as you read before, it is *not* matter—you can't see it, touch it, or weigh it.

Thinking about food this way, you might realize that some substances are food for one type of organism but are not food for a different type of organism. For example, humans cannot digest fiber and use it as a source of energy. So fiber is not food for us. But some bacteria can break down fiber as a source of energy and matter. For these bacteria, fiber is food.

The big idea here is that the "food" in food webs provides *both* matter and energy for living things. Many things we sometimes refer to as food in everyday conversation (such as water, vitamins, and "plant food" fertilizers) aren't food by this definition because they don't provide energy that living things can use to live and grow. In this reading, we'll refer to these kinds of matter as "nutrients." **Beware:** Some people use the word *nutrients* differently, referring to anything that contributes to the health of living things, including energy-supplying food, as well as water, vitamins, and minerals.

1.3 How Are Nutrients Different from Food?

What about oxygen, water, vitamins, and minerals? We know that living things need these kinds of matter to live and be healthy. Are these materials energy-supplying "food" for living things?

Scientists measure food energy in terms of Calories. High-caloric matter, such as doughnuts and ice cream are definitely "food" because they can provide living things with energy. But how many Calories are in a glass of water or a breath of air or a vitamin pill? These materials contain *zero* Calories; this means they can't provide living things with energy. But they're still useful materials for living things. In this reading, we refer to these kinds of matter as *nutrients* because they're useful to living things, but they don't provide energy for living things.

For example, water is essential for living things, but imagine drinking only water and eating nothing for a few days. How would you feel? You would likely feel weak and would eventually die because you aren't getting the energy from food that is essential to sustain life.

Similarly, plants take in water from the soil and carbon dioxide from the air, but these molecules don't contain usable energy; they aren't food as scientists define the term. Instead, the water and carbon-dioxide molecules are converted to energy-supplying food in the form of sugar molecules (and eventually proteins and fats, too). This food-making process is called *photosynthesis*. The sugar molecules the plant makes can then provide it with both energy (in the bonds between the atoms) and matter (the atoms and molecules themselves).

Students often get confused about a plant's source of food because they think it comes from the soil (e.g., minerals and water from the soil or the soil itself). Students may believe that plants eat food from the soil, just as we eat food from our plates. This misconception is further reinforced by such terms as "plant food," which are used to describe commercial products containing minerals that can be used to fertilize plants. What is the difference between these minerals (fertilizers) and "food"? In short, materials needed for plant life and growth are divided into energy-supplying *food* materials and other materials we call *nutrients* that the plant needs but don't supply it with energy.

Plants use different kinds of nutrients to support life processes, but these nutrients don't directly provide plants with energy. *Nonmineral nutrients* that most plants need are carbon, oxygen, and hydrogen. Plants get these nutrients from water molecules (H_2O) absorbed through their roots and carbon-dioxide molecules (CO_2) diffused into their leaves from the air. These nonmineral nutrients supply the matter plants use to make sugars during photosynthesis and to add to their mass. The matter plants take in from the soil are *mineral nutrients* that contain elements like nitrogen and phosphorus. These mineral nutrients are what you're buying when you pick up a box of "plant food" or fertilizer at the store. Plants use these nutrients from the soil not for energy but for building big, complicated molecules that are essential in other chemical processes in the plant. These minerals, while important for the health of the plant, provide neither energy nor a significant amount of matter (usually around only 3%).

It's important that students learn to distinguish between energy-supplying *food* and non-energy-supplying *nutrients*. Thinking about the role of vitamin pills versus the role of food might help some students understand the difference between nutrients and food. Ask a student to role-play what it would be like to receive only water and vitamin pills for a week. This usually results in the student dramatically acting out a weakening and dying process. Why? Because without food (defined as energy-supplying matter), we eventually use up our stored energy, and once our bodies use up fat supplies, they actually begin to degrade vital tissues to get the energy they need to continue essential life processes. Eventually this leads to complete systemic collapse … and death.

STOP

STOP AND THINK: What Is Food?

Now go back and look at the "What Is Food?" chart. Think about what changes you would make in your responses now that you know the scientific definition of *food*.

1.4 Summary: Matter and Energy in Food Webs

Food webs are one way to illustrate and study the flow of energy and movement of matter within an ecosystem. These models have strengths and limitations: They allow simplified views of a system so you can see the big picture, but the simplification is just that—a reduced set of complex interactions. The intent of this reading is to deepen your understanding of the complexities so that you can not only better understand these models yourself but also more effectively help students make sense of the simplifications.

In part 2 of this reading, we'll focus on what happens to *matter* in food webs, and part 3 will address the movement of *energy* in food webs. You can start with either the matter story or the energy story. In the end, you will be able to tell the story of food webs from both an energy perspective and a matter perspective.

Part 2. What Happens to Matter as It Moves in a Food Web?

What happens to matter as it moves from one organism to another in a food web? What is happening to the atoms and molecules?

Look back at figure 1 at the beginning of this reading. Do the arrows in this diagram show the movement of matter in a food web? Many textbooks present food-web diagrams in a way that gives the impression that matter and energy move the same way in an ecosystem. However, energy and matter aren't the same, and they don't move through food webs in the same way. It's important that students understand these concepts to gain deeper understandings in science class and make better informed decisions in their lives outside of school. Issues such as recycling, energy-efficient cars, good nutritional choices, and environmental pollution all rely on an understanding of the difference between energy and matter and being able to track the two in systems.

As you read this section, think about what kinds of arrows you would draw in figure 1 to show how matter moves in a food web. But before we get to that story, we need to make sure we understand how scientists define the food that is represented in food webs. Is food matter? Or is food energy? Or is it both?

STOP AND THINK

Imagine setting up an ecosystem in your classroom, such as a small aquarium with a couple of fish, some plants, a few snails, and some invisible bacteria floating in the water and in the gravel at the bottom.

Could this system sustain itself (survive) if a clear-glass lid were placed on top and sealed so you couldn't open it? This means you would *not* be adding any food or air to the aquarium. No new matter would be introduced to the system if the lid were sealed. What would happen to the matter in the aquarium over time? What would happen to the plants? The fish? The snails? Where would they get the matter that they need to live and grow? How would the matter move through the system?

Think about this scenario as you read more about matter in food webs. We'll revisit this scenario at the end of the reading.

2.1 Is Food Matter or Energy or Both?

STOP AND THINK

Is Food Matter or Energy or Both?

Think about this question and then look back at section 1.2 to check your understanding.

2.2 How Are Nutrients Different from Food?

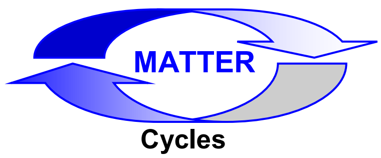
STOP AND THINK

How Are Nutrients Different from Food?

Think about this question and then look back at section 1.3 to check your understanding.

2.3 Where Does Matter Go?

What is happening to matter—water molecules, carbon-dioxide molecules, sugar molecules, hydrogen atoms, and so forth—as it moves in a food web? Where does the matter come from, and where does it go? The big idea is this: Unlike energy, which gets lost as heat in a food web, matter is continuously recycled.



Matter isn't created in ecosystems, and it isn't destroyed; it is merely rearranged (through chemical reactions) and transferred from one organism or part of the system to another. As with energy, matter is often transferred through the system as one organism eats another. In addition, matter and energy come together when plants produce food during photosynthesis. This is why textbook artists and students often portray the path of matter through a food web as the same path energy follows. But something different must be happening to recycle the matter rather than having it flow out of the system. This is where the roles of producers and decomposers are vital and make the story about matter different from the energy-flow story.

What do we mean by *producers* and *decomposers*? Plants get most of their matter from the air (the carbon and oxygen in carbon dioxide), as well as some from water from the soil (hydrogen). Because plants can use this non-energy-supplying matter to make energy-supplying food matter, they are called *producers*. Some animals get their food by consuming the plants; they're classified as a special kind of consumer called *herbivores*. Other animals get their food matter by eating other animals; they are a type of consumer called *carnivores*. Dead organisms and waste from producers and consumers (e.g., feces, dead-plant parts such as leaves or fruit) are broken down by yet another kind of consumer—*decomposers*. Decomposers use some of this once-living matter as their food, and some of it is returned to the air (as carbon dioxide) and the soil (as mineral and nonmineral nutrients, including nitrogen, phosphorus, and water). Plants take in these materials decomposers leave behind—carbon dioxide from the air, and water and minerals from the soil—and the cycle starts all over again.

2.4 Why Are Producers So Important?

Green plants, algae, and some bacteria can use energy from sunlight to change carbon dioxide and water into energy-supplying food matter, initially in the form of sugars. This food-making process is called *photosynthesis*, and organisms that can create food are called *producers*. Plants use some of the sugar made during photosynthesis as a source of energy. The "energy-flow story" of photosynthesis is usually taught in schools (see section 3.6). What is often left out is the "matter story" of photosynthesis. Plants do capture light energy and store it in sugar molecules for later energy needs. But they also use some of that sugar to make cellulose and other large molecules (such as starches, fats, and proteins). These very large molecules are then used to make the parts of the plant—to build plant structures. Humans and other animals use the large molecules they get from the food they eat to build and grow their bodies. But plants don't "eat" food taken in from the environment; they make their own food (sugars) and use it to make other molecules that they then use to build their body parts. These large molecules are made mostly of carbon, hydrogen, oxygen, and nitrogen atoms. (This is one reason plants need the nitrogen that decomposers release into the soil from once-living things.)

One of the most common and very important atoms that make up living things is *carbon*, which originates from the carbon dioxide in the air that plants use to create food. This is why we can say that the huge bulk of a redwood tree came mostly from the air. The *biomass* of the tree (the amount of matter once the water is removed) is largely attributable to the mass of the carbon and oxygen atoms that originally entered the tree from the air as part of the carbon-dioxide molecules and were changed into sugar and other molecules.

To really understand the unique and critical role of photosynthesis, we have to appreciate the difference between the matter green plants take in—water and carbon dioxide—and the food matter that they produce. Water and carbon-dioxide molecules don't contain usable energy for plants; they are *not* food. But producers can transform the water and carbon-dioxide molecules into energy-supplying sugar molecules that all living things can use as a source of energy and matter to live, grow, and reproduce. These sugar molecules contain both energy (in the bonds between the atoms) and matter (the atoms and molecules themselves). The carbon atoms (that originally came from the carbon dioxide) are used to build new molecules within the plant, creating its biomass. *The big idea here is that food contains both matter and usable energy, and only producers can create this food.* Consumers, including humans, cannot make their own food. And scientists, in all their wisdom, are not able to create food in a laboratory setting. We are all dependent on producers to perform this vital function.

One way to help students appreciate the importance of photosynthesis is to ask them if they can do what plants can do. Can you stand outside in the sunshine and breathe in carbon dioxide and drink water to stay alive? Can you produce your own food inside your body? You can also engage students in appreciating the amazing power of plants by showing them a baggie filled with exhaled air (carbon dioxide) and a bottle of water and then compare those two kinds of matter with a bowl of sugar or sugar cubes. Challenge students to imagine that plants can take two things that look nothing like sugar and use energy from sunlight to turn them into sugar.

2.5 Why Are Decomposers So Important?

Imagine a forest where there are no decomposers. Each year, leaves, pine needles, pine cones, and bark fall to the ground. Animals and plants die and lie on the ground. Things would begin to pile up and up and up. Thanks to decomposers, this doesn't happen. What happens to the biomass from dead organisms? Decomposers break down the leaves, needles, cones, and animals, returning the majority of the carbon to the air and water and minerals to the soil, where plants can use them again.

Decomposers are organisms that are typically small in size and don't travel over large distances. They include bacteria, fungi, and some types of algae. These decomposers are ubiquitous. They are in the air, the soil, and the water, as well as in and on plants and animals, including us. Some bacteria can survive in extremely inhospitable environments, such as frozen Antarctic lakes and steaming hot springs. Bacteria live on or in just about every material and environment on Earth. According to some estimates, each square centimeter of your skin averages as many as 1 million bacteria, and more than 700 species of bacteria can be found in the human mouth (Aas, 2005; Kong, 2012). Even a single teaspoon of soil contains anywhere from 100 million to 1 billion bacteria (Hoorman, 2016).

Bacteria and fungi (molds and mushroom, for example) perform the vast majority of decomposition.[1] These decomposers break down, outside of their bodies, the matter from previously living things or their waste. They release chemicals (enzymes) into their surroundings to break down their food. They then absorb some of the digested materials to get their matter and energy supplies. This external breakdown of

[1] People often think of earthworms, millipedes, dung flies, slugs, vultures, termites, and snails as the decomposers of the world. These organisms (called *detritivores* or scavengers) are considered a type of decomposer. Like bacteria and fungi, they get food from once-living matter. The difference is that detritivores and scavengers actually eat large chunks of the once-living matter, while bacteria and fungi secrete enzymes to digest the organic matter, break it down, and then absorb some of the resulting molecules. It's important for students to understand that the bacteria and fungi engage in the vast majority of the chemical breakdown of once-living matter.

matter by decomposers makes sense if you think about the fact that these organisms are typically very small and need some way to break matter down into pieces small enough for them to absorb.

Decomposers feed on dead plants and animals and on *organic waste* materials from other organisms (e.g., feces). These chemically complex waste materials are called *organic* because they are derived from living or once-living organisms. Decomposers break down the complex organic matter/molecules into simpler, nutrient forms. For example, through chemical reactions, sugar molecules are broken down into carbon dioxide that is released into the air. Protein molecules are also broken down to release carbon dioxide into the air, but they release nitrogen, sulfur, and other atoms and molecules into the soil as well. Thanks to decomposers, there is no waste of matter in an ecosystem that is functioning as it should. Everything that was once alive will be converted into simple nutrients by decomposers.

A common student misconception is thinking that decomposers break down their food (once-living things) into nutrients that enter the soil, and that plants use these nutrients *as food* to gain in biomass (to grow bigger). It's tempting to believe that all of the matter in a huge tree, or even a small plant or blade of grass, comes from minerals and water in the soil. It's easier than accepting that most of the biomass of a plant actually comes from the carbon dioxide in the air!

Plants *do* need the small pieces of matter that decomposers release into the soil. But these small pieces of matter are like vitamins and minerals for people. They're necessary for the proper functioning of all the chemicals that make up living organisms' metabolisms, but they don't make up the mass of plants any more than the vitamins and minerals people need make up their mass. Yet decomposers are still very important to plant life. Without them, plants don't have access to the minerals they need to stay healthy and build larger molecules like proteins. In addition, decomposers release carbon dioxide into the air and water into the soil, which plants can use for photosynthesis (to make more food). This is how matter is recycled in ecosystems.

Decomposers consume or break down the waste materials (excretions) and dead tissue from plants and animals at all levels of a food chain or food web (see figure 2). They consume food from all kinds of once-living things—producers, herbivores (primary consumers), and carnivores and omnivores (secondary consumers). They leave behind matter that producers can use again directly to make more food, which is then passed along to herbivores and omnivores who eat them, and then to carnivores and omnivores who eat the herbivores. Thus, matter is continuously used and reused in a food web.

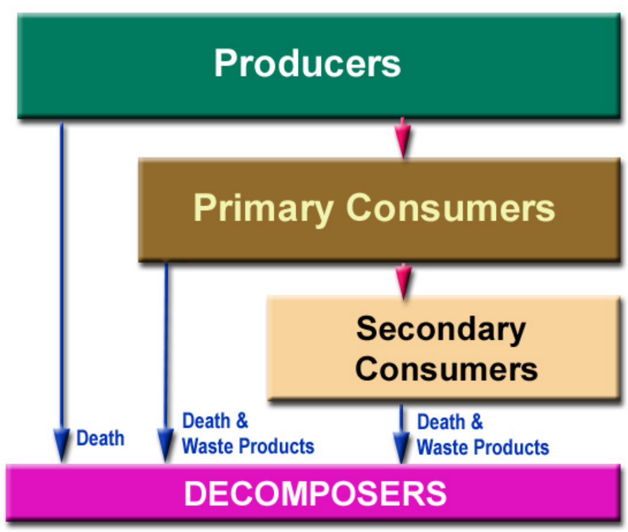


Figure 2. Decomposers—connected to all trophic levels

As decomposers convert once-living matter into simpler forms, large amounts of heat are generated. This heat comes from the process of breaking down food material to release energy (cellular respiration).

If your students have ever set up a compost heap, they may have noticed the heat generated as the organic materials were broken down. The heat energy from these compost piles is "lost" to the food web (energy *flows through* the food web), while living things can break down and reuse the matter in the compost heap (matter is *recycled* in a food web).

2.6 Summary—Revisiting the Food-Web Problem: Matter in an Aquarium

Think again about the aquarium question posed at the beginning of part 2—the one with a couple of fish, a few plants, some snails, and some invisible bacteria in a sealed glass container. What is happening to the matter within that system? What organisms are in the system, and how does each organism get the matter it needs? What would a diagram look like that shows what happens to matter in this system? What words and arrows would you include in such a diagram, and how would you label the arrows?[2]

Key Ideas about Matter in Food Webs
When working with students, it's important to keep these big ideas in mind:

- Matter cycles within the ecosystem. Matter is what gives an organism the "stuff" to build its body structures (to grow) and the nutrients necessary for the life process to work correctly. These materials can be used and reused through a variety of chemical reactions, including photosynthesis and cellular respiration.
- Decomposers play a vital role in matter cycles because they provide the final steps necessary to break down matter into simpler forms (carbon dioxide, water, and minerals like nitrogen and phosphorus) so the cycle starts all over again.
- All organisms within an ecosystem are interconnected and dependent on the system.
- Food webs are just models that show simplified views of some of the complex processes within an ecosystem.

Part 3. How Does Energy Flow in Food Webs?

The food web in figure 1 at the beginning of this reading shows the initial source of energy in that ecosystem—the Sun. The role of the Sun is important in most ecosystems, since food webs need a constant source of new energy. Scientists say that energy *flows through* an ecosystem, but it isn't reused or recycled. Flowing implies that the energy comes in at some point, usually from the Sun, and then moves through and out of the system. A continual supply of new energy must enter the ecosystem to keep the system functioning. Figure 1 shows the one-way flow of energy from the Sun into and then through the food web, but it doesn't show the details of how the energy changes form or leaves the system.

How do we use food webs to make sense of the energy flow from one organism to another? Consider the organisms in figure 1. They can be organized into two broad categories as shown in table 1 on the following page.

[2] In the aquarium, the plants get matter from the water and from tiny air bubbles in the water. Fish get matter by eating plants. The snails are detritivores who get their matter from dead plant and animal material and from algae. There are also bacteria in the aquarium, which are decomposers. A diagram showing matter cycling in the system would have arrows from the plants to the fish. Arrows should go from both the plants and the fish to the snails, algae, and bacteria. The drawing should also show the decomposers giving off carbon dioxide, water, and minerals, which the producers can use again.

Table 1. Organization of organisms in figure 1

Consumers	Producers
• Mountain lion (carnivore) • Owl (carnivore) • Spider (carnivore) • Snake (carnivore) • Fox (carnivore) • Rabbit (herbivore) • Mouse (herbivore) • Grasshopper (herbivore) • Bee (herbivore) • Bird (omnivore) • Mushroom (decomposer) • Bacteria (decomposer)	• Grass • Raspberry bush • Daisy

Producers are organisms that can make their own food. The most common producers are plants, which use light energy from the Sun to make sugar through a process called *photosynthesis* (see section 2.4).

Plants don't always use the sugars they make right away. They can make molecules called *starches* from unused sugars. These starch molecules are a way for plants to store the sugar molecules until they need energy. Plants also use the sugar molecules to make larger molecules, like cellulose and proteins, that they need to make cells, leaves, trunks, and other plant parts, as well as enzymes and hormones that control all the chemical reactions taking place inside them.

Producers are unique among living things because they can make their own food. For example, humans cannot simply take in sunlight and use it to create energy-supplying food. Think of how different our lives would be if we could simply stand outside in the sunlight, take in carbon dioxide (CO_2) and water (H_20), and make food—no more cooking or trips to restaurants!

Organisms that cannot make their own food are called *consumers*. When consumers eat plants, they break down the plant carbohydrate, protein, and fat molecules to release the stored energy they need to maintain all their life processes.

Based on what consumers eat, scientists have defined different feeding—or *trophic*[3]—levels. The levels are based on how many organisms are between the consumer and the producer. So if a consumer eats a plant, it's a *primary* consumer. If a consumer eats a rabbit, which has eaten plants, then it's a *secondary* consumer (two levels away from the producers). Four types of consumers are identified in table 2: herbivores, carnivores, omnivores, and decomposers. Your students may already be familiar with these four words but aren't likely to understand them in terms of trophic levels and energy transfer.

[3] We use the technical terms, such as *trophic levels*, in this reading because they are often used in instructional materials, but this language isn't necessary for elementary students. Scientists use such technical vocabulary terms to make it easier to communicate specific meanings. Scientific terms should be used in the classroom when they help clarify a concept, but they should not be introduced until students have some experience with the concept or phenomenon they represent.

Table 2. Characteristics of the four types of consumers

Consumer	Trophic Level	Food Source
Herbivores	Primary consumer	Plants
Carnivores	Secondary consumer or higher	Animals
Omnivores	More than one level	Plants and animals (may eat at multiple consumer trophic levels)
Decomposers	Not at a defined level	Dead organic material or the wastes of living organisms

Primary consumers are *herbivores*, which obtain their energy by eating producers. A grasshopper by its very name tells us that it is an herbivore; it gets its energy by eating grasses (producers). *Omnivores* can be primary consumers as well, since they acquire energy by eating producers. However, they also get their energy by eating herbivores, so they can be secondary or higher consumers too. For example, when I eat a turkey sandwich with lettuce and tomatoes, I'm acting simultaneously as a primary consumer (using producers like lettuce, tomatoes, and grains for energy) and a secondary consumer (using turkey, a primary consumer, as my energy source). *Carnivores* have a more limited diet, eating only consumers to acquire energy. Consequently, they're only secondary or higher consumers.

Look over the previous descriptions and notice how the language emphasizes passing energy from one organism to another (rather than what eats what). It's important to emphasize this language with your students so they are supported in internalizing the idea that "eating" is more than just chewing up food; it also involves the flow of energy from one organism to another. Interestingly, the same organism can be classified at more than one trophic level when its diet may not be highly specific. A frog, for example, is a carnivore that doesn't care if dinner is an herbivorous bug or a carnivorous bug. A frog may be a secondary consumer at one meal and a higher-level consumer at another. Table 3 presents examples of some common consumers.

Table 3. Examples of common consumers

Herbivores (Primary Consumers)	Carnivores (Secondary or Tertiary Consumers)	Omnivores (Primary, Secondary, or Tertiary Consumers)
• Grasshoppers • Mice • Rabbits • Deer • Beavers • Moose • Cows • Sheep • Goats • Groundhogs • Caterpillars • Bison	• Frogs • Snakes • Hawks • Spiders • Herons • Wolves	• Foxes • Bears • Turtles • Monkeys • Raccoons • Humans

3.1 Food Chains

The trophic level defines an organism's position in a food web. Figure 3 highlights how energy flows through different trophic levels in a simple food chain. Food chains begin with producers, which convert the energy in sunlight into chemical energy in food. Grass uses some of the food it produces to live and grow, but some of the food the grass makes is passed on to a primary consumer, such as a cow. The cow uses some of that food energy, but if a wolf (a secondary consumer) eats the cow, some of the energy is passed on to the wolf. When the grass or the cow or the wolf dies, decomposers can use the remaining food energy stored inside them.

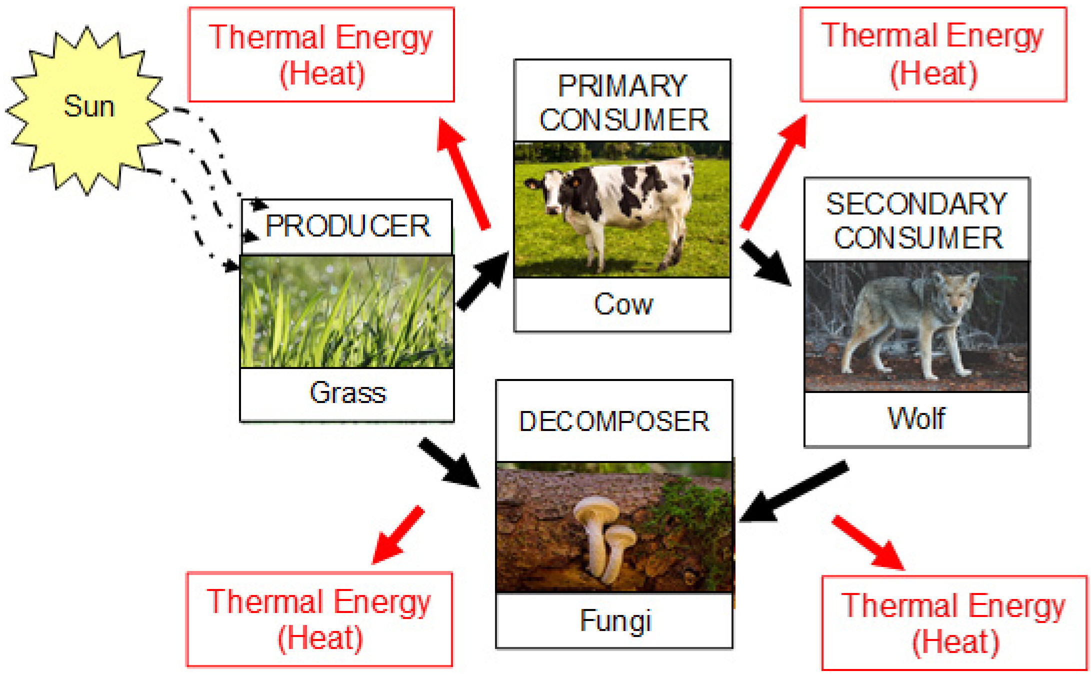


Figure 3. Energy flow through different trophic levels in a simple food chain

STOP AND THINK

How would you label the arrows in figure 3 to match the caption?

As mentioned earlier, students often learn to describe food chains in terms of what eats what. Consequently, younger students will read the arrows between organisms as "is eaten by." For example, the grass is eaten by the cow. However, they should learn to see and interpret food chains in terms of energy flow or matter cycling (see part 2). Encourage students to say that grass provides energy for cows and to label the arrows as "provides energy for."

3.2 Food Webs

Careful observation of natural ecosystems reveals that organisms are often components of multiple food chains. For example, think about the different organisms that eat grass or other plants. While anteaters have a special diet of one main food (ants), consider how many different foods a hawk eats (e.g., a mouse, a small bird, a fish, and so forth). This is why the relationships and energy flow in natural ecosystems cannot be represented with a simple linear food chain. Rather, scientists create complex food webs that actually integrate multiple food chains. Look at figure 4.

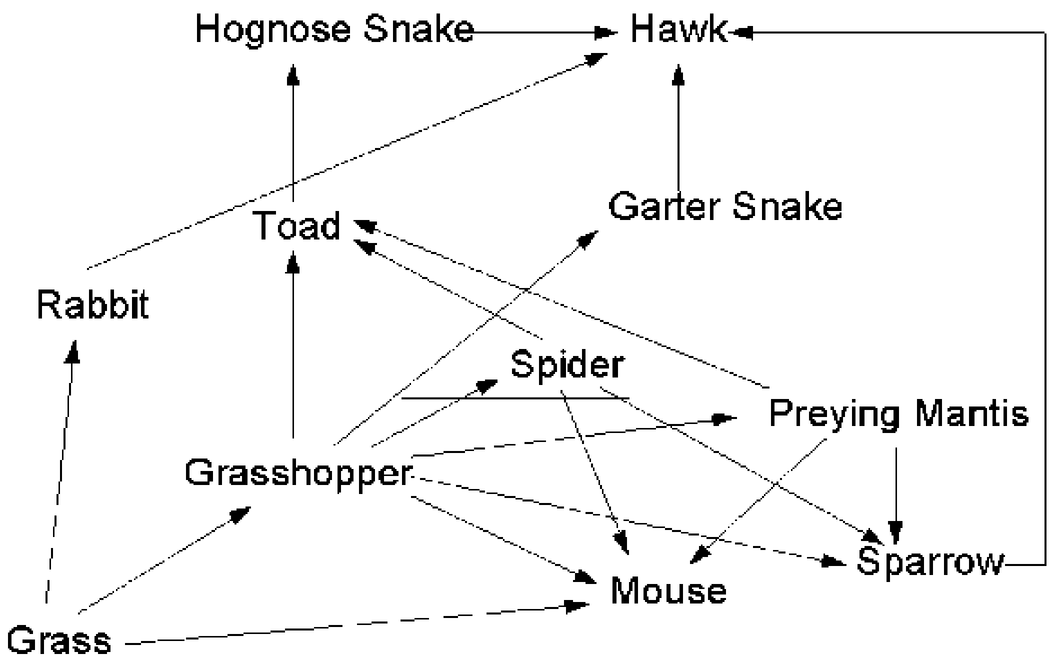


Figure 4. Typical food web in a field ecosystem

STOP AND THINK

How many food chains can you find in the food web in figure 4?[4] What could be added to this food web to make the energy story clearer?[5]

Figure 5 presents a food web from a very different ecosystem. As you did with the field-ecosystem food web, look at the tidal-marsh food web for its complexity of interlocking food chains and try to identify the individual food chains. How many trophic levels are in the food chains you identify? [6]

If you were using this diagram in your classroom, what could be done to emphasize that energy is flowing through this food web?

[4] Did you identify grass → rabbit → hawk, or grass → grasshopper → toad → hognose snake → hawk? There are many other possibilities as well.

[5] The Sun could be added as the original source of energy, and the arrows could be labeled to indicate "energy is passed to." In addition, grass could somehow be marked as the producer that changes sunlight into energy-supplying food.

[6] There are more than 40 food chains in the tidal-marsh food web representing more than four trophic levels. For example: vegetation → grasshopper → salmon → harbor seal → killer whale.

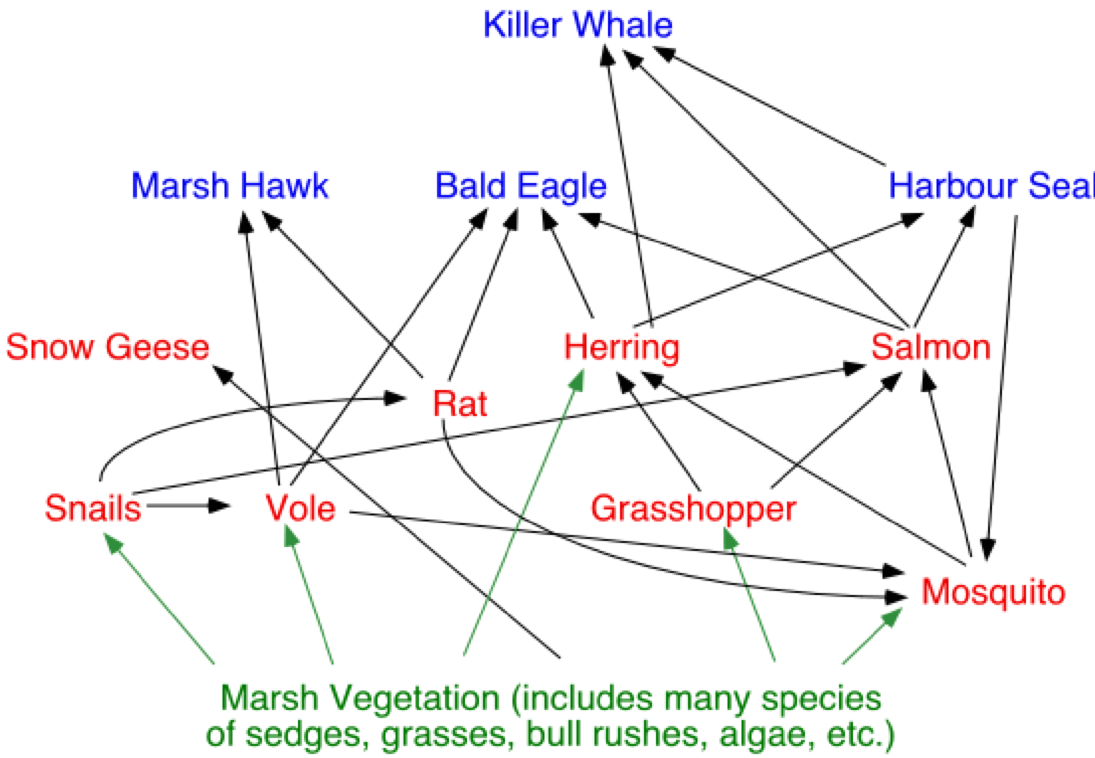


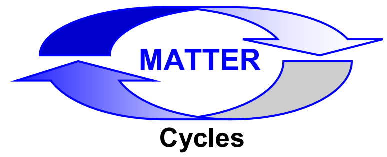
Figure 5. Typical tidal-marsh food web

This section emphasizes an energy-focused view of the relationships among different types of organisms within food webs. This knowledge should help you support students in tracing the pathway of energy flow from organism to organism. But what is energy? And what happens to it as it moves through food webs? What happens to it after it leaves the food web? In the next section, we'll explore these questions.

3.3 Energy in Ecosystems

Energy is a concept that cuts across all branches of science (e.g., life science, physical science, Earth/space science). For example, energy is a fundamental factor in understanding food webs, volcanoes, levers and pulleys, weather, earthquakes, digestion, photosynthesis, magnetism, and so forth. Because of its unifying nature, energy is often touched on in multiple contexts during any given school year from elementary grades through high school. Energy is a difficult concept to understand, and students' understandings of it will grow over time as they encounter it in these different contexts. But how energy is represented can lead to different understandings and can sometimes cause misconceptions. It's important not only to understand energy within a particular context, such as in food webs, but also to think about how it will be presented later (e.g., when teaching about the water cycle) to maintain the conceptual unity. Additionally, it's important to recognize the differences between energy and matter, especially when thinking about food webs.

Energy, matter, and food aren't the same things, although students often get confused and think they're one and the same. This is especially true when thinking about food webs. It's common for students to see or draw food webs in which arrows are used to show the pathways of both energy and matter. Although the arrows may look similar, energy and matter don't move through an ecosystem in the same manner. We've already explored some of the differences between matter and energy and how they move through an ecosystem, but now we'll focus in more depth on the flow of energy in food webs. The big idea to keep in mind is that *energy flows into, through, and out of an ecosystem, while matter cycles within it*.



Let's think about what energy is and then explore how energy flows in food webs.

3.4 What Is Energy?

Energy—what is it? It cannot be seen, touched, heard, smelled, tasted, or weighed. It is a complex concept to understand and teach. Yet it's important in many areas of science and connects the disciplines.

Energy is often easier to think about in terms of what it does rather than what it is. Asking students to define energy usually results in responses like "It makes things work" or "It lets us do things." Both of these responses imply a connection between energy and movement, which is how students often view energy. For scientists, when anything moves a distance, they say that work is being done. This relationship provides us with a basic definition of energy:

Energy is the ability to do work.

This definition is a good starting point for understanding what energy is, but it leaves some gaps. For instance, it's easy to understand that energy is used to produce muscular movement when we run or walk, or even that sound energy causes the eardrum to vibrate and move the three small bones in the middle ear.

But how do heat and light fit the basic definition of energy? How can we tell that heat and light are doing work?

The presence of heat is often an indication that energy is present and being used to do work. For example, when sunlight strikes the skin, it produces heat. Similarly, we know that when the body transforms the energy in food to provide energy for bodily functions, heat is generated. Heat and light energy can also be used directly to do work. For instance, heat can boil water and cause ice to melt.

We can think about light doing work in relationship to food webs. In food webs, producers use light to convert carbon dioxide and water into a form of matter that contains usable energy (food). So light energy is used to change the matter within plants (see part 2). This idea enables us to expand the definition of energy:

Energy is the ability to do work or to change matter.

To understand relationships between living organisms in food webs, it's important to keep a few key tenets about energy in mind. One fundamental concept is the conservation of energy:

Energy cannot be created or destroyed.

The idea of energy conservation within a system is a challenging one for students to understand, and it conflicts with many of their ways of thinking about energy. Young students often assume that energy comes from wall plugs, and that there is an endless supply of it. Older students often describe energy as getting used up and disappearing ("It's just gone"). Some students generalize the lessons they've learned about recycling and assume that energy is recycled as well, while others are aware of the limited nature of oil supplies and conclude that all energy will disappear when the oil supply is used up. However, if the energy cannot be created or destroyed, then it must come from someplace and go to someplace. So what happens to energy if it can't be destroyed?

Energy can transform from one form to another.

This idea can be illustrated by thinking about energy transformations in a flashlight. When the switch is turned on, the chemical energy stored in molecules in the battery is transformed into electrical energy that flows in a circuit through the lightbulb, where it's converted to light energy and heat energy. The light energy and heat energy then flow out into the environment.

As we consider energy within food webs in an ecosystem, we need to think about where it originates and how it moves through the ecosystem, always keeping in mind that the energy doesn't go away or disappear. It simply changes to different forms and eventually leaves the food-web system. As the energy changes from one form to another, organisms can use some of it within the system (e.g., food molecules), and some is in a form that living things cannot use (e.g., heat given off into the environment).

Heat given off into the environment is unusable for living things because the heat energy isn't concentrated enough for organisms to use it to do work or change matter. For example, when you stand in a cold room, heat from your body warms the air around you. This heat is energy, but it's usually not enough to do useful work in living things (you couldn't easily collect the heat leaving your body and use it to move your leg). However, even this unusable energy can influence the lives of organisms.

3.5 A Food-Web Problem: Energy Flow in an Aquarium Ecosystem

Energy in the form of food is essential for all living things, and as we've said, this energy flows into, through, and out of food webs. But where does this energy come from, and how do all living things in a food web use it? How much of the energy in a food web do living things use, and how does it leave the food web?

As you explore these questions further, consider setting up an ecosystem in your classroom, such as the small aquarium described at the beginning of part 2 that has a couple of fish, some plants, a few snails, and some bacteria. In part 2 we explored what happens to *matter* in this closed system; now let's find out what happens to *energy* in this aquarium. Keep this scenario in mind as you read through the next section. What would happen to the producers, consumers, and decomposers in this system? Where would they get their energy? How would the energy move through the system?

3.6 How Does Energy Get into a Food Web?

Energy enters most ecosystems and food webs as light from the Sun. However, living things cannot use sunlight directly to get energy to live and grow. Living things get their energy from the chemical bonds in food. This is true for plants as well as animals. Many students misunderstand this idea and believe that plants use the energy from sunlight directly. That is incorrect. Before it can provide energy for plants or animals, light from the Sun has to be changed into chemical energy stored in food molecules. This happens in a process called *photosynthesis*, which occurs only in green plants, algae, and some bacteria. The incredible ability of producers (through photosynthesis) to transform carbon dioxide and water into energy-supplying food is critical to living things on Earth.

To understand the importance of photosynthesis, consider the representations of this process in figures 6 and 7. As you look at the two representations, think about which one does a better job of clarifying the important energy transformation (from light energy to stored energy in food) that occurs in photosynthesis. Which representation do you think would be more appropriate for your students?

Figure 6 depicts a simplified view of the overall process of photosynthesis, in which plants convert water and carbon dioxide (H_2O and CO_2) to sugar and oxygen. Water and carbon dioxide are simple molecules with low-energy bonds holding them together. In contrast, energy is more concentrated (and thus more readily available for organisms to use) in more complex molecules like sugar. Sugar molecules contain many energy-storing bonds. So the plant uses the energy in sunlight to build high-energy sugar molecules out of low-energy molecules (H_2O and CO_2). Another set of complex chemical reactions is required to release the energy stored in the sugar molecules. This set of reactions is called *cellular respiration* (see section 3.8). Sugars, fats, and proteins stored within the plant are also the energy source for animals that eat the plant.

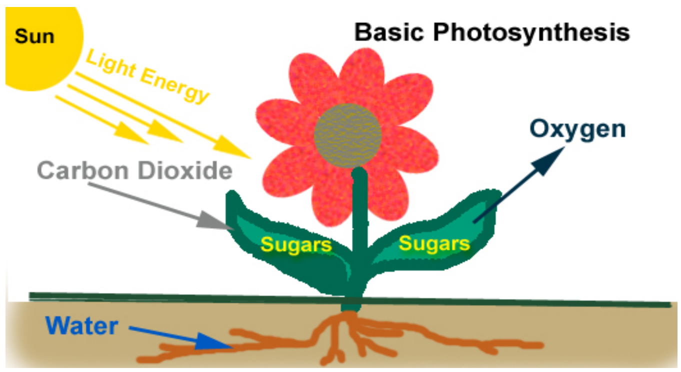


Figure 6. Diagram of a plant showing molecules being used (carbon dioxide and water) and molecules being produced (sugar and oxygen) during photosynthesis

Note: Students may misinterpret diagrams like this, thinking that the sugar is released through the leaves with the oxygen or that animals eat all of the sugars. Actually, the plant needs those sugars as its own source of energy to live. The sugars are made in the leaves through photosynthesis and then move throughout the plant to give energy to every cell.

The overall summary of photosynthesis in figure 7 emphasizes the transformation of non-energy-supplying material into chemical energy that living things can use. This representation highlights the result of sunlight energy being used to rearrange molecules (H_2O and CO_2 molecules change into $C_6H_{12}O_6$ molecules), transforming light energy to chemical energy.

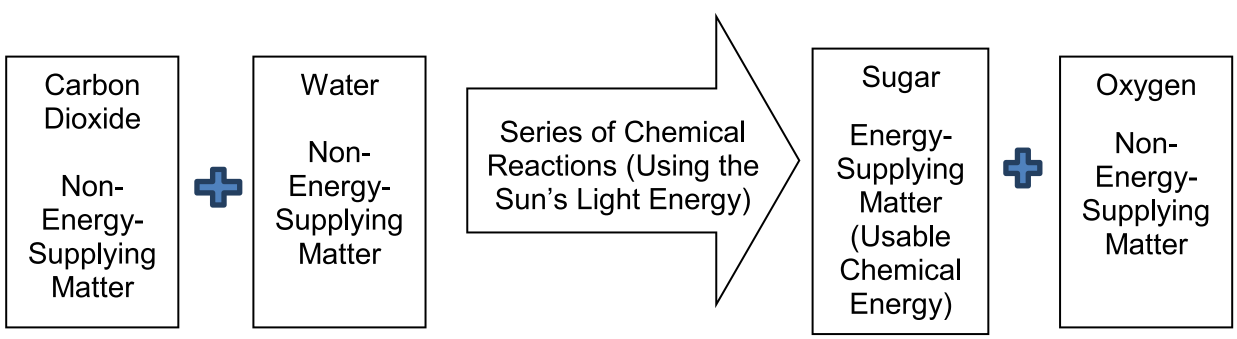


Figure 7. Photosynthesis summary

Typically, photosynthesis is represented as a balanced chemical equation. This representation inaccurately suggests that there is one simple chemical reaction when photosynthesis, in reality, involves a *series* of chemical reactions. Using a chemical equation to represent photosynthesis can also be problematic in terms of student understanding. The equation can focus students on memorizing the details of photosynthesis instead of thinking about the big ideas. *The important idea for students to understand is that green plants use energy from the Sun to make food in the form of sugar.* Plants then use that sugar as their source of energy, and animals that eat the plants also use that sugar as their source of energy. Without photosynthesis, there is essentially no energy living things can use.

Let's reconsider the definition of energy as "the ability to do work or to change matter." In photosynthesis, water and carbon dioxide are matter the Sun's energy has changed. This leads to the following definition:

Photosynthesis is the process by which producers use energy from sunlight to produce sugar (usable energy for most plants and animals) and oxygen.

How do plants accomplish this feat of using energy from sunlight to produce useful materials (sugar and oxygen)? Photosynthesis is a complex process involving a series of chemical reactions usually occurring in specialized structures called *chloroplasts*, which are found in all plant cells that carry out photosynthesis. Chloroplasts contain the pigment *chlorophyll*, which gives plants their green color. Light absorbed by chlorophyll provides the energy needed to start the sequence of chemical reactions that make up photosynthesis. It's important not to overwhelm students with many of these details (such as the equation, chloroplasts, and chlorophyll) until they have a solid understanding and appreciation of the big idea—that plants can transform light energy, water molecules, and carbon-dioxide molecules into food molecules that contain the energy living things require. These details are better left for future study in middle or high school.

3.7 Does Energy Flow in Food Webs *Always* Start with Sunlight?

While the Sun is the ultimate energy source for most land-dwelling organisms and for many sea-dwelling organisms, sunlight is absent below certain depths in some bodies of water, such as the world's oceans. And yet life does exist on the ocean floor. Where does the energy come from to support life in these circumstances? Scientists have discovered that sulfur, in the form of hydrogen sulfide (a gas that smells like rotten eggs), is the energy source that sustains life in deep-sea vent areas through *chemosynthesis* rather than photosynthesis. This is one reason why it's important to avoid absolutes, such as "the Sun is the source of all energy on Earth," when discussing energy with students.

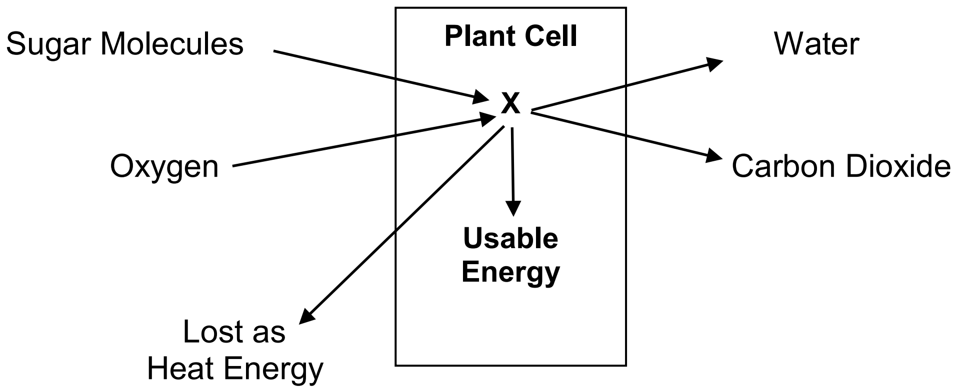
3.8 What Happens to Energy Inside Each Organism in a Food Web?

A part of the food-webs story that most students miss is that plants use ("eat") the sugar they make. Plants don't just make food for people and animals to eat; they need it themselves. Any sugar the plant doesn't use is stored (in fruit and other plant parts), which other organisms eat and use for energy. In this regard, plants and animals are alike. Both plants and animals can get energy from sugar molecules.

Plant and animal cells cannot take the energy directly from the sugar molecules, however. Instead, a series of chemical reactions is required to release the stored energy. These reactions, called *cellular respiration*, occur in each cell in each organism. One type of cellular respiration occurs when oxygen molecules and sugar molecules (food) react. When they react, energy stored in the molecular bonds of food is released to enable an organism to carry out life processes. At the end of these reactions, carbon dioxide and water molecules remain, as shown in figure 8. In addition, unusable heat energy is given off.

STOP AND THINK

In what form does energy enter the plant cell in figure 8? What happens to that energy?[7]



X = site of chemical reaction called *cellular respiration*

Figure 8. Cellular respiration in a plant cell

The word *respiration* often causes confusion about this process. Students generally associate respiration only with human breathing—we take oxygen into our lungs and breathe out carbon dioxide. They assume that oxygen is directly turned into carbon dioxide, and that these breathing-related activities occur in the lungs. But this is an oversimplified and incorrect view of respiration. As humans, we take in food and oxygen that enter each cell in our body and react, releasing energy for us to use to stay alive. Carbon dioxide is another product of this reaction. The exchange of oxygen and carbon dioxide that students typically assume occurs in the lungs actually takes place in the cells—hence, the name *cellular respiration*. This process is the same for many living things (including plants and animals that don't have lungs). Cellular respiration requires that cells take in oxygen ("breathing") and sugar molecules ("eating"), which then react to release stored energy in the sugar molecules. Carbon dioxide and water are also products of this reaction.

Figure 9 shows a typical representation in many biology textbooks that compares photosynthesis and cellular respiration. This is a very simplified and potentially misleading description of the complex biochemical processes that are occurring. It's important to examine such simplified representations for the ways they might reinforce or contribute to misconceptions. In this figure, for example, the only reference to energy is the light energy from the Sun. It doesn't show what happens to that energy either within the organisms or between them, nor does it show energy leaving the system as heat energy. This may lead to the misunderstanding that energy is needed only to start the photosynthesis process and then "disappears."

[7] Energy enters the cell stored in sugar molecules. When cellular respiration occurs, some of the energy is lost as heat. The cell uses the rest of the energy for life processes.

The diagram may also lead to confusion about what is happening with matter—the carbon dioxide, water, oxygen, and sugar. Many adults who have studied diagrams like this think that plants produce sugar *for animals to use* (not for plants to use). Another common misinterpretation is that animals breathe in oxygen, which is turned directly into carbon dioxide and exhaled. In turn, plants breathe in only carbon dioxide, which is turned back into oxygen *for animals to use* (not for plants to use). They have no concept of oxygen traveling to cells in *all* organisms, including plants, and being involved in a chemical reaction (cellular respiration) that releases energy and produces carbon dioxide and water.

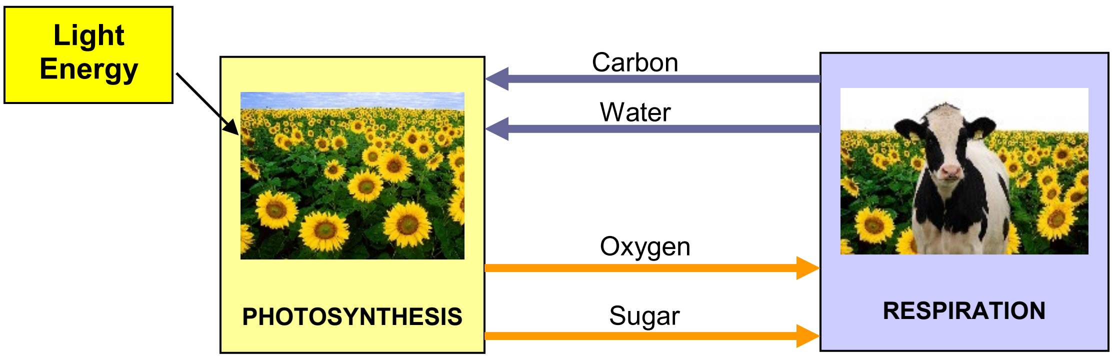


Figure 9. Common but misleading representation of the complementary processes of photosynthesis and cellular respiration

The figure might also contribute to the misconception that plants get their energy from the Sun, while animals get energy from cellular respiration. In fact, plants also conduct cellular respiration, using oxygen and the sugars they produce to get the energy needed to power their life-sustaining internal processes. Try adding labeled arrows to figure 9 to emphasize that plants also use oxygen and sugar for cellular respiration. Can you think of other ways to change the diagram to address student misconceptions?

So how might we summarize this information about where the energy comes from to keep organisms alive? Energy comes to Earth in the form of sunlight, but living organisms cannot use light energy directly. They require chemical energy (food) to stay alive. Most plants, algae, and some bacteria can convert light energy from the Sun into chemical energy stored in food molecules through the process of photosynthesis. Plants and animals acquire chemical energy by using the sugars plants make. In each cell, oxygen and sugar molecules combine during cellular respiration to release stored chemical energy in a usable form.

3.9 How Much Energy Moves from One Organism to Another in Food Webs? How Does the Energy Leave a Food Web?

When a plant transforms sunlight into chemical energy, much of the energy from sunlight is lost as heat. Similarly, when your body transforms chemical energy from food into kinetic energy for movement, much of the chemical energy from food is lost as heat. Only a small fraction of the stored chemical energy is actually used for movement. Every time energy is transferred from one useful form to another useful form, some portion of the energy becomes heat. Heat is generally not a useful form of energy because it cannot be captured and used to do other work but is released to the universe.

With each transformation of energy from one form to another, some of the energy becomes unavailable to living things for further use.

Consider burning a piece of wood in the fireplace. The wood is a concentrated source of energy. As it burns, the chemical energy in the wood (converted from sunlight through photosynthesis) is converted to energy in the forms of light and heat. We could use the energy while the log is burning to light a room or cook food, but that stored energy quickly moves from a highly concentrated form to a less and less concentrated form. The light and heat disperse throughout the room to the rest of the house, and even outside the house. As the energy is converted from chemical energy in the log to light and heat throughout the room, usable energy is lost but not destroyed; we just can't use it.

How does this apply to ecosystems and energy flow through food webs?

We know that organisms don't create energy but rather obtain their energy from other organisms they eat as food (consumers) or by creating their own food (producers). We know that some energy is lost when it's transferred from one form to another. Every time an organism uses food in cellular respiration, some energy is lost in the form of heat energy. But how much energy is used, and how much is lost? In other words, how efficient is the energy transfer within the system?

The arrows in food chains and foods webs tell us about the direction of energy transfer, but they don't tell us about *how much* of the energy in one trophic level (producers, primary consumers, secondary consumers) is actually passed on as useful energy to another trophic level. Scientists refer to this as the *energy conversion efficiency*. The energy conversion efficiency varies from organism to organism in a trophic level, but scientists have made important generalizations about it from the community of organisms at one trophic level to the community of organisms at the next trophic level. When teaching food webs, we must be careful not to take generalizations about energy transfer from one trophic level to the next and apply them to energy transfer from one organism to another.

Figure 10 outlines information that is commonly presented in science classes. What does the information tell us about the ecosystem? What does it tell us about individuals within the ecosystem? Often in science classes, producers are presented as having 100% of the energy; primary consumers, 10%; and secondary consumers, 1%. These numbers are averages over many different communities and should not be confused *with individual* energy efficiency. (It would be incorrect, for example, to say that a cow gets only 10% of the energy from the grass it eats.)

When discussing the amount of energy in living organisms, biologists use the measure of biomass. *Biomass* is the amount of body tissue, or organic matter, in living things. It seems strange to use a measure of mass, which is a property of matter, to discuss a measure of the amount of energy. Energy and matter are not the same! But living organisms get their energy from organic matter (such as carbohydrate, fat, and protein molecules), and it's a lot easier to measure the amount of mass in large numbers of organisms.

The pyramid in figure 10 shows that only about 10% of the energy available at one trophic level is transferred to the next higher level in the pyramid.[8] The energy of the producers (the first level of the pyramid) is the largest for several reasons, but mainly because there are typically many more producers in a system than consumers. As we move up the pyramid, the amount of energy in each level of consumers is smaller.

[8] Typically in science texts, an average will be used to relay the idea that energy is lost from level to level. On average, only about 10% of the energy is passed from one trophic level to the next.

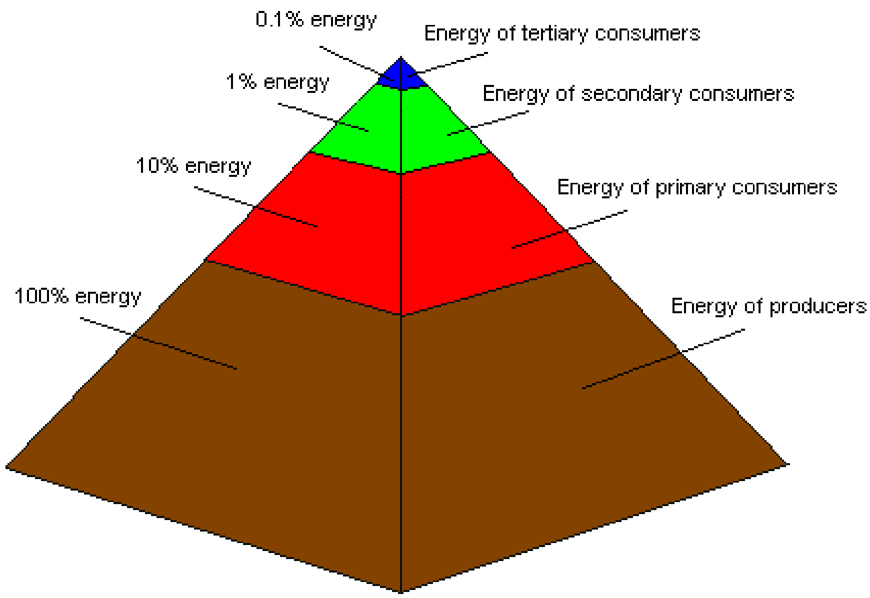


Figure 10. Energy pyramid showing overall energy flow in an ecosystem

3.10 Why Isn't All of the Energy from One Trophic Level Passed on to the Next Level?

Why isn't all of the energy from one trophic level passed on to the next level? There are several reasons for this inefficiency. First, not everything in the lower level is eaten. Consider a squirrel (a primary consumer) eating an acorn from an oak tree (a producer). The squirrel eats only part of the acorn, not the whole oak tree, and leaves the rest of the acorn on the forest floor. Furthermore, not all of the available acorns will be eaten. Second, an organism cannot digest everything it eats. For example, we humans eat foods that contain fiber we cannot digest. These undigested materials represent energy that is lost as waste, not transferred. Third, the only energy organisms can transfer to other organisms at higher trophic levels is the energy they have stored in their bodies at the time they're consumed. Fourth, energy is lost as heat as it is converted from one form to another.

Note that the Sun isn't represented in the pyramid in figure 10 even though sunlight provides the energy producers use. Although sunlight contains very large amounts of energy, most plants capture only 1% or 2% of it. Prairie grasses in the western United States are some of the most efficient plants at harnessing the Sun's energy, but even they capture little more than about 3% of the energy that reaches the prairie surface. The remaining energy is reflected away, absorbed by humidity in the air or by the ground or lost in other ways before the plants can use it. However, the good news is that plants use photosynthesis to convert the captured sunlight to chemical energy with very high efficiency. That is, most of the energy from the Sun that *is* captured by plants—even though it's a very small amount of the total energy from the Sun that hits Earth—is converted to chemical ("food") energy.

So energy flows through most ecosystems by coming in as sunlight, which plants convert to sugars (where chemical energy is stored). Plants and animals use these sugars to create the high-energy molecules their cells can use. As the organisms use up this energy to live and grow, and as the energy is converted from one form to another, it becomes less and less usable within the system and passes out of the ecosystem (typically as heat).

3.11 Why Is This Idea about Energy Inefficiency So Important to Understand?

It's important to understand energy inefficiency because it explains why food webs have fewer higher-level consumers. In a savannah ecosystem, for example, there are many grass plants, some gazelles, and very few lions. The reason for the very small number of lions compared to gazelles and the small number of gazelles compared to the abundant number of grass plants is the efficiency of the system. The primary-consumer population will use only 10% of the energy grass plants contain to power their activities (including growth and maintenance). The remainder of the energy is either stored in forms that aren't available to the next consumer (e.g., bone) or converted to heat. In addition, some energy remains in animal waste or is left uneaten, which is energy that decomposers will use later. This means that many grass plants are needed to support just a few gazelles. Similarly, many gazelles are needed to support just one lion.

Many people become vegetarians because they recognize that we can feed people more efficiently if we eat producers directly rather than growing more plants to support the raising of chickens and cattle that humans then consume. As noted in *National Geographic* (Foley, 2014, p. 45), "for every 100 calories of grain we feed animals, we get only about 40 new calories of milk, 22 calories of eggs, 12 of chicken, 10 of pork, or 3 of beef." In fact, by 2050, the world population is expected to grow about 35%, but food production will likely need to double (100%) if people in the developing world become more prosperous and eat more meat. To address the food challenges of the future, it will take a worldwide citizenry that understands energy flow in food webs.

3.12 Summary—Return to the Food-Web Problem: Energy Flow in an Aquarium

Think again about a sealed aquarium that contains fish, plants, snails, and bacteria. Will the organisms survive? For now let's look at the problem only in terms of energy. Can all the living things get the energy they need to survive? The answer is yes, as long as there is a continual supply of light energy coming into the system. The plants could use the light to make food, which could feed both the plants and the fish. The snails and bacteria could live off dead organic matter in the system. But if the light were removed, the plants wouldn't be able to produce new sugar molecules. They would live on their store of sugars for a short time but would eventually die. While the plants were alive, the fish could eat them for the sugars, but the fish would quickly need more food and would die. The snails and bacteria would live off the decaying plants and fish but would soon need more food and would die. Without a new supply, the energy continues to leave the system as heat.

Now that we've discussed energy conversion efficiency in ecosystems, we can also think about the amount of biomass of each species that should be present in our aquarium to keep the system in balance. The total biomass of the producers should be much greater than the total biomass of the primary consumers, which should be greater than the total biomass of the secondary consumers, and so forth. In our aquarium, the total biomass of the plants should be much greater than the total biomass of the fish. A delicate balance is necessary to maintain the system. If more fish were added to the aquarium and they ate all the plants, what would happen to the system?[9]

You may have noticed that we haven't discussed decomposers in much depth in our discussion of energy flow. With regard to energy, decomposers serve as another type of consumer. They need the energy to

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[9] If more fish were added to the aquarium without adding more plants, this would upset the energy balance in the system. There wouldn't be enough energy to support the fish, which would eat all the available plants and then die without additional food. From a practical standpoint, this is why most fish in aquariums cannot survive without the addition of fish food. To support the energy needs of just a few fish in an aquarium, you would need an enormous number of plants, as represented in figure 10.

survive and don't process it much differently from other consumers. Where decomposers do play a significant role is in the story of matter cycling (see section 2.5).

Part 4. Review: What Is the Relationship between Matter Cycling and Energy Flow in Food Webs?

As we've learned from our discussion of decomposers, living organisms in an ecosystem use and reuse materials such as carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur. The total amounts of these materials don't change, and they can be described as cycling within ecosystems. You may remember studying in high school or college biology classes the specifics of the water, nitrogen, and carbon cycles. Each of these cycles traces a particular type of matter (water, nitrogen, or carbon) on its recycling pathway through the ecosystem.

In comparison, energy doesn't cycle but rather moves in a linear direction through a food web, being converted from one form to another as it's transferred from one living organism to another. Energy transfer isn't 100% efficient, and some energy is lost as heat. Scientists describe the energy conversions in an ecosystem as the *flow of energy*.

Energy flow and the cycling of matter are both key processes of ecosystems. Though they're linked, they are nonetheless distinct from each other.

The relationship between energy transfer and matter cycles is represented in figure 11. Trace the cycling pattern of matter using your finger. Does the diagram show the flow for all matter? Which path would carbon follow?[10] Next, trace several pathways of energy through the system. Where does the energy pathway always end up in the diagram?[11]

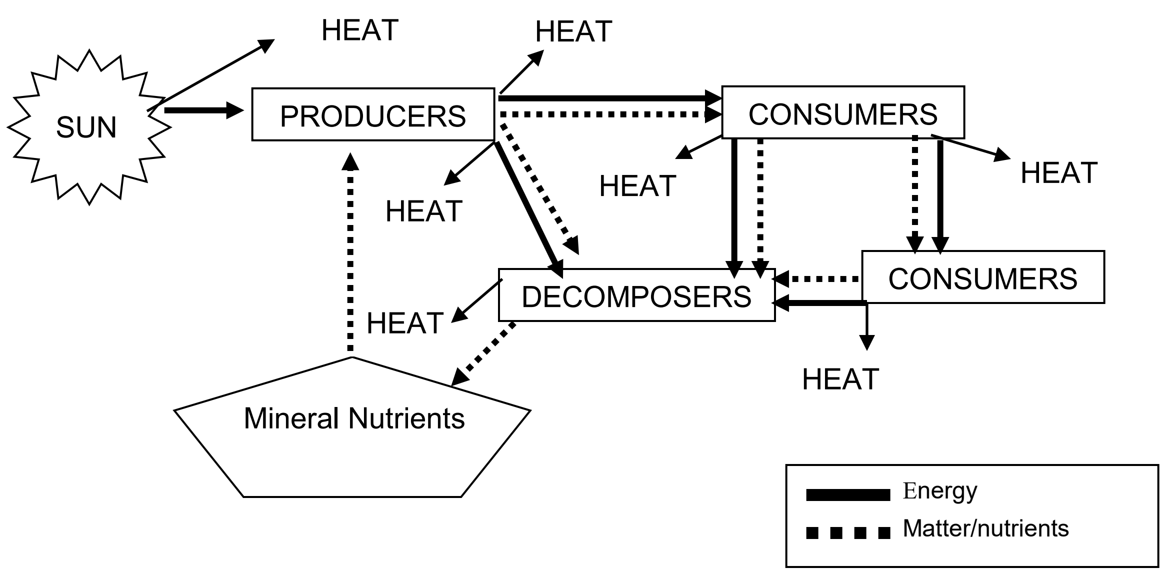

Figure 11. Energy flow and matter cycles in ecosystems

[10] Carbon would follow a path not represented well in figure 11. In addition to the matter/nutrients path, carbon leaves producers, consumers, and decomposers as carbon dioxide and is reabsorbed by the producers. This direct path is missing in the simplified illustration.
[11] The energy always ends up as heat.

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