Core Knowledge® SCIENCE

Matter Cycling and Photosynthesis:

Where does food come from, and where does it go next?

Science Literacy

Science Literacy Student Reader

Sunlight energy and photosynthesis

Chloroplast

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Matter Cycling and Photosynthesis

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ISBN: 978-1-68380-815-2

Matter Cycling and Photosynthesis

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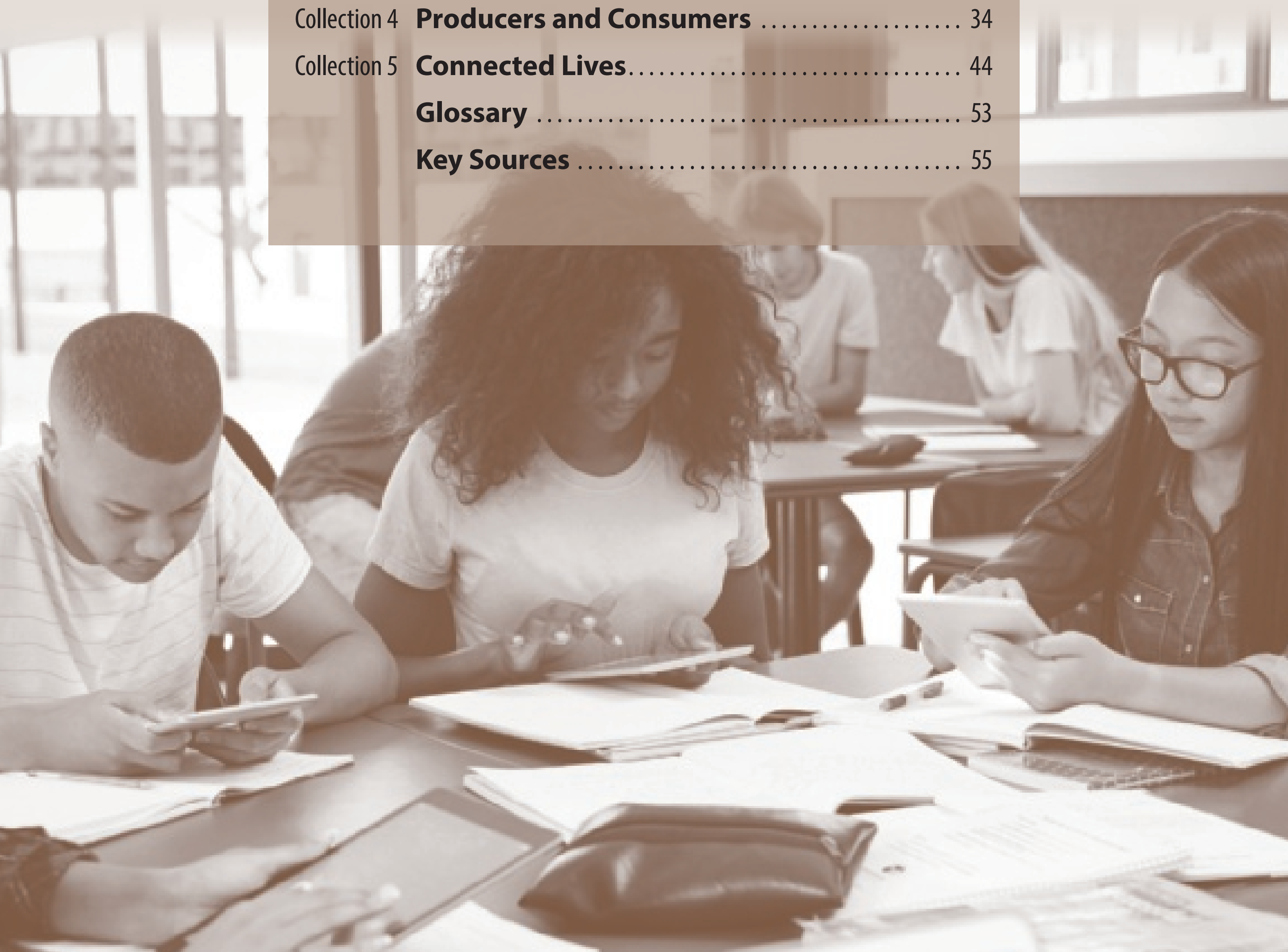


Put Yourself in This Scene

The fictional, animated Disney film *Moana* features a young heroine who is attempting to save her island and people by returning a piece of jade to Te Fiti, an island goddess who has been angry since the demigod Maui stole it from her. The film is based in part on Polynesian mythology, in which Maui is the creator of many aspects of Earth and beyond. In the film, Maui sings a fun, rhyming song in which he brags to Moana that he is responsible for every natural phenomenon. He claims he was just at play when he made the tide, the grass, and the ground. He also claims to have buried parts of an eel and sprouted a coconut tree.

> *Kid, honestly I can go on and on*
> *I can explain every natural phenomenon*
> *The tide, the grass, the ground*
> *Oh, that was Maui just messing around*
> *I killed an eel, I buried its guts*
> *Sprouted a tree, now you got coconuts*

Maui offers himself as an explanation for natural phenomena. In a way, that is what mythology does, too. What are the origins of the Maui myths? Are they just made-up stories?

Like other myths, the Maui creation myths involve plenty of fiction, but they are also based on observations that ancient people made about nature. What's the reality-based part of the eel-to-coconuts story? If an organism such as an eel is buried in soil, even in relatively barren, sandy soil on a small island, that soil will benefit from the nutrients that are released by the decomposing eel. The eel's remains act as a fertilizer. Could a coconut tree sprout from the remains of an eel without a coconut—the seed—being in the ground, too? No, that is not possible. But this myth could have been based on the observation of something similar, such as coconut tree seedlings growing better where fish remains were buried in the soil. In fact, as Polynesian people migrated to new islands throughout the Pacific, it is likely that they brought coconuts and other seeds with them, to introduce crops to islands that did not offer many edible plants. It is also likely that plants grew better in areas where decaying organisms were discarded and that people recognized this and made the connection.

Science now tells us a great deal about the origins of natural phenomena, such as how plants were introduced to islands or how the remains of organisms can aid growing plants.

This book is about scientific literacy, which means knowing how to think about science topics that you read or hear about, including topics that might not be in a scientific context. Our world has 24–7 news, social media, and too many websites to count. The amount of information we have to sort through is overwhelming, and all the information is not reliable. In the internet age, sources of information are often obscure or not trustworthy. It is good to process information with a healthy degree of skepticism while also recognizing meaningful connections between science and mythology, art, literature, and other things that may not seem very scientific.

We will make our way back to the topic of fish remains as food for plants by the end of the book. Along the way, the series of reading selections and the writing exercises that go with them will help you flex your mental muscles and sharpen your science literacy skills. The ability to read about science, understand the information, and tell truth from fallacy or misrepresentation is important. Science literacy helps you as an individual and as a consumer, and it shapes the ways you affect the community in which you live.

Plant Gallery

Bamboo is a family of grasses that often produces tall, strong, fast-growing stalks. One species can grow up to 35 inches in a single day!

Some bristlecone pine trees, from the White Mountains of Nevada, can be nearly 5,000 years old! The arid conditions in the tree's habitat result in very slow growth of dense wood that is resistant to disease, insects, fungi, and erosion.

The coconut palm tree's offspring can end up on other islands if coconuts drop to the sand, roll into the sea, and get carried on a current.

Mosses can form green carpets on forest floors, rocks, and the bark of trees. They thrive in shady, damp places.

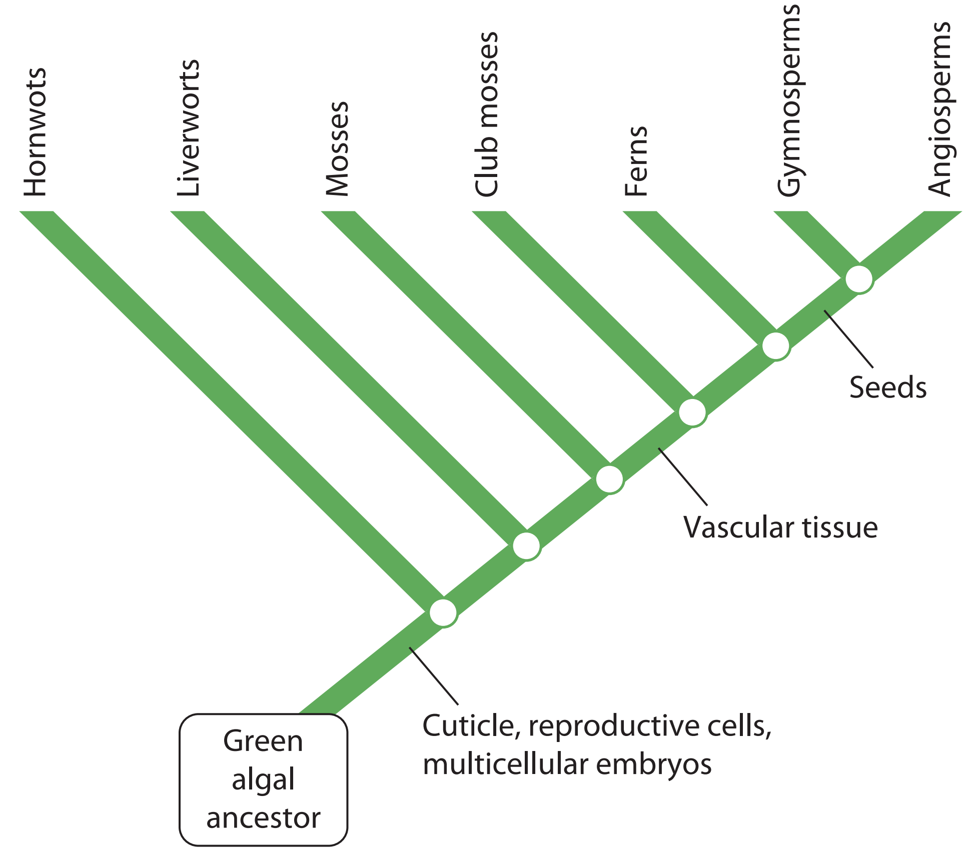
Wheat is a type of grass that humans have been cultivating for about thirteen thousand years. The grains of wheat plants are ground into flour that is used to produce breads, pastas, cakes, and many other foods.

The leaf of a fern, called a frond, often starts as a fiddlehead before unfurling.

Kudzu is a vine. Out of its native habitat, it becomes invasive and can overwhelm landscapes and crowd out other plants. Its vines can grow in length by one foot per day.

Claude Monet's paintings of water lilies have fetched more than $40 million at auction. Water lilies are aquatic flowering plants whose flat leaves and colorful flowers are at the surface of the water while the roots are anchored in the mud below.

Maple fruits are called double samaras. They spin like helicopter blades as they fall to the ground in spring.



The plant kingdom evolved from green algae. The waxy outer covering, or cuticle, allowed plants to survive on land. Later, when vascular tissue evolved, plants were able to grow taller. The evolution of seeds allowed plants to spread more easily.

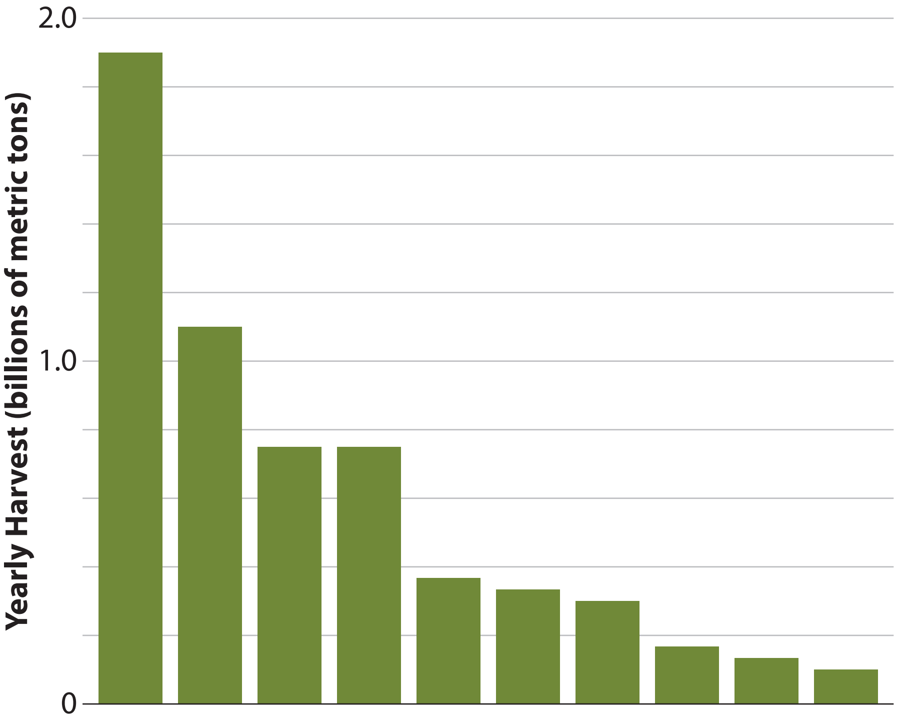
Green algal ancestor

Angiosperm

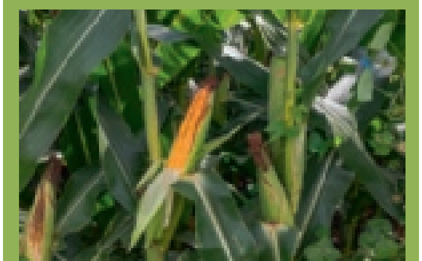
Plants That Feed the World

Sugarcane

- Sugarcane is processed into table sugar, molasses, and several byproducts.
- The stalks are stripped of leaves and then crushed to release the juice.
- The juice is refined and dehydrated, producing crystals of sucrose.
- 1.9 billion metric tons of sugarcane are harvested in a year.



Maize

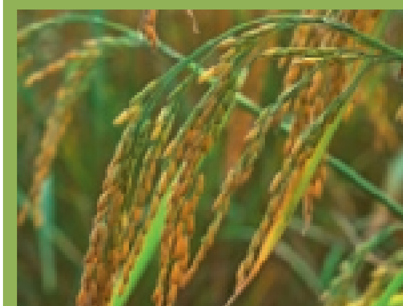


- Maize is known as corn in the United States which is the world's largest producer.
- Corn is eaten as food, fed to livestock, and processed into oil and syrup.
- Corn is made into compostable containers and cutlery.
- It is processed into ethanol, a fuel.
- 1.1 billion metric tons of corn are harvested per year.

Wheat

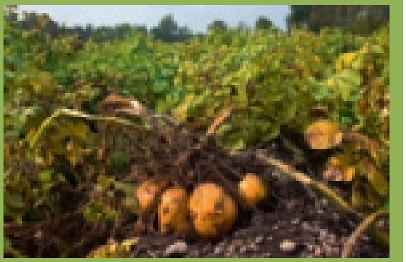
- Wheat produces a grain that is ground into flour.
- Wheat is high in gluten, a protein that some people have trouble digesting.
- 765 million metric tons of wheat are harvested per year.

Rice



- Rice primarily grows grown in wet paddies.
- A grain that is stored dry, it is usually cooked as whole grains but can be processed into rice flour to make rice noodles, rice cakes, dumpling wrappers, candies, alcoholic drinks, and more.
- 757 million metric tons of rice are harvested per year.

Potatoes



- Potatoes have been bred into a variety of types, but the non-sweet varieties are the most popular.
- French fries, mashed potatoes, and potato chips are a few of the foods made from potatoes.
- 370 million metric tons of potatoes are harvested annually.
- The United States produces 19 million tons of potatoes each year.

Soybeans

- Soybeans can be eaten whole but are often processed into products such as tofu and soy sauce.
- 334 million metric tons of soybeans are harvested per year.

Cassava

- Also known as manioc, cassava is a starchy root crop.
- It can be boiled, roasted, or fried.
- The roots can be harvested, and then the plant's stem can be stuck in the ground to regrow roots.
- 305 million metric tons of cassava are harvested per year.

Tomatoes

- Tomatoes can be eaten raw, cooked into sauces, added to salsas, and processed into pastes.
- They are also used for one of the most popular condiments in the United States, ketchup.
- 181 million metric tons of tomatoes are harvested per year.

Barley

- Barley is another useful grain, with 160 million metric tons harvested per year.
- It can be used to make breads, soups, and stews but is also grown to produce a type of sugar used to brew beer.

Bananas

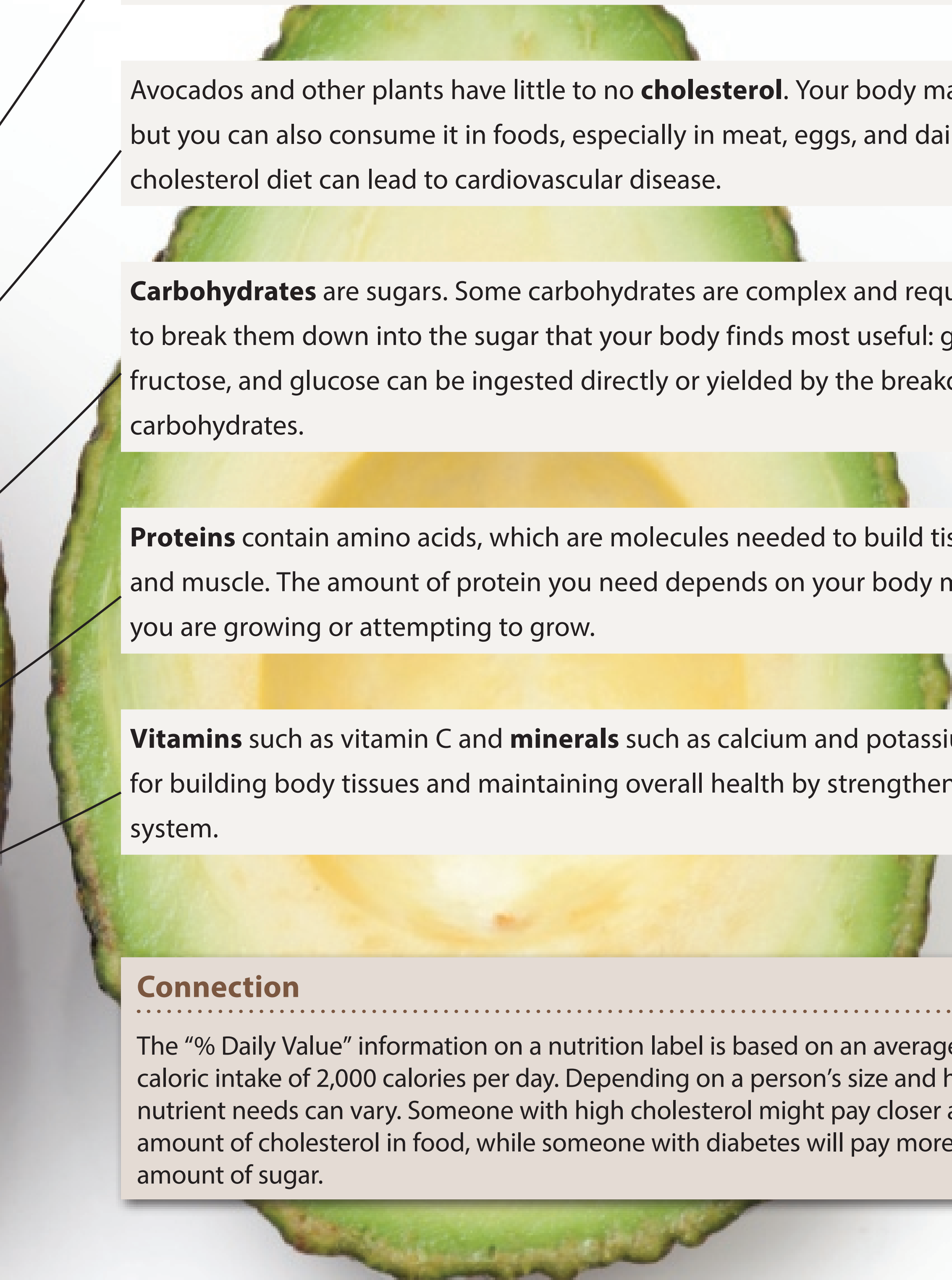
- Bananas have been bred into several varieties, including the Cavendish type that dominates the market in the United States.
- Bananas can be harvested well before they are ripe and then allowed to ripen naturally or ripened by adding ethylene gas to the air around them.
- 117 million metric tons of bananas are harvested per year.

All That in One Avocado?

Nutrition Facts

Amount per			1 cup, sliced (146 g)
Calories			**234**
			% Daily Value*
Total Fat 21 g			32%
Saturated fat 3.1 g			15%
Cholesterol 0 mg			0%
Sodium 10 mg			0%
Potassium 708 mg			20%
Total Carbohydrate 12 g			4%
Dietary Fiber 10 g			40%
Sugar 1 g			
Protein 2.9 g			5%
Vitamin C	24%	Calcium	1%
Iron	4%	Vitamin D	0%
Vitamin B6	20%	Cobalamin	0%
Magnesium	10%		

*Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs.



Avocados are rich in unsaturated fat, which is a type of fat that is considered good for human health. They also have some saturated fat, so they should be eaten in moderation. **Fats** are food molecules that are high in energy and can be broken down into sugars.

Avocados and other plants have little to no **cholesterol**. Your body makes cholesterol, but you can also consume it in foods, especially in meat, eggs, and dairy products. A high-cholesterol diet can lead to cardiovascular disease.

Carbohydrates are sugars. Some carbohydrates are complex and require multiple steps to break them down into the sugar that your body finds most useful: glucose. Sucrose, fructose, and glucose can be ingested directly or yielded by the breakdown of complex carbohydrates.

Proteins contain amino acids, which are molecules needed to build tissues such as bone and muscle. The amount of protein you need depends on your body mass and whether you are growing or attempting to grow.

Vitamins such as vitamin C and **minerals** such as calcium and potassium are important for building body tissues and maintaining overall health by strengthening your immune system.

Connection

The "% Daily Value" information on a nutrition label is based on an average person and average caloric intake of 2,000 calories per day. Depending on a person's size and health, calorie and nutrient needs can vary. Someone with high cholesterol might pay closer attention to the amount of cholesterol in food, while someone with diabetes will pay more attention to the amount of sugar.

Sugar

Plants produce the six-carbon sugar **glucose** through photosynthesis. They use glucose to assemble other carbohydrates. Some of this is in the form of simple sugars such as fructose, which makes fruits sweet. Some is stored as the complex carbohydrate starch. And some is fibrous cellulose that makes up plant cell walls.

On a nutrition label, all of these are included in the "Total Carbohydrate" figure. The simpler sugars are grouped under "Total Sugars" and are separated from "Dietary Fiber," which is usually indigestible cellulose. Food with a total carbohydrate number that is much higher than the sum of the total sugar and dietary fiber is likely very high in starch, which is a big molecule made of lots of repeating glucose molecules bonded to one another. Potatoes are very starchy. A tomato, on the other hand, is mostly simple sugars and a bit of fiber.

Simple sugars occur naturally in some foods, and they can also be added to foods to enhance sweetness. For example, a commercial can of blueberries has the fructose and glucose of the blueberries themselves, but people may add sucrose or corn syrup in the purple fluid that surrounds the berries to make the blueberries even sweeter. These are some added sugars that you might find on nutrition labels or in the ingredients lists for processed foods:

- High-fructose corn syrup
- Molasses
- Sucrose
- Dextrose
- Agave nectar
- Lactose
- Malt syrup
- Honey

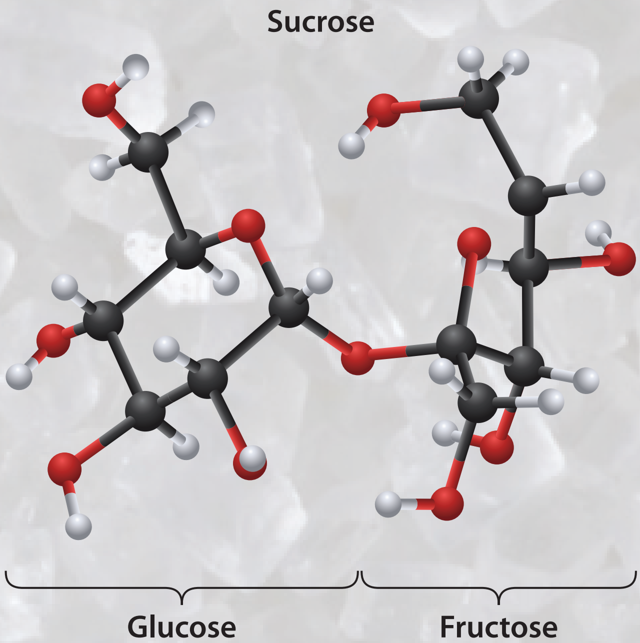
When in doubt, if you see something that contains -*ose* in the name, that is likely an added sugar.

Plant Type and Part	Total Carbohydrate	Total Sugars	Dietary Fiber
Banana (whole fruit, peeled)	26 g	9 g	5 g
Corn (yellow kernels, raw, 1 cup)	27 g	9 g	3 g
Potato (flesh only, whole, baked)	34 g	2.7 g	2 g
Rice (white, cooked)	37 g	0.1 g	2 g
Soybeans (seeds, boiled, 1 cup)	14 g	5 g	10 g
Tomato (Roma, canned, diced, 1 cup)	8 g	7 g	<1 g

The high concentration of carbohydrates in corn makes it an excellent source of sweeteners such as corn syrup.

Sugar in the Kitchen

When you talk about sugar in baking or cooking, you are most likely referring to **sucrose**—the crystalized stuff that can be spooned into a glass of lemonade. Sucrose is formed when one molecule of glucose bonds to one molecule of fructose.

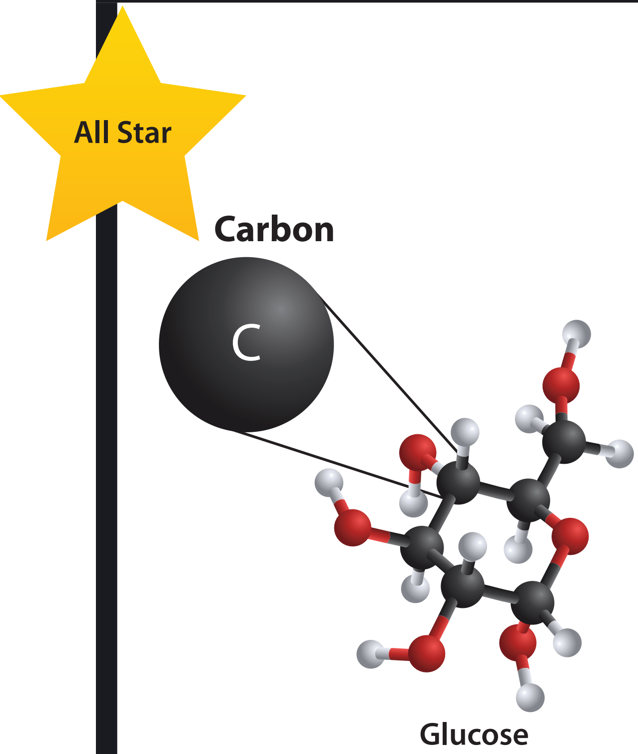


Sucrose contains 12 carbon atoms (shown as black spheres), 22 hydrogen atoms (white spheres), and 11 oxygen atoms (red spheres).

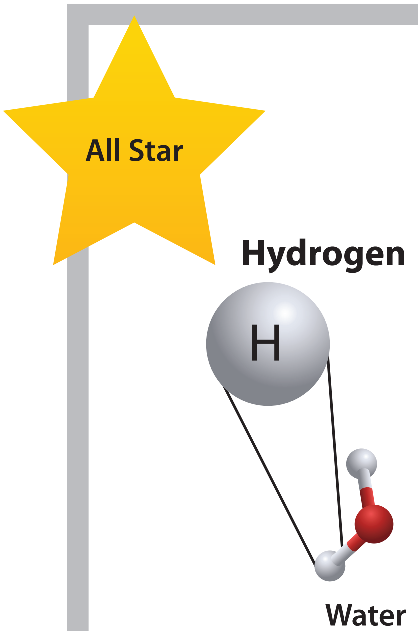
The sucrose that we consume comes mainly from sugarcane and sugar beets. The juices from these plants are squeezed out and boiled down to yield sucrose crystals. When sucrose crystals mix with water or some other watery liquid, they tend to dissolve. This separates the sucrose molecules, producing a sugary sweet solution. That solution could be your sweetened lemonade, or it could be the thick syrup that will harden into a lollipop.

Food manufacturers and chefs need to be aware of sucrose's tendency to crystallize. Consider a solution for making lollipops. If the solution is saturated with sucrose, the sucrose could crystallize when the lollipops form. This would give the lollipops a gritty texture. To prevent this, corn syrup can replace some of the sucrose in the recipe. The corn syrup's molecules, mostly glucose, get in the way as sucrose crystals attempt to form. The glucose provides a sweetness like sucrose. This will keep the lollipop sweet in taste and smooth in texture.

All-Star Building Blocks of Food



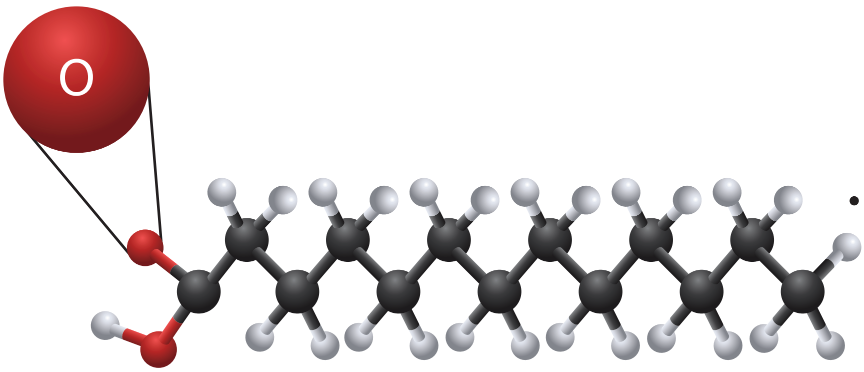
- Carbon is known as the backbone of life on Earth because it is the basis of so many organic molecules, from glucose to complex sugars such as cellulose and starch.
- Carbon accounts for a tiny fraction of the molecules in the atmosphere, but plants take it in in the form of carbon dioxide and use photosynthesis to produce food for themselves.
- There is more carbon in the atmosphere now than there was fifty or a hundred years ago because humans have burned so many hydrocarbons—fossil fuels such as oil and gasoline. Domestic cattle have released methane, a carbon compound.



- Hydrogen is the most abundant element in the universe. It accounts for about 75% of all known matter.
- Hydrogen also tends to be one of the most abundant atoms in food. For example, in glucose, there are twelve hydrogen atoms to the six atoms of carbon and six atoms of oxygen.
- Hydrogen forms bonds with many other atoms and molecules. Two hydrogen atoms bond with one atom of oxygen to make a water molecule.
- Water is a product of cellular respiration and a reactant in photosynthesis. This means it is constantly cycling into and out of these cellular processes and therefore into and out of many different systems.

All Star

Oxygen

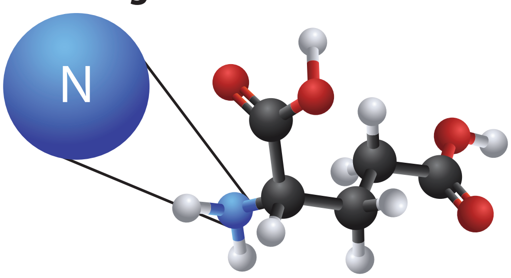


Saturated fat

- Oxygen in the atmosphere is found mostly in a diatomic, or two-atom, form, O_2. It accounts for about 21% of the molecules in air.
- Oxygen is taken in by organisms and used in cellular respiration to release energy that organisms can use. It also ends up in glucose and other food molecules, such as fat.
- Photosynthesis releases oxygen gas into the atmosphere. This helps maintain the supply of oxygen in the atmosphere and in bodies of water.

Honorable Mention

Nitrogen



Glutamate

- Nitrogen, as N_2, nitrogen gas, is the most abundant element in the atmosphere. To get into a food chain, however, it must be altered to make it available to plants. Botanists say it is “fixed” by nodules on the roots of some plants, especially legumes such as beans and peanuts. This process converts the nitrogen gas into forms that can be taken up by the plants and used to make proteins.
- Nitrogen is a key ingredient in amino acids. About twenty amino acids are the building blocks of proteins in the human body.
- Proteins are large molecules that form much of the structure of tissues such as bone and muscle. By mass, nitrogen accounts for about 16% of protein.
- Nitrogen-rich fertilizers can be added to soil to help plants grow. Decaying remains of organisms and the waste products that animals excrete are often excellent fertilizers.

Photosynthesis

Photosynthetic organisms use the energy in sunlight to produce glucose. This reaction is the base of most food chains, including those that humans are a part of.

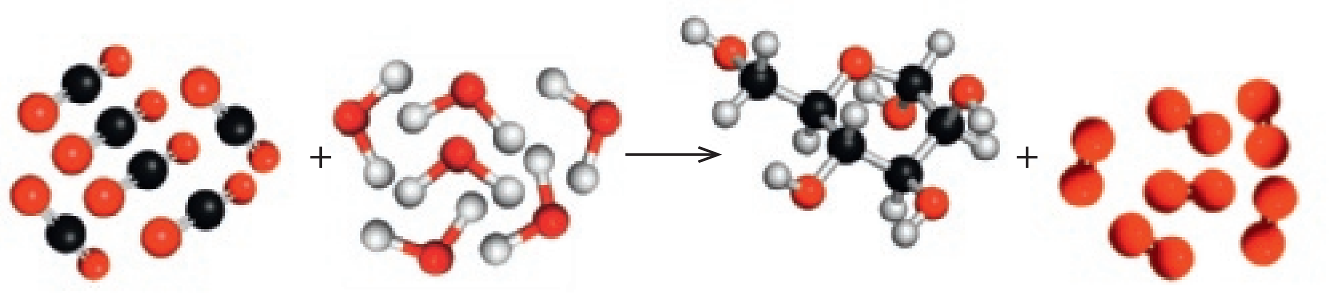
In a chemical reaction, whatever goes in must come out in terms of atoms and total amount of matter. Take carbon, for example. There are six molecules of carbon dioxide on the reactants side of the equation. That means there must be six carbon atoms on the products side.

Light is a key ingredient in **photosynthesis**, but because it does not consist of matter, it is not considered a reactant. Instead, it might be indicated by a sun icon over the arrow or labeled as “light” in the same place.

$$6CO_2 + 6H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6O_2$$

The conservation of matter is indicated by the number of hydrogen atoms, too. To make one molecule of glucose requires six water molecules in the reactants to provide the twelve atoms of hydrogen.

The oxygen content of the atmosphere and large bodies of water depends in part on photosynthetic organisms producing oxygen gas through photosynthesis. For example, in a pond, the photosynthetic plants and plankton release oxygen into the water, which allows animals such as trout to survive. Oxygen from water also escapes into the atmosphere. Scientists estimate that photosynthesis in the ocean accounts for most of the oxygen in the air.



More than Glucose

The primary product of photosynthesis is glucose, but glucose and other substances are used to produce other compounds, including monomers and polymers.

Chlorophyll

The pigment that gives plants their green color and ability to harness the energy in sunlight is called chlorophyll. Iron and magnesium are key elements in chlorophyll.

Lignin

One of the defining characteristics of plants is the presence of cell walls. If these walls become hardened, the plant stem can become strong. This is what allows many plants to grow tall and massive. Lignin is the chemical that gives cell walls their rigidity and strength. In addition to providing structural strength, lignin helps protect plants from disease. The sprawling elm tree shown here owes its strength to lignin.

Words to Know

A *monomer* is a molecule that can bond to other identical molecules to form a polymer.

A *polymer* consists of many units of identical or similar substances.

Glutamate

The amino acid glutamate is synthesized in plants and animals. Plants and meats that are rich in glutamate offer what is now known as the fifth taste: *umami*, or savoriness. Soy sauce, which is produced from fermented soybeans, is an example of a food that has intense umami flavor.

Alkaloids

Plants produce a wide variety of alkaloids. An alkaloid is a compound that is basic, meaning the opposite of acidic. Many different drugs have been made from plant alkaloids. Some alkaloids are poisonous and serve this function to protect plants from being eaten. Strychnine, which is derived from a tree native to South Asia and Australia, is an alkaloid used to make rat poison.

Terpenoids

Another diverse class of compounds produced by plants is the terpenoids. Grapes, herbs, ginger, and other plants' characteristic flavors are the result of terpenoids. Pitch, which is made from the sticky resin produced by a variety of different trees, has been used to waterproof boat hulls and underwater pilings for centuries.

Anticancer Alkaloids

Medical scientists and pharmaceutical developers have looked to plants for many decades as a source of biologically active compounds that could fight diseases. The rosy periwinkle, native to Madagascar, was used in traditional healing to treat diabetes. Further experimentation showed that two alkaloids produced by the plant were effective at fighting several types of cancer. Since the 1950s, tens of thousands of cancer patients have benefited from drugs based on these compounds.

Fructose

Glucose is a component of fructose, another sugar. Fructose and glucose combine to form sucrose, or table sugar. Unlike glucose, fructose cannot be utilized directly by most cells in the body. It is first processed in the liver. One of the byproducts of this process is triglyceride, a type of fat that enters the bloodstream and can result in buildup of plaque in blood vessels. This is one way in which a high-sugar diet can lead to cardiovascular disease.

Fertilizers

Fertilizer Buying Guide

Bags of commercial fertilizer have a label with a three-part number, known as an NPK number. The number represents the percentage of the fertilizer that is nitrogen (N), phosphorus (P), and potassium (K). For example, 28-7-14 fertilizer is 28% nitrogen, 7% phosphorus, and 14% potassium.

Nitrogen is a key ingredient of chlorophyll, which in turn makes plants green and likely to grow well. Too much nitrogen can inhibit root growth, while phosphorus is especially good for root development. Potassium is good for plants' ability to withstand stress, such as periods with too little water or too much heat.

Figure out the nutrient balance in your soil before you add fertilizer. You can buy a soil nutrition testing kit to measure your soil's natural NPK values. If the ratio of the nutrients is already 1:1:1, then a 16-16-16 fertilizer should work. If your soil is lacking nitrogen and slightly low on potassium, a 24-8-16 blend could be more appropriate.

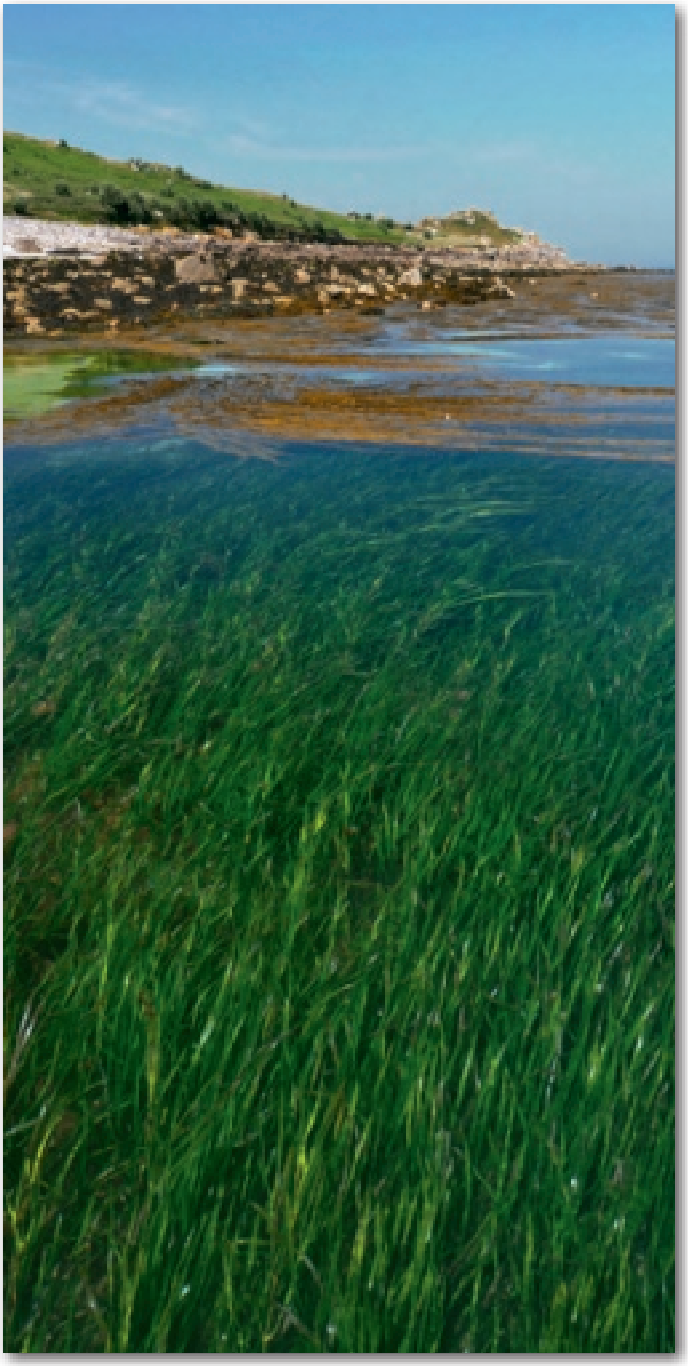
Synthetic fertilizers are produced by chemical manufacturers. Because the nutrients are relatively pure, they are easily and quickly absorbed by plants. The downside: they tend to work for a shorter amount of time, which means you might need two or three applications of this kind of fertilizer. With an organic fertilizer, you won't need to apply it as often because it works more slowly and takes advantage of bacteria that are part of the mix. Seaweed, manure, lobster shells, bone meal, fish bones, and other natural ingredients are used in organic fertilizer, so this product is similar to the first fertilizers that humans used.

Salmon Feed the Forest

July 11, 2021

We anchored in Barnard Inlet at dusk, observed the thick school of chum salmon in the evening, and slept a bit, and now we're patrolling the shores of the river that empties into the sea. The salmon were surprisingly still at night, perhaps to avoid detection by the brown bears that line up by the dozen to gorge on these fish. Now, the salmon are on the move, surging and leaping their way upstream to spawn and, eventually, die. Our team is attempting to map where the salmon and the nutrients they carry in their bodies give themselves back to the land. This happens in a few different ways. First, as salmon are picked off by hungry bears, some of the nutrients their flesh carries will make their way to the forest floor as bear scat. Nitrogen from the scat will get into the soil and be taken up by plants. The salmon that make it all the way upstream to spawn and die give their nutrients back to the forest, too. Decomposition of salmon carcasses in the water sends nutrients into the streambeds, and some of that nutrition will work its way into the soil and plant roots of the riverbanks. Many animals feed on salmon carcasses: wolves, skunks, raccoons, otters, foxes, mice, squirrels, deer, and a variety of birds. When these animals feed on carcasses and excrete waste, they deliver vital nitrogen that was out at sea just weeks earlier.

All told, we think that at least 25% of the nitrogen that's available to the forests in this region comes from the sea by way of migrating salmon. This is a huge transfer of matter. We need to better understand the pathways the nitrogen takes because dams and fishing that block salmon from getting upstream could be denying the forest the nutrients it needs.



Plants in Water, Water in Plants

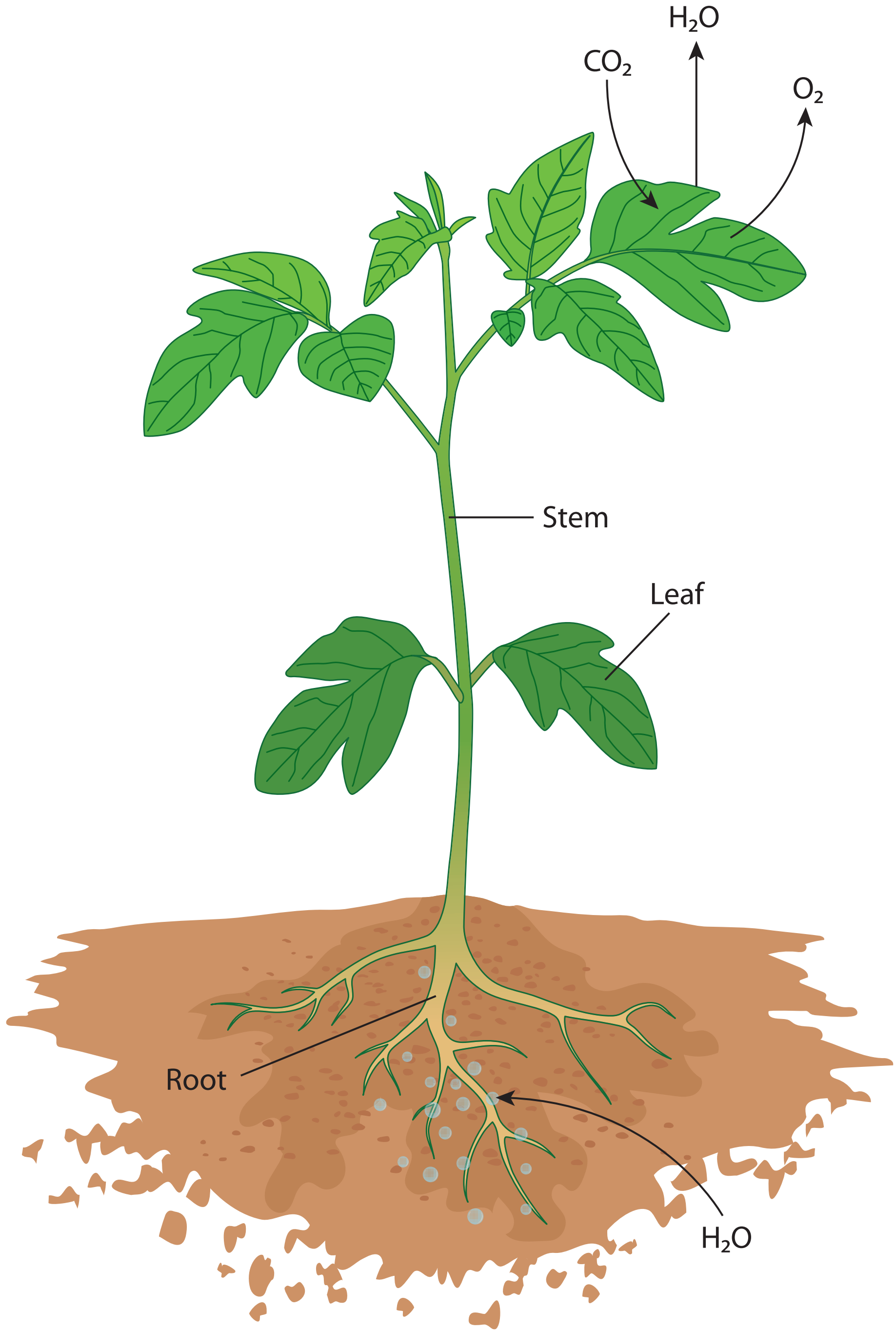
Plants need carbon dioxide and water to conduct photosynthesis. Aquatic plants have easy access to water. But how do they absorb carbon dioxide? Meanwhile, terrestrial plants can take in carbon dioxide from the atmosphere, as they have easy access to air. But how do they get enough water?

Aquatic plants such as eelgrass (*Zostera marina*) had ancestors that lived on land. As these plants moved back into the sea, they lost their waxy cuticle. This allowed for dissolved gases and nutrients to pass more easily into and out of the grasses. Carbon dioxide and another form of dissolved carbon, bicarbonate, can be absorbed from the water and used for photosynthesis. In fact, eelgrass and other aquatic plants are so good at removing carbon from the water that they are thought of as much more efficient carbon sinks than terrestrial forests are. Replanting and preserving seagrass habitat could go a long way toward reducing the amount of carbon dioxide in the atmosphere and the sea.

Word to Know

A plant's *cuticle* is a waxy coating on leaves or flowers that keeps in moisture and keeps out germs and insects.

Terrestrial plants have access to plenty of carbon dioxide (CO_2). It is in the air around the plants' leaves, and the leaves take in this gas through tiny pores. Oxygen gas (O_2) is released from the leaves as a byproduct of photosynthesis. Water cannot get through terrestrial plants' waxy cuticles. Instead, it must be absorbed by the roots, which are mostly buried in the soil. The roots are adapted to absorb water as well as nutrients that are dissolved in the water. Water vapor is released from plant leaves via the same pores that take in carbon dioxide and release oxygen. Notice that the diagram shows oxygen leaving the plant, but it's important to know that oxygen is used by the plant, too. Just like an animal's cells, plant cells conduct cellular respiration, unlocking the chemical energy found in glucose to power other processes. That's why plants photosynthesize—to make sugar that the plant then consumes via cellular respiration.



Connection

Plants are part cycles of different types of matter, including nutrients such as nitrogen, along with carbon, water, and oxygen. Plants do this as living organisms but also as decaying remains. A decomposing tree, for example, releases large amounts of nutrients to the soil, allowing that tree's offspring and other plants to thrive.

Plant Sap and Resin Products

Turpentine Pine trees are tapped to collect a sticky resin that can be processed into different products. Turpentine is used to clean paintbrushes. It can also be used to make varnish and wax for furniture.

Amber Fossilized amber is basically hardened pine resin. Sometimes, amber contains preserved remains of organisms from thousands or millions of years ago. Scientists can extract DNA from these remains. This idea was used in the book *Jurassic Park*, which was later made into a series of movies. If the mosquito had bitten a dinosaur, that DNA could be extracted from the gut of the mosquito.

Shellac An insect known as the lac bug feeds on sap on a variety of trees. The insects digest the sap and secrete a protective resin, called lac, onto the tree branches. This resin is harvested and processed into lac flakes, which can then be mixed with alcohol to produce shellac. Shellac is brushed into wood to enhance color and provide a protective coating. About 20,000 metric tons of lac are produced each year in India.

Latex Also known as rubber, latex is tapped from the rubber tree. The sticky white resin has been used to produce tires, surgical gloves, and many other elastic products.

Maple Syrup The sap of the sugar maple tree can be tapped and boiled down into syrup. The sap is about 2% sugar when it is tapped. Maple syrup must legally be at least 66% sugar.

Birch Extract Like maple syrup, sap from a birch tree can be tapped. Birch beer, which is like root beer, can be brewed from concentrated birch sap.

Incense Incense is a substance that is burned to emit a fragrant smoke. It is made of sap or resin from different types of plants.

Words to Know

Sap is the nutritious liquid that flows within a plant's conducting tissues. One part of the system carries sugar from leaves to all other parts of the plant. *Resin*, which is sometimes called sap, is stickier, and its purpose is to heal a plant, especially if its bark has been stripped off or a branch has been cut.

Dissolved Oxygen and Aquatic Life

Fish Kills in the Sudbury River

By Sooah Kim, Cindy Liu, Joyelle Turner, and Matt Murphy
Mr. Flight's Grade 12 Advanced Biology Class, Lincoln H.S.

Introduction

Water is made of hydrogen and oxygen, but the oxygen of water is not available to fish and other aquatic living things. However, mixed in with water are molecules of oxygen gas. Living things can use this for life. It is called dissolved oxygen.

Dissolved oxygen is affected by the temperature of water. In the rivers and ponds of New England, dissolved oxygen levels tend to be higher in winter, when temperatures are low. In summer, when rivers and ponds are warm, dissolved oxygen levels decline. Low oxygen levels can lead to death for fish. Mass-mortality events of fish and other animals, also known as "fish kills," have been observed but rarely studied in detail in the Sudbury River. We visited the Fairhaven Bay area of the river three to five times per week for a full year to record water temperature, dissolved oxygen levels, and evidence of fish mortality. We began this work as juniors in the standard biology class and completed it as seniors in the advanced class.

Fish remains in shallows of the Sudbury River in February

Methods and Materials

Our investigation involved using a probe kit to measure water temperature and dissolved oxygen. We used a small mooring to mark a specific spot ten feet from the banks of the river, at the boat landing off Route 27, in the Fairhaven Bay area of the Sudbury River. This spot served as our water sampling site. We used a canoe or hip waders to get to the stake, then lowered the probe to a depth of 60 centimeters from the surface to take measurements. We had a schedule that allowed one or two of us to sample the site on any given day.

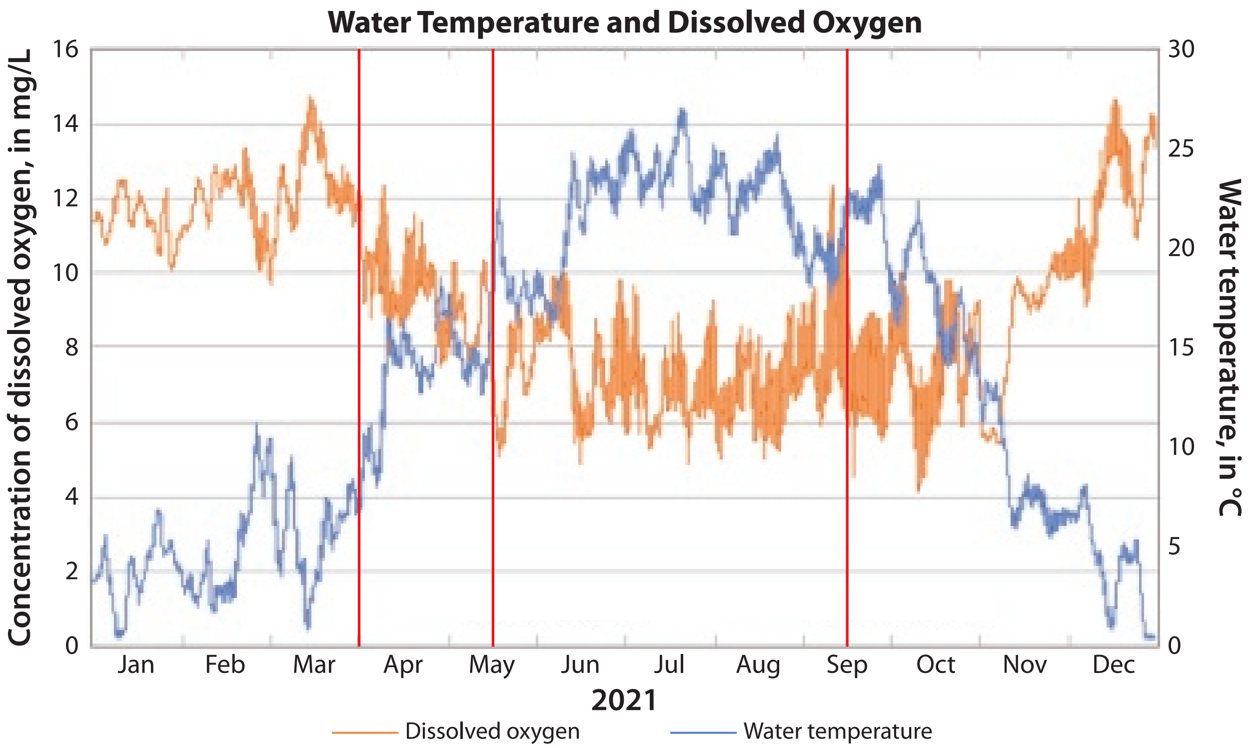
In winter, when the ice was too thick to break through with our canoe, we used a one-inch drill bit to make a hole through the ice through which our probe could fit.

We also noted visual observations of fish mortality, such as carcasses of bluegills, smallmouth bass, and pickerel. Photographs were taken to record these events. Carcasses were left in place.

We could not collect data at the same time every day, but we did manage to collect all data between dawn and dusk throughout the year.

Results

The temperature and dissolved oxygen data are shown in the graph. We marked three mass mortality events in red. The dates of those events and species that were affected are noted in the table.



Date of Mass-Mortality Event	Species Killed
March 28, 2021	smallmouth bass, *Micropterus dolomieu* bluegill, *Lepomis macrochirus* pumpkinseed, *Lepomis gibbosus* yellow perch, *Perca flavescens*
May 14, 2021	smallmouth bass, *M. dolomieu* bluegill, *L. macrochirus* northern pike, *Esox lucius*

Date of Mass-Mortality Event	Species Killed
September 14, 2021	largemouth bass, *Micropterus salmoides* bluegill, *L. macrochirus* pumpkinseed, *L. gibbosus*

Discussion

The data show a cause-and-effect relationship between water temperature and dissolved oxygen levels. In winter, when the water temperature dropped near freezing, the dissolved oxygen level was between 10 and 14 mg/L. In summer, when the water temperature was in the twenties (°C), the dissolved oxygen level was between 5 and 10 mg/L. Three fish kills coincided with low points in dissolved oxygen and high points in temperature. Two of those occurred in summer. The other occurred in March, when the water temperature was relatively low and the dissolved oxygen level was 8 g/L. Our hypothesis is that the abundant decaying plant and animal matter from the winter spurred a lot of bacterial activity, which sucked up oxygen. Meanwhile, because aquatic plants such as water chestnut were not yet abundant in the spring, there was not a steady source of oxygen to the river system. We hypothesize that the dissolved oxygen level was considerably lower than 8 g/L the night before we visited the site and that the fish kill occurred overnight because of those anoxic conditions. Given the vulnerability of aquatic systems to anoxia at night, future study of this system would benefit from nighttime data collection.

Notably, the black bullhead catfish, *Ameiurus melas*, was not a victim of any of the fish kill events, despite being a very abundant fish in the river. A review of the literature suggests that catfish are less vulnerable to anoxic conditions. If climate change continues to raise summertime water temperatures, we could see declines in the populations of the sunfish, perch, pike, and bass, and the catfish could thrive.

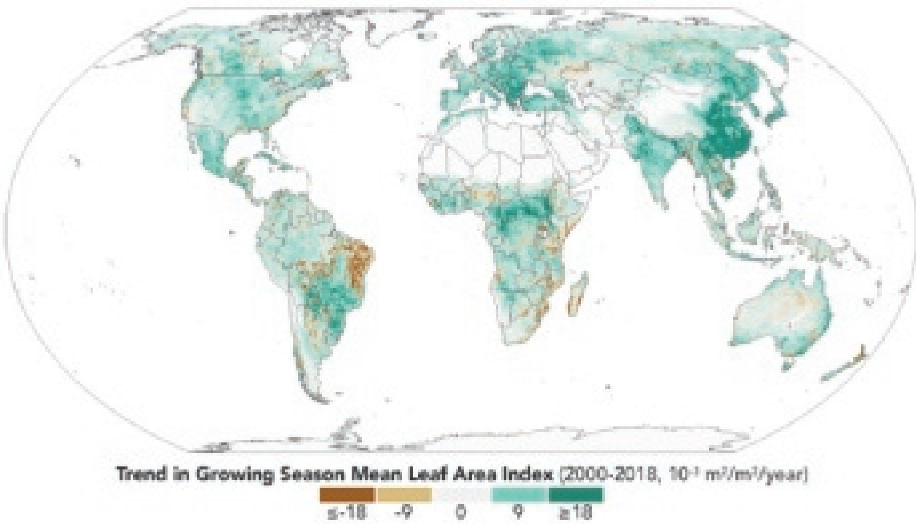
Word to Know

Anoxic means lacking oxygen. If a body of water is anoxic, it has low levels of dissolved oxygen, and organisms are therefore threatened, especially those that cannot produce oxygen through photosynthesis.

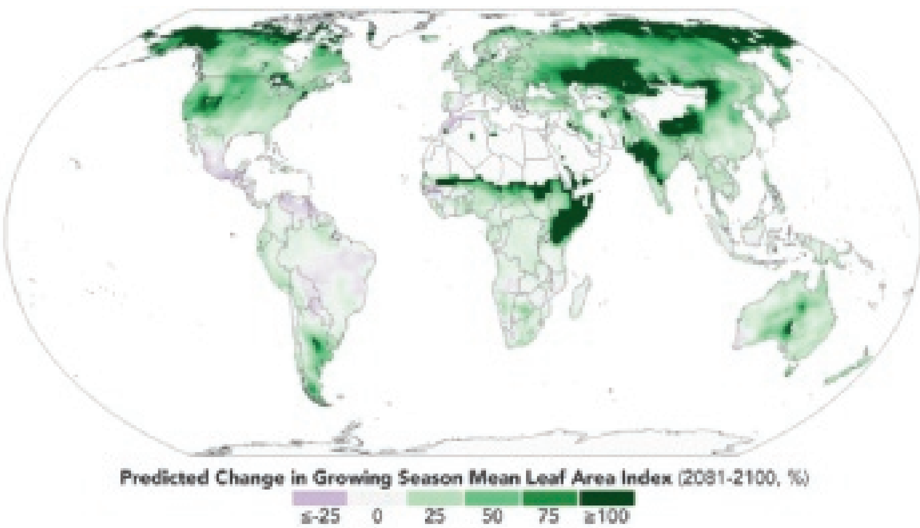
Will a Greening Earth Slow Global Warming?

If there is a silver lining to be found in the increase of carbon dioxide in the atmosphere, it might be this: More CO_2 means there's more of the raw material that plants and other photosynthetic organisms need to grow.

NASA data show the trend over the first two decades of the 21st century. The green areas are where overall leaf coverage of the land during the growing season increased between the years 2000 and 2018.



This greening effect is expected to get more intense later in the century, as shown in this NASA image. Note how much greener the northernmost areas of North America and Asia are predicted to be.



What does the greening of Earth mean? Scientists estimate that it has prevented the climate from warming by an additional 0.25ºC. In other words, Earth would have been even warmer now if the greening in recent decades had not occurred.

Does this mean nature will fix the problem by covering more of Earth with plant life? No, it's not that simple. More carbon dioxide makes it easier for plants to photosynthesize, but it also means some habitats will get too warm for some plants to survive there.

The higher temperatures will also attract more insects to the habitats. Even northern forested areas that were once too cold might decline even though there's more "food" for them in the form of CO_2. Intense heat waves could increase the risk of drought and fire, so the forests may burn to the ground. This has a "double whammy" effect on climate change. It takes away a place where carbon can be stored and instead releases new carbon dioxide into the atmosphere.

Forest damaged by a type of beetle that is spreading and thriving thanks to warmer temperatures

Important to the greening trend is how much of the seasonal leaf coverage is crops, not long-lasting trees. China and India have added large areas of cropland in recent decades, but crops are not great at storing carbon over a long time. Once the plants are harvested, the leaves decompose, sending carbon back into the atmosphere. Much of the carbon in the edible parts will cycle back to the atmosphere, too.

The type of greening that puts a dent in the amount of carbon in the atmosphere is the growth of forests and other habitats that absorb and store carbon for many years. For example, China's "green wall" reforestation project is designed to prevent desert expansion and could help fight global warming on a long-term basis.

This lush potato farm represents a temporary form of carbon storage. Most of the carbon these plants remove from the atmosphere will cycle back into the atmosphere as the leaves and stems decompose and the potatoes are eaten and the sugars they contain are burned by human cells.

TH **Teigan Howard**

Check out these beautiful trees I saw today! It gets tiring to hear how climate change might ruin these beautiful sites, so I was glad to read something online the other day that showed how Earth is getting greener. The extra carbon dioxide in the atmosphere makes it easier for plants to grow faster, especially in summer. Maybe if we reduce greenhouse gas emissions and the greening trend continues, climate change will not be all that severe?

JH **Joe Howard**

I've been saying this for a while now, Teigan. CO_2 is plant food. The more there is in the atmosphere, the more plants can grow. We are worrying way too much about global warming. Nature will take care of it.

BH **Bill Howard**

Say it ain't so, Joe! It's not a simple either/or thing. Yes, carbon dioxide functions as plant food (they convert it to sugar to feed themselves), but it also is a greenhouse gas that is warming the planet. Some greening might be occurring, but that doesn't mean the trend is permanent or that it negates the effects of carbon dioxide on the climate, not to mention the acidification of the ocean. I think you're giving your nephew the wrong idea about things, as though carbon dioxide can do just one thing and not a bunch of other things at the same time. In the atmosphere, carbon dioxide helps trap heat. In the ocean, it breaks down into carbonic acid, which makes the water more acidic. Both of these things are happening while carbon dioxide is helping some plants grow faster. If plants and algae could gobble up all the carbon dioxide we emit, then the scale of greening would be greater and we wouldn't be seeing an uptick in atmospheric CO_2 year after year.

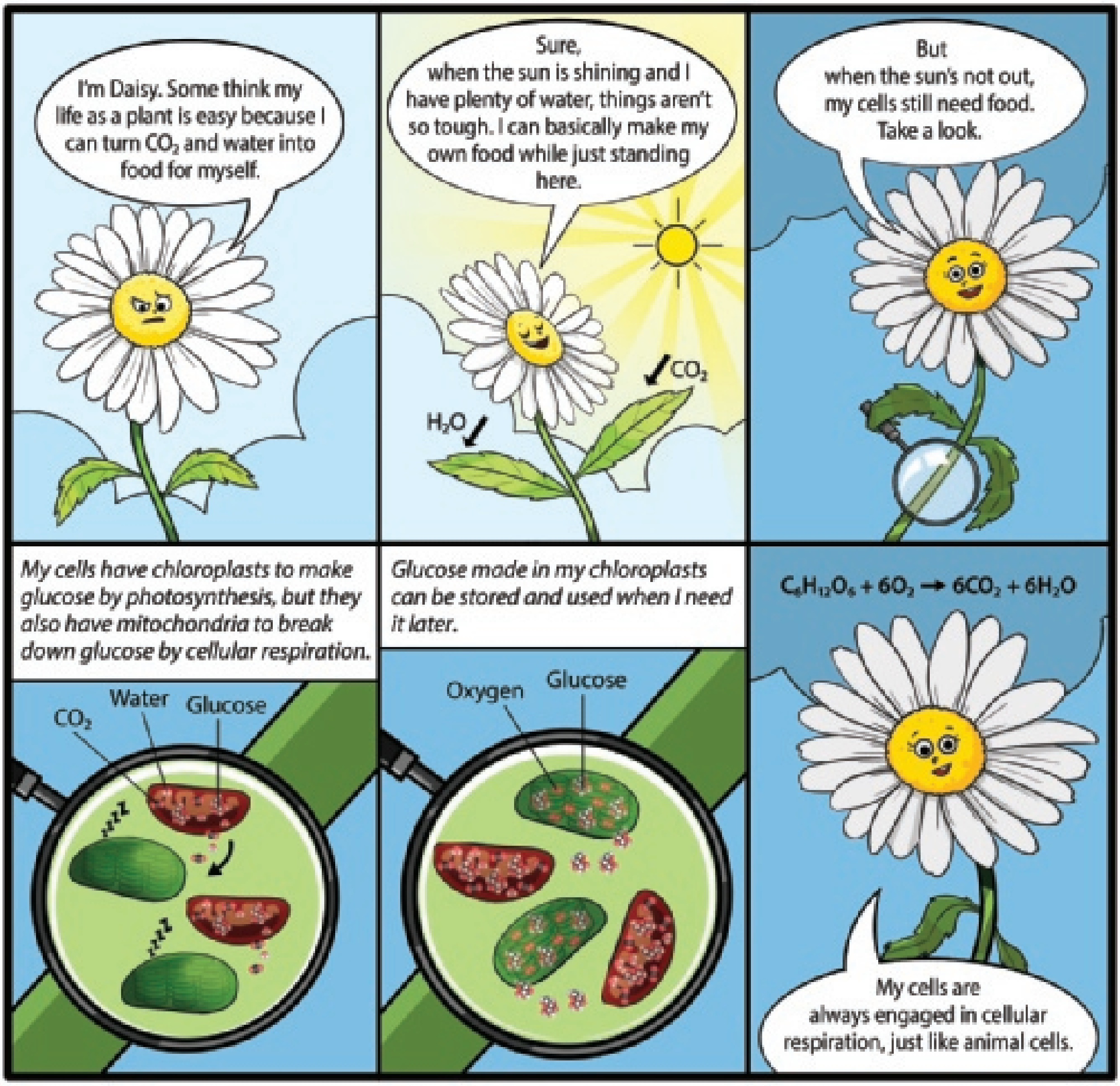
JH **Joe Howard**

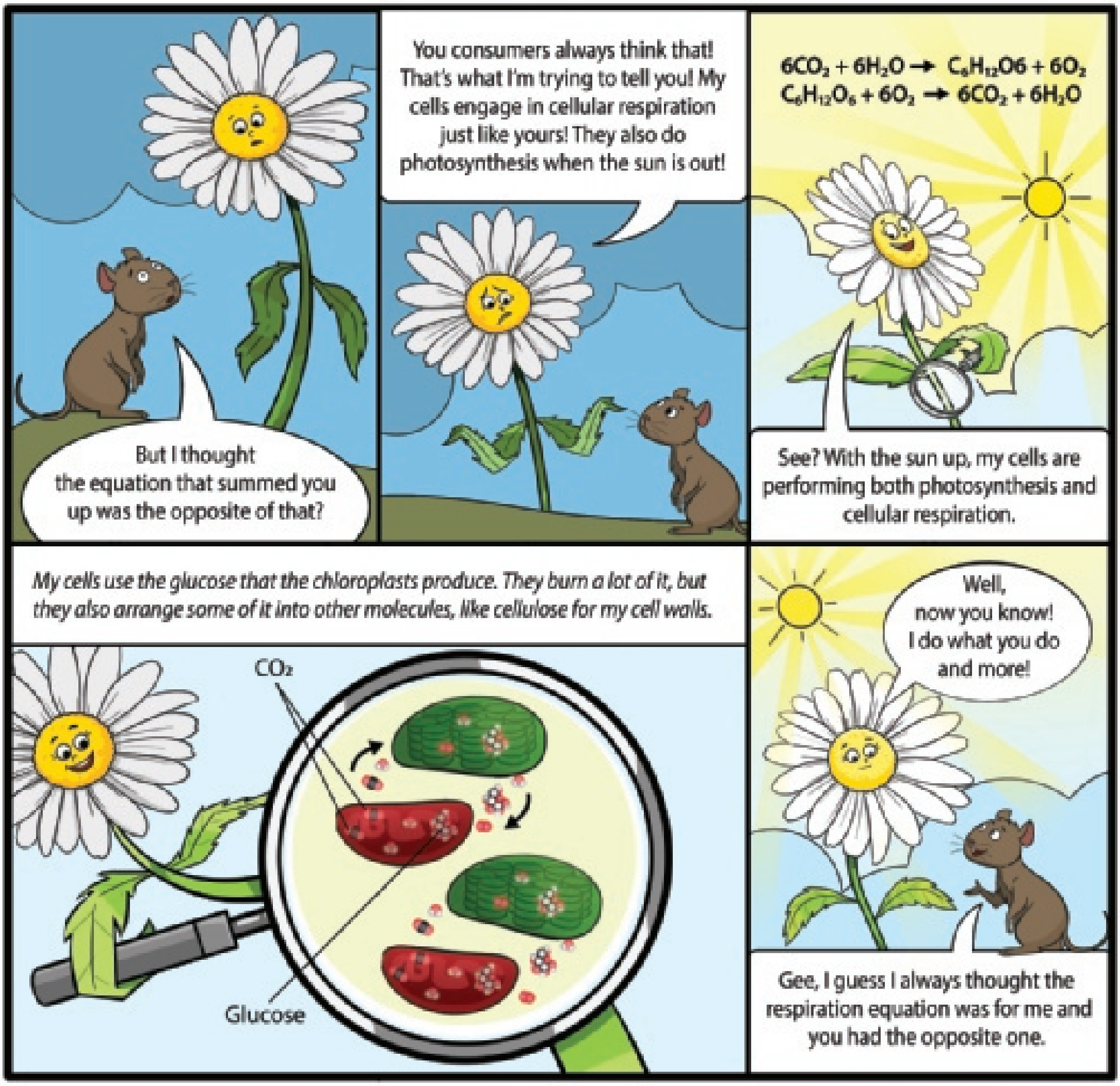
We just need to be more patient. The greener Earth gets, the more CO_2 the plants will be able to suck up and store. It will just take a while to reach that tipping point. Patience, brother! Maybe we won't be around to see it, but it's going to work out!

Spot the BS

Heads up! There's some **b**ad **s**cience on this page. Can you detect which social media comments are misrepresenting the roles that carbon dioxide plays in different systems?

Plants Need Oxygen, Too





Vocabulary

cellular respiration, n. the chemical process by which living cells convert glucose and oxygen to carbon dioxide and water, releasing energy

Sugar Storage Strategies of Plants

Plants make and store the sugars they produce. On a sunny day, they may produce a lot of glucose. Whatever glucose their cells don't burn in cellular respiration can be stored for later. Short-term storage can get a plant through the night. Long-term storage can get a plant through the dark, cold winter. This requires large, specialized plant parts.

Carrots, radishes, parsnips, sugar beets, and dandelions are flowering plants that produce large roots called taproots that store sugars produced in the leaves. When you eat a carrot, you are eating the taproot of a carrot plant. The sugars in taproots can be both simple sugars such as glucose as well as more complex carbohydrates such as starch. Humans have bred and even genetically engineered some plants to be sweeter or have specific, pleasing colors or textures.

Other plants store sugars and starches in **bulbs**. In a bulb, the stem is short and small but may contain starches. In bulb plants like onions, sugars are stored in the bases of leaves, which protect the stem. Because bulb stems often have starch, bulbs can regrow a new set of leaves and roots. Fennel, garlic, shallots, and leeks are other examples of bulbs that we eat. Daffodils and tulips will emerge from bulbs in the spring.

A tuber is a thickened area of a stem or root used for starch storage. The sweet potato is a **root tuber**. Potatoes are examples of **stem tubers,** which like root tubers are places where starch is stored.

Some plants have specialized horizontal underground stems called **rhizomes.** These don't provide much support for the plants. Instead, their function is to store sugar or starch. They tend to be fibrous because, like the rest of the plant's stem, they contain vascular tubes for moving water and sugar up and down the plant. A ginger stem is an example of a rhizome.

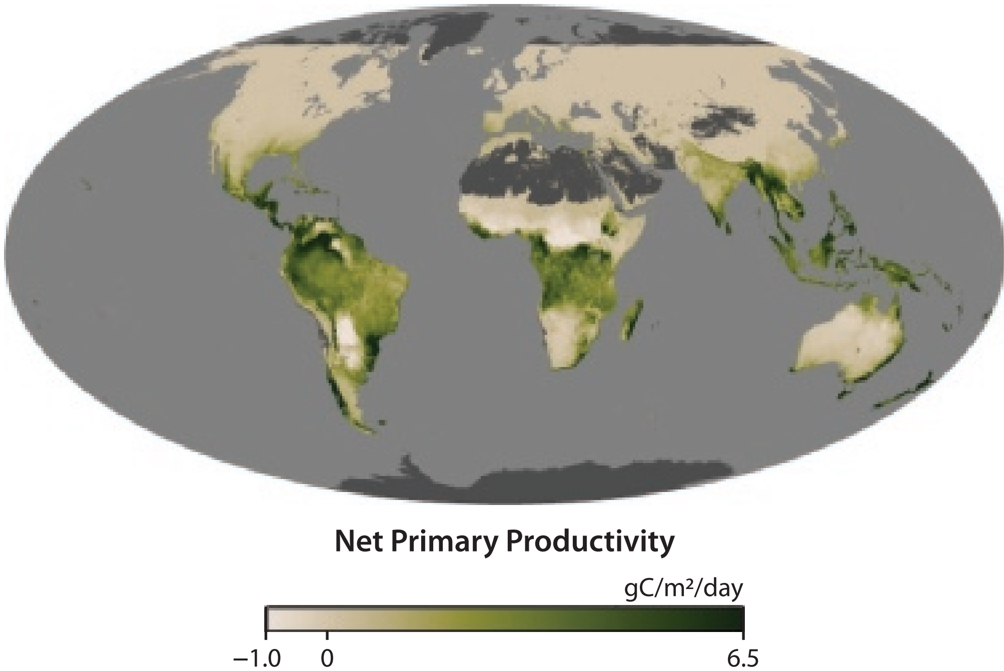
Many plants have fruits that are also the site of sugar storage. A tomato is a **fruit**, a plant structure that contains seeds. A raisin is a dried grape. Dry fruits tend to be more intense in flavor because they are more concentrated without all that water.

Connection

Why is this article's title using the word *strategies* as though plants come up with plans? Well, in evolutionary science, scientists refer to different ways that organisms have become adapted to survive as strategies. It's not that these organisms are consciously strategizing. But the word is a concise way of describing how life itself evolves and branches off when it possesses new ways of surviving and reproducing.

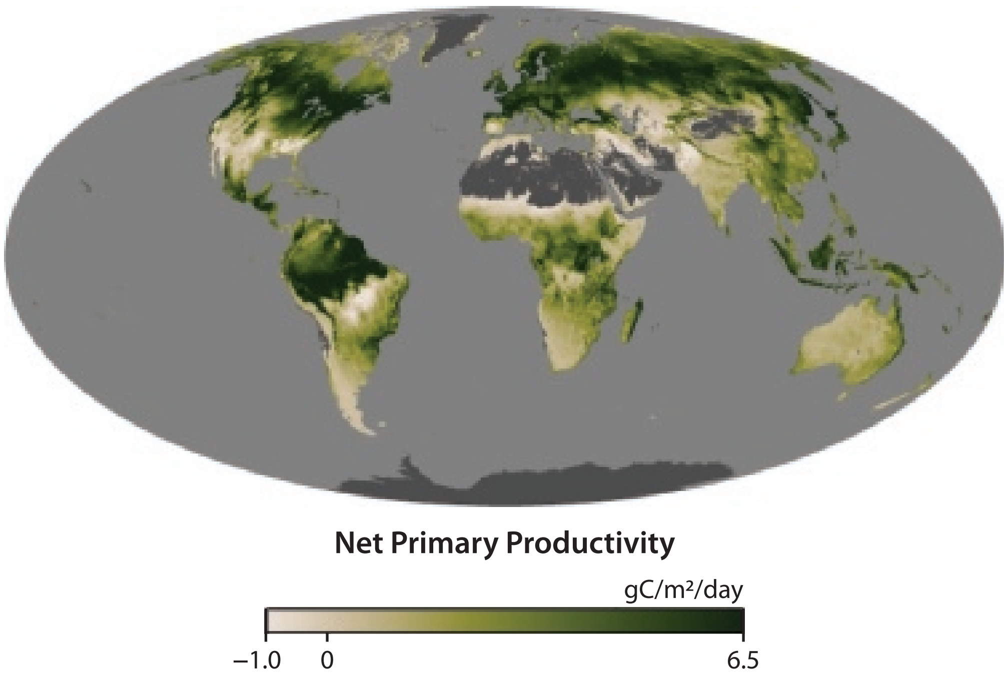
Seasonal Primary Productivity

The productivity of plants is a measure of how much carbon they take out of the atmosphere and turn into sugars, starting with glucose. Because photosynthesis depends on sunlight, productivity varies with the seasons, especially in temperate zones that are either tilted toward or away from the sun, depending on the time of year. These images from NASA summarize productivity data.



January 2016

In July, when the Northern Hemisphere is tilted toward the sun, productivity is very high in North America and Asia, but the productivity in these areas is very low or even negative in January due to dead plants emitting carbon while other plants are dormant. The Southern Hemisphere is tilted toward the sun in January. Productivity is higher in the southern areas of Africa and South America, as well as the wetter areas of Australia and New Zealand. Overall, plant productivity is higher in July because so much of Earth's landmass is in the north.

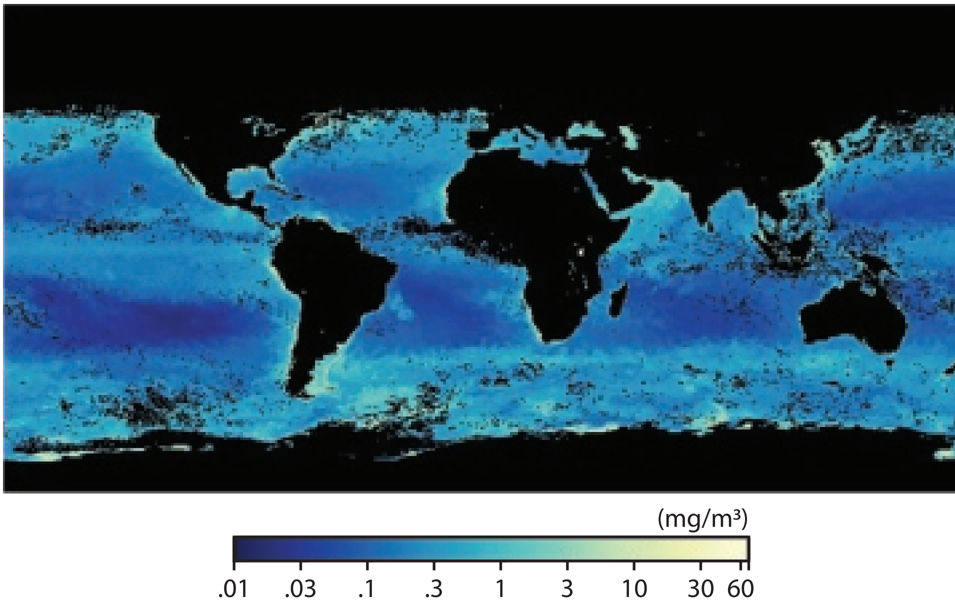


July 2016

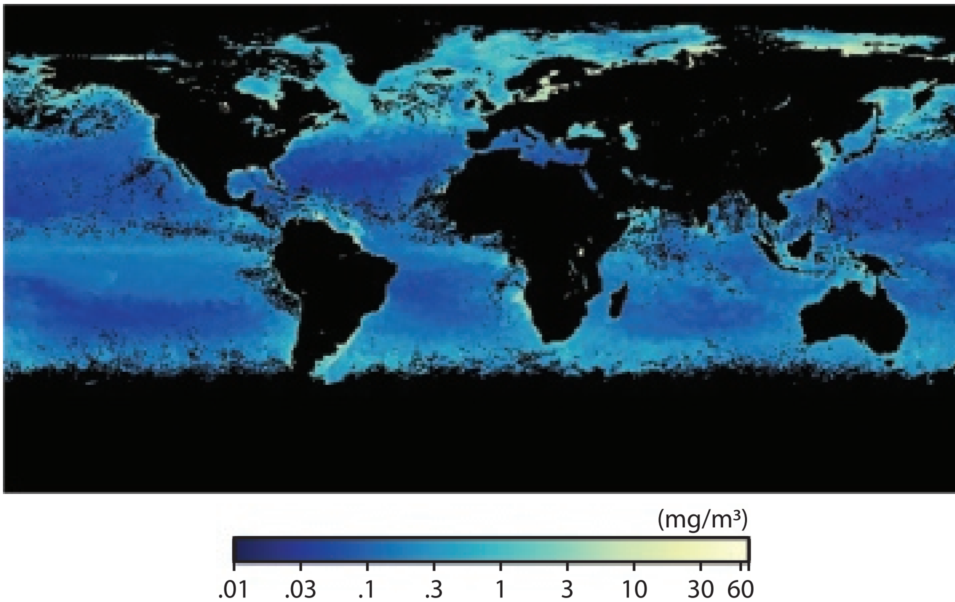
The ocean has photosynthetic organisms, too, mostly in the form of phytoplankton. Water temperature varies less than air temperature from season to season, so phytoplankton can survive and use chlorophyll to suck up carbon dioxide throughout the year, but too little sunlight reduces productivity or makes it impossible.

For example, there is too little sunlight in the Bering Sea off Alaska in wintertime to support plankton, so the January image appears dark across the northernmost part of Earth.

The July image indicates high plankton productivity off Alaska because there are many hours of daylight. Other regions of the ocean are too warm to support plankton, so there is very little productivity from plankton at any time of year. The dark blue band across the South Pacific, for example, indicates there's very little plankton there, though in winter (July) it is somewhat higher.



January 2021



July 2021

Dig into Data

Both sets of maps are generated by data from satellites. If the two sets were merged, the black landmasses of the plankton productivity maps could be filled in, and the gray oceans of the plant productivity maps could be made blue. But the color schemes of the two data sets don't exactly match.

Tasting the Other Kingdoms

We tend to think of the foods we eat as being either plant- or animal-based. But there are plenty of things to eat from the other kingdoms, and in some ways our health depends on them. I try to incorporate plants, animals, <u>and</u> representatives of the other kingdoms into my restaurant's menu every day.

Bacteria are never on the menu, but some bacteria are vital for our digestive systems to function properly. Fermented foods such as sauerkraut and kimchi can help our bacterial "flora" flourish, and yogurts and cheeses do the same. From protist and fungi, we get foods such as kelp and mushrooms.

Red algae might be called "seaweed," but it is not a plant. It is a kind of alga. Red algae are farmed and processed into thickening agents such as carrageenan, which is added to ice cream and chocolate milk. Some marine protists are eaten more directly as food. They are excellent sources of vitamins and iron.

Mushrooms are fungi. A fungus breaks down material of organisms—mostly those that are already dead—to take its nutrients and build its own tissues. Some fungi are edible, like this oyster mushroom, but others are poisonous, so it's important to know which is which before you go foraging for fungi in the forest.

Fungi can be eaten, but they can also be devastating to food crops. The banana tree, for example, is very vulnerable to a fungus called *black sigatoka.* Other fungi infect fruits and vegetables in our own kitchens. Don't you hate how quickly that beautiful pint of fresh-picked strawberries can be overtaken by yucky gray mold?

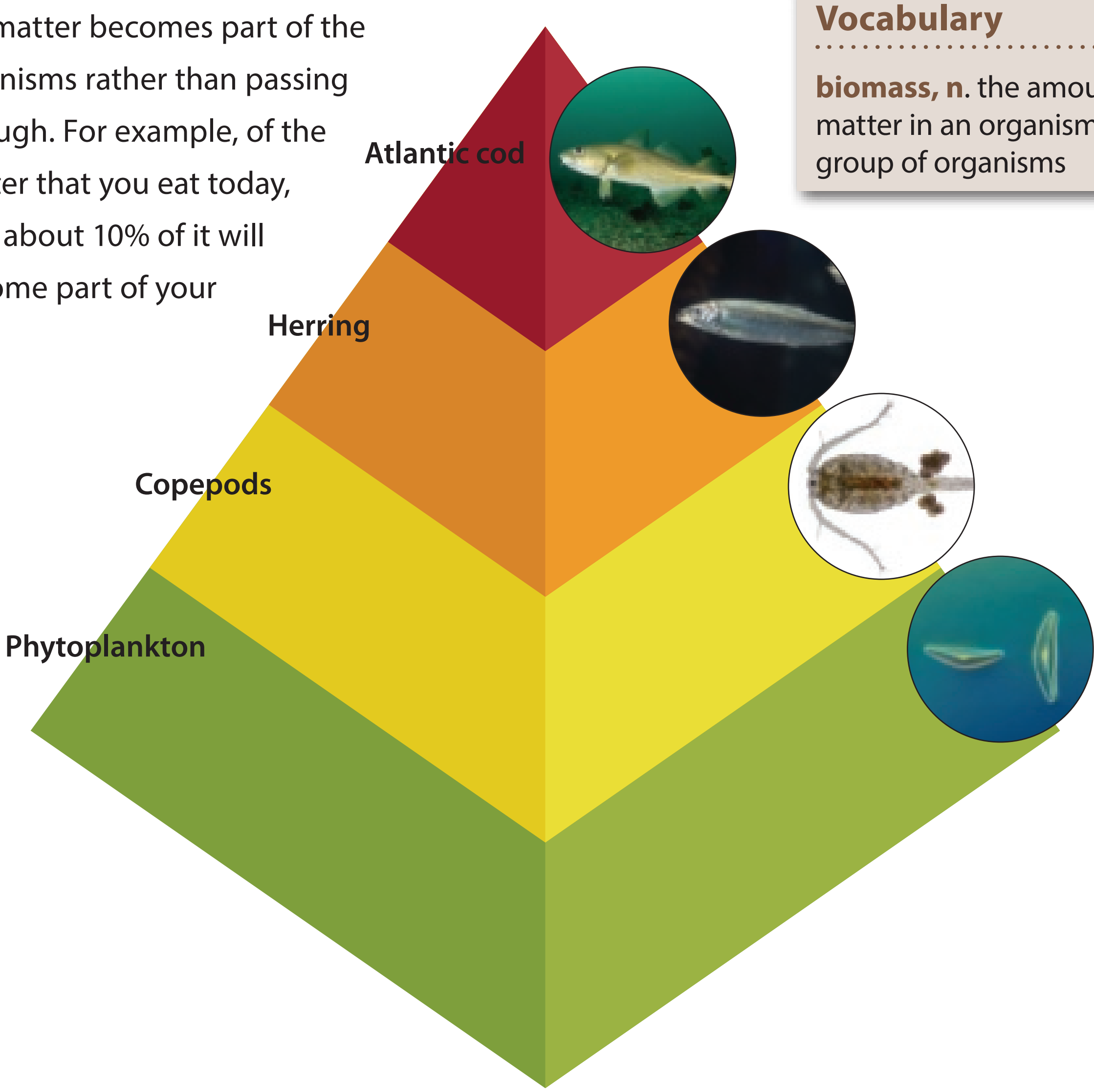
Producers and Pyramids

Plants and other producers are at the bases of most of Earth's food chains. Sunlight provides the energy, the environment provides much of the matter that plants take in, and then energy and matter in the producers work their way up food chains as consumers consume. In general, about 10% of the matter that is consumed at each step in a food chain becomes **biomass**, meaning the matter becomes part of the organisms rather than passing through. For example, of the matter that you eat today, only about 10% of it will become part of your body's tissues. This same is true, in general, of energy. About 90% of the energy that is moved up to the next level of a food chain is burned by day-to-day cellular processes and lost to the environment as heat.

Pyramids of biomass or energy summarize these trends in specific food chains or ecosystems.

Vocabulary

biomass, n. the amount of matter in an organism or group of organisms



PLANKTON POWER!

Protein and Energy Supplement by BioFloCo

Tired of wasting money and holding your nose as you gulp down whey or peanut protein powder, only to see minimal gains in weight? We were tired of it, too. That's why we turned to Mother Ocean, the original source of all life, to get back to the base of the ultimate food chain: plankton. Plankton is packed full of carbohydrates and protein, and because it's low on the food chain, you don't have to worry about chemicals that accumulate in higher-level animals like tuna. Best of all, we guarantee that your body will be able to hold on to 90% of the mass that you take in when you eat a post-workout shake made of Plankton Power. You read that right. Mix 100 grams into a glass of milk, and at least 90 grams will be added to your frame as lean muscle. Don't believe us? Give it 90 days, and if it doesn't work, we'll give you your money back!

Spot the BS

Heads up! There's some **b**ogus **s**alesmanship on this page. Which of the claims made in the ad does not seem possible, given the general trends in how mass and energy are utilized when food is consumed?

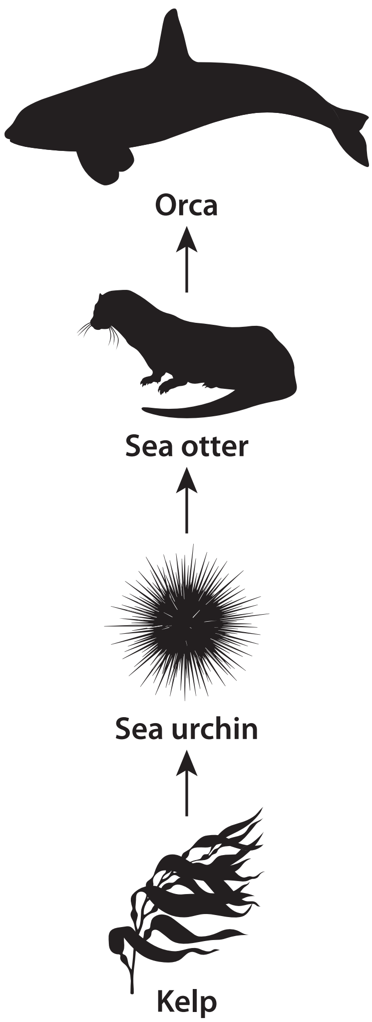
Food Chains and Webs

Relationships among different organisms in nature can be represented in food chains and food webs. These are diagrams that indicate which organisms are eating or being eaten by other organisms.

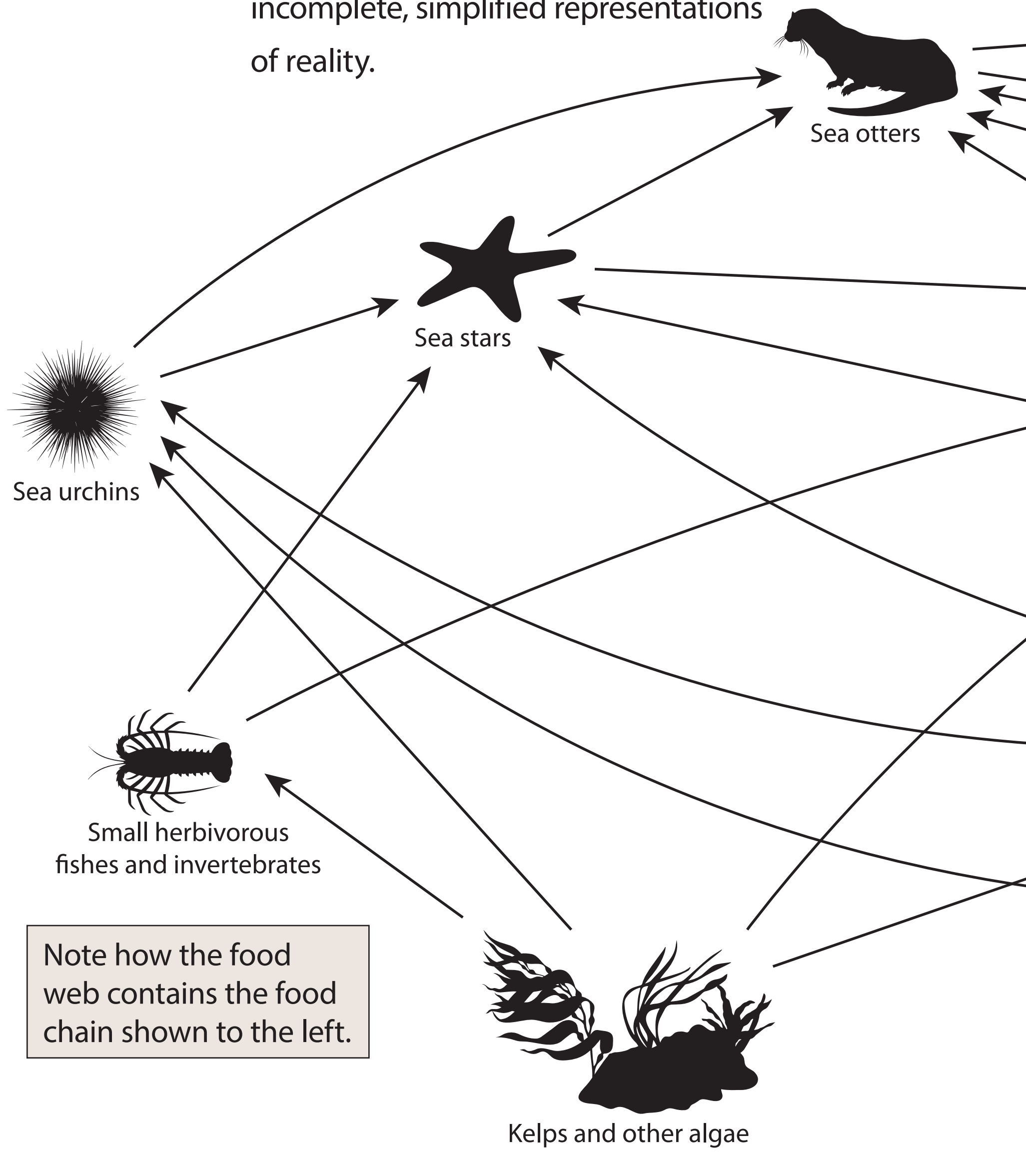
A food chain shows one path of production and consumption. A producer is at the start of the chain, then primary consumers, secondary consumers, and so on.

A food web is more complicated and is aimed more at capturing all the predator-prey relationships in an ecosystem.

Both are models and are almost always incomplete, simplified representations of reality.



A food chain is focused on a single sequence of production and consumption.

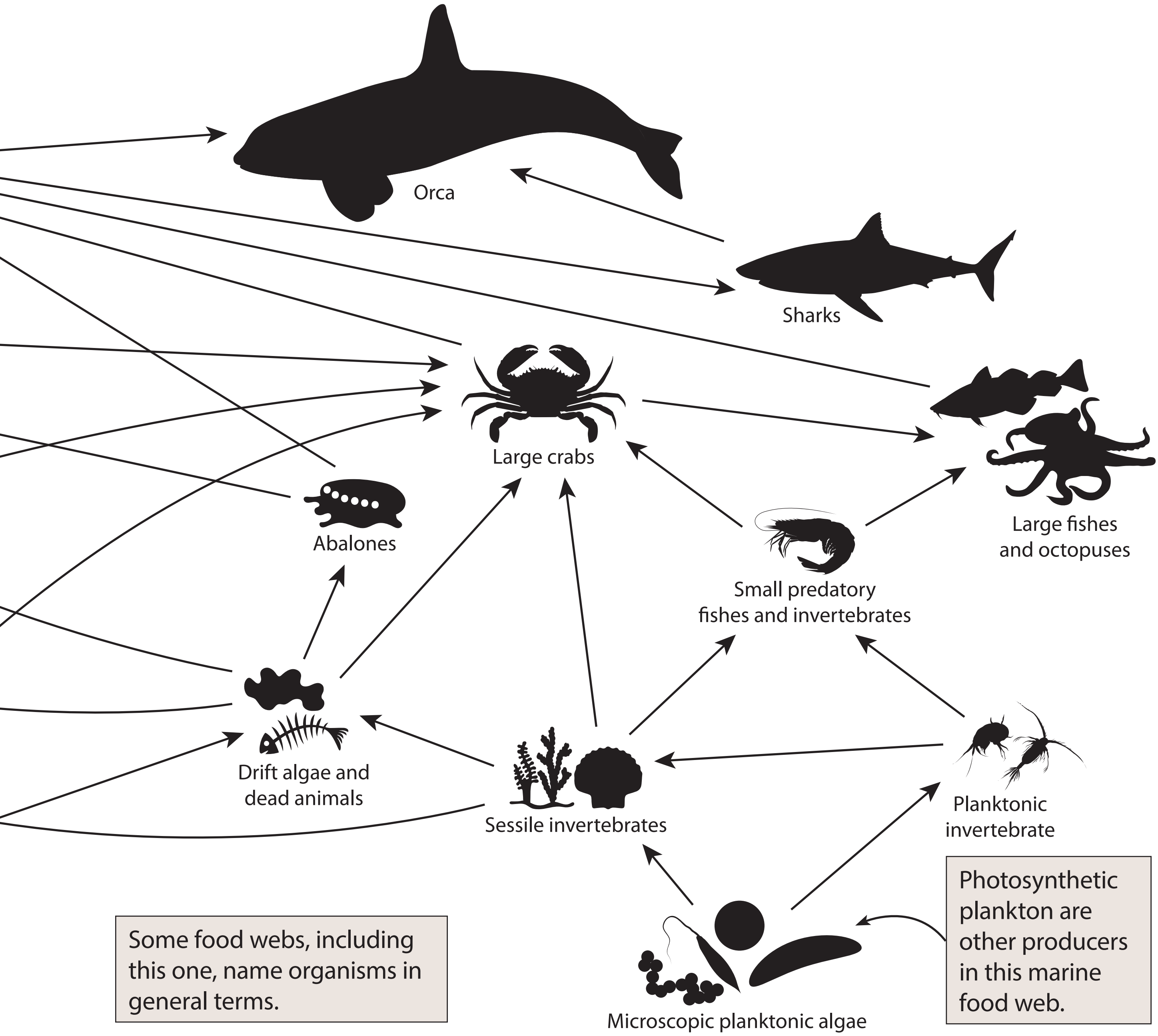


Note how the food web contains the food chain shown to the left.

Word to Know

A *species* is a group of organisms that is identified by its ability to reproduce with each other and, in some cases, its distinct characteristics.

Note how some types of organisms, such as crabs, can consume many types of organisms and be consumed by many. Different species occupy different levels or areas of food chains and webs.



Some food webs, including this one, name organisms in general terms.

Photosynthetic plankton are other producers in this marine food web.

Decomposition Diaries

10 Years Ago

Your Memories

May 26, 2012

I'm working for a landscaping business this summer while I'm home from college. It's hot work, and I smell like gasoline and grass clippings when I get home every night, but the pay is decent and at least I'm outside. Another thing I'm trying to get out of this job is some research on decomposition and nutrient cycling, which I'm hoping might inspire a senior-year thesis a few years down the line for my biology major.

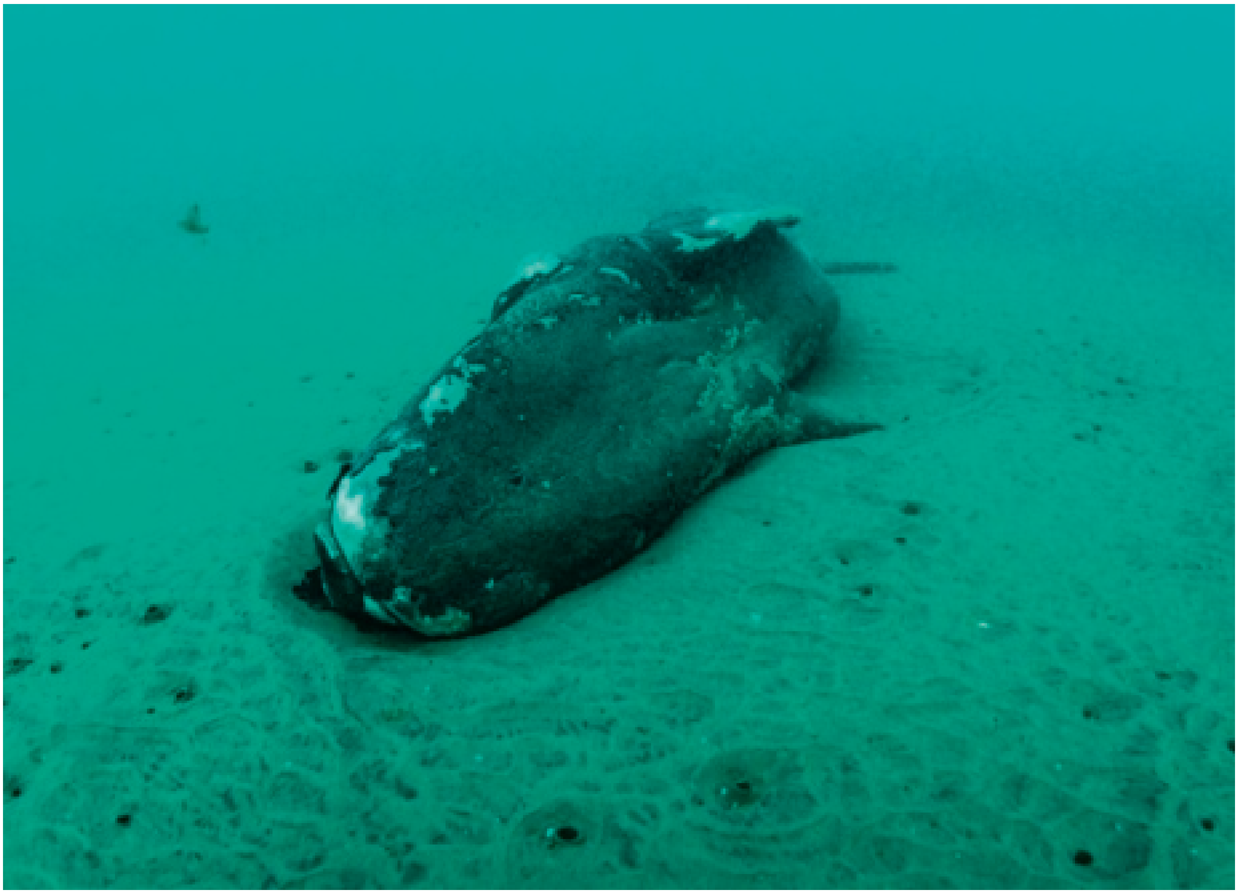
About 25% of our clients want us to use mulching mowers, meaning the grass clippings get dropped on the lawn, whereas the other 75% want us to use bagging mowers that vacuum up the clippings for a neater appearance. Bagging costs a little extra per lawn because we take all the clippings to the nearest composting yard and pay a fee to dump it. I also try to tell clients that there's a hidden cost to bagging: The lawn ends up short of nutrients, so the homeowner ends up hiring us to spread fertilizer a few times a summer just to give the lawn the nutrients it could've had if the grass clippings were allowed to decompose where they were cut. It's kind of a joke. We do all this work to take away matter from the system, and then we end up having to bring it back through chemical fertilizer.

Anyhow, my little project for the summer will be estimating the biomass of grass that we take away from the non-mulched lawns and comparing it to the amounts of fertilizers that we end up adding to those same lawns. I'll also try to work cost data into my project. If my boss is on board, I'll ask if we can hand out a copy of my research report to all our clients at the end of the season, to show them how it makes more sense to just let us use mulching mowers. But he might not want to, because he makes more money by bagging the clippings and then applying fertilizer!

What's up today?

New Post

May 26, 2022



An old social media post popped up today to remind me that it's been ten years since I began studying nutrient cycling in ecosystems, thanks to my landscaping job back home in Ohio. Today I'm in a deepwater sub observing a whale carcass on the ocean floor off the coast of Argentina. The project studies the day-by-day breakdown of a whale that was caught in heavy fishing gear and sank to the seafloor. Normally, a whale carcass would float for a few weeks, and sharks would make off with a lot of its flesh. In this case, however, our team will get to see what happens to 100% of its biomass. Using time-lapse cameras and strobe lights, we've seen some massive sharks and other scavengers coming by to feed. Eventually all the flesh will be taken away, and then the bones will be worked on by bacteria. When the species that feed on the carcass die or excrete waste, nutrients such as nitrogen and calcium from the whale become part of the water. Upwelling will carry these nutrients to the surface, where they will become part of the same food chain that is supporting this whale's relatives. The circle of life! It's very cool to witness these processes. And riding a sub is a bit more interesting than riding a lawnmower, I must say.

The Life of a Carbon Atom

350 million years ago

I don't remember much about the last few thousand years. I was just floating in the atmosphere, drifting up and down in different air masses, and circling the world hundreds of times. I've decided to start a diary of my travels. Today I was taken in by a large fern, through a pore in one of its large green fronds. Then I got separated from my partners, O_2, whom I'd been with for ages. Now I and others like me are stuck in a cellulose molecule that's part of this fern's stem.

The tree fern has died. Its remains are breaking down under a thick mat of other dead ferns in this boggy swamp. The molecule I was part of is breaking apart. Some of the molecules are turning into methane and floating up into the air. Others are stuck in place because more and more organic material is building up on top of us, slowing down decomposition.

More times passes, and now I'm surrounded by lots of other carbon atoms. We're deep in the ground now. Pressure and heat have hardened us into coal.

1928

I'm dug from the ground by a coal miner. Ha! I'm in Nova Scotia, Canada. Some of the carbon atoms that were next to me for a few hundred million years are now in separate chunks of coal in a cart that's being pulled up toward Earth's surface.

I ride a few more vehicles and then get loaded into a steamship in Bath, Maine. The coal gets shoveled into a furnace that sits below a boiler, and the steam produced by the burning coal makes the ship move. I'm burned about three days into the trip to Ireland, and I bond with a molecule of O_2 in the air of the furnace. We are carried out of the smokestack and into the air over the North Atlantic. The air cools quickly, and we sink down to the sea, where we dissolve into the water. There's plankton here, and a single-celled diatom takes us in. Again, I'm separated from my newest O_2 partners, and I become a sugar molecule. This time, though, I'm just in glucose and only for a few hours. I'm burned for energy, and I end up paired with an O_2 again. Released by the diatom, I dissolve into the sea again.

Next, I become part of a bicarbonate ion $HC0_3^-$. A young clam absorbs us and, with calcium, makes me a part of its hard shell.

1940

A clammer digs up the clam from the flats of the Chesapeake Bay. The animal is eaten, and the shell is broken down into material for someone's cottage driveway. I remain locked in the shell as part of a calcium carbonate molecule.

1967

The rain is slightly acidic, and over time the calcium carbonate of the clam shell is weathered. Eventually I am back in a bicarbonate molecule that's running off the land in the rainwater, back into the bay. Another young invertebrate takes me in. This time it's a shrimp. The shrimp is devoured by a menhaden, which is then eaten by a striped bass. In a blur, I'm back in a glucose molecule and then in a different sugar that's stored in the muscle of the bass. This is such a burst of activity compared to what I'm used to, I can barely keep up.

The striped bass migrates to Massachusetts, where it is caught by a human and eaten. The fish is digested, and I end up back in a molecule of CO_2 in the human's bloodstream. I'm exhaled into the air inside a school gymnasium on Martha's Vineyard during a basketball game.

2021

As luck would have it, I've been in the atmosphere since '67. We have had some near misses with plant leaves and the ocean surface, but I've been with this same O_2 for over fifty years, just floating in the air and helping to warm the atmosphere. What's next for us? With more CO_2 in the atmosphere, we might be here for another thousand years, or we could be taken in by a sunflower or corn stalk any day now.

Because I can be part of so many different processes, reactions, molecules, and substances, sometimes I'm in three different things in the span of a week, and then other times I'm stuck in something like coal or limestone for millions of years. The only constant in my life is change. Hey, I'm part of the **carbon cycle**.

Vocabulary

carbon cycle, n. the biochemical cycle through which carbon moves among living and nonliving materials in Earth's spheres

Debate Transcript

How to Handle Food Waste

Kyle and Ari are members of a university debate class. Today they are debating what the school should do with discarded food from the cafeteria.

Kyle's First Proposition: The amount of food that is wasted by students of this college is just gross. Part of the problem is the dining halls having an all-you-can-eat approach, which allows students to fill their trays with foods they're not even going to eat. Given that President Simon has made it clear that no changes will be made to how much food students can get at each meal, we need an environmentally responsible way to manage uneaten food waste. Dumping food waste into trash cans with non-recyclable, non-compostable material is as good as setting the waste on fire, because all the college's non-recyclable waste ends up at an incinerator. It does not go to a landfill, where at least some of that food waste would be consumed by insects and worms and some of the methane could be captured. We strongly urge the college to divert all food waste to one or more of the three composting businesses in the area. All three have offered to accept the waste and sell it back to the college as garden-ready compost at a discount price. This compost could be a boon to our horticulture department as well as the college's botanical garden. The composting businesses are also good for the local economy.

Connection

In formal debate, one side supports or makes a proposition within a set amount of time, and the other represents the opposition, also with a time limit. The formal structure of a legitimate debate prohibits interruption and removes the noise of informal argument or bickering. This makes it easier for the audience to follow as arguments and evidence are presented.

Ari's First Opposition: We acknowledge that the amount of discarded food in our dining halls is high. We also agree that the food waste generated by this college should not be mixed with the non-recyclable, non-compostable waste, as it does indeed end up being processed by an incinerator, meaning more of it becomes carbon dioxide in the atmosphere. None of us want that. However, our position is that the best destination for our food waste is the area's hog farms. These farms are efficient converters of our food waste. Hogs have a feed conversion ratio of about 3 to 1, meaning one pound of food becomes one pound of pork. The hogs are not fussy eaters; they will eat pretty much any food waste that we provide. A composting yard gets such a wide variety of substances in the waste we provide that the composting process is a complicated, multistage affair that takes about a year. The impact of the composting businesses on the local economy is very small compared to the impact of hog farms in the area. Manure from the hog farm can be sold to the college at the same cost as compost.

Kyle's Second Proposition: It's important to distinguish between the feed conversion ratio of hog farms in general and the feed conversion rate of hogs fed a hodgepodge of food waste from college dining halls. Yes, feed that is produced for hog farms is used very efficiently, because that feed is dry and made specifically for hogs to eat. A half-eaten turkey sandwich, a cup of cereal milk, a scoop of ice cream, a wad of old lettuce, and other food waste that we send off to a hog farm is going to be very wet, so a lot of the mass is water. If we looked at the original masses of the things that go into commercial hog feed, we would find that the feed conversion ratio is not very good at all. The same will be true if we send out food scraps to a hog farm. At best, a hog would put on about one pound of weight for every ten pounds of food waste it gets from us. This is to say nothing of the things that would inevitably slip into the food waste buckets—like tea bags, bones, napkins, seeds, and other things that hogs will not be able to digest. Secondly, the amount of waste that hog farms produce is massive. Their feces is often stored in pens that belch methane into the atmosphere, and these pens can leak into the environment. We should not think of these hog farms as neat, clean, efficient ways of turning our wasted food into something good. Yes, some of it will become pork, but a lot of it will become poop, methane gas, and other kinds of waste. Composting is far more efficient.

Ari's Second Opposition: There's no getting around the fact that our food waste does result in inefficiencies and a cycling of matter that puts a lot of carbon into the atmosphere. Whether that carbon goes into the atmosphere via hog gas or carbon given off by decomposing food in a composting yard, it's pretty much the same thing. It may not be pretty, but hog farming is quicker and more efficient at turning our food waste into another form of matter that humans can use. In fact, each hog represents a carbon sink. Think of a 300-pound hog. That's a lot of carbon! If the food that fed that hog instead gets composted, most of the carbon is going straight into the atmosphere and not being stored in a carbon sink at all.

Kyle's Proposition: Final Words: Again, our opponents are confusing long-term carbon storage with short-term fixes. Yes, a 300-pound hog is a carbon sink, but only until it is butchered and its flesh is packaged and eaten by humans. Then, that carbon gets taken up by human cells, and a lot of it ends up back in the atmosphere after cellular respiration does its thing. We aren't talking about whales here or planting trees that can suck up carbon for a century. We're talking about hogs that are bred and fed to eat a lot, grow fast, and die young. Composting, on the other hand, can help carbon get to long-term carbon sinks such as hemlock, oak, maple, and pine trees. Compost-rich soil can also lead to carbon being locked in soil, too. If, for example, our arboretum's soil were enriched by compost produced from our own food waste, the arboretum could become more of a carbon sink. This is not true if we instead ship our food waste to hog farms. We are also in a period in which we should be consuming less meat, due to the carbon footprint of the meat industry. Turning our food waste problem into a gift to Big Pork is just turning one problem into another. We strongly encourage the college to send all its food waste to local composting businesses so that the solution to our food waste problem is an actual solution.

Ari's Opposition: Final Words: It's true that the meat industry has, historically, had a pretty big carbon footprint. But that's more of an issue with beef. Ruminant animals such as cows can better digest cellulose and convert some of it into methane gas, which is a much more powerful greenhouse pollutant than carbon dioxide. Hog waste can result in methane emissions if the waste is not managed properly, but the local hog farms are not industrial-scale hog farms with massive retention pools flooded with wet hog poop. At the local farms, hog waste is dried, turned into manure, and sold to local crop farmers. In other words, the same farms that our opponents have painted as filthy polluters are composting organic material just like the composting businesses that our opponents favor. Hog farming just happens to shift more carbon to animals—including humans—while making a highly efficient use of discarded food waste from our campus. We strongly encourage the college to send its food waste to area hog farms and be part of a fuller cycle of matter that includes animals.

Glossary

anoxic, adj. lacking oxygen

bacteria, n. a large group of single-celled organisms that have cell walls but lack nuclei and organelles

biomass, n. the amount of matter in an organism or group of organisms

carbohydrates, n. naturally occurring compounds made up of carbon, hydrogen, and oxygen that play a crucial role in life processes

carbon cycle, n. the biochemical cycle through which carbon moves among living and nonliving materials in Earth's spheres

carbon footprint, n. the amount of carbon compounds emitted resulting from the consumption of resources by a single person or group

carbon sink, n. any feature that absorbs more carbon than it releases

cardiovascular, adj. related to the heart and circulatory system

cellular respiration, n. the chemical process by which living cells convert glucose and oxygen to carbon dioxide and water, releasing energy

cellulose, n. a chemical compound composed of many linked glucose units

cell wall, n. the structural layer surrounding the interior parts of some types of cells

chloroplast, n. the organelle in plant cells that conducts photosynthesis

cholesterol, n. an organic compound, specifically a type of lipid, that is a natural component of animal cell membranes

compost, n. a mixture of decayed organic material used to fertilize plants

conservation of matter, n. the principle that the mass of matter involved in a chemical reaction remains constant before and after the reaction

cuticle, n. the waxy coating on a plant's leaves or flowers that keeps in moisture and keeps out germs and insects

decomposition, n. the process of decay of once-living material

evolution, n. change in characteristics over an extended period of time

fat, n. an oily or greasy substance that occurs naturally in living organisms

fructose, n. simple sugar produced by many plants and found abundantly in fruit

fungi, n. a group of organisms such as mushrooms, molds, and yeast that feed on organic matter and reproduce by spores

glucose, n. a simple sugar represented by the formula $C_6H_{12}O_6$

gluten, n. a structural protein naturally found in many grains

grain, n. a small, hard, dry seed harvested as a human or animal food source

green algae, n. a large grouping of photosynthetic organisms that live mostly in freshwater

invertebrate, n. an animal without a backbone

methane, n. an odorless, flammable gas represented by the formula CH_4

mineral, n. a solid, inorganic chemical compound

mitochondrion, n. an organelle in which respiration and energy production take place

monomer, n. a molecule that can bond to other identical molecules to form a polymer

nutrient, n. a substance that is chemically essential for life and growth

organic molecule, n. a chemical compound that contains a carbon-hydrogen bond

phenomenon, n. an observable occurence

photosynthesis, n. the chemical process by which organisms use energy from sunlight to convert carbon dioxide and water into glucose and oxygen

photosynthetic, adj. describing an organism that conducts photosynthesis

phytoplankton, n. microscopic photosynthetic organisms

plankton, n. masses of minute animal and plant life that generally float passively in a body of water

polymer, n. a chain-like chemical structure of many units of identical or similar substances

predator, n. an animal that hunts other animals for food

prey, n. an animal that is hunted as food by another animal

primary productivity, n. the rate at which energy is converted to food source biomass by photosynthesis

proteins, n. a class of large biomolecules made up of amino acids and present in all living organisms

resin, n. a sticky substance in plants, similar to sap, that aids the function of healing

sap, n. the nutritious liquid that flows within a plant's conducting tissues

scavenger, n. an animal that feeds on refuse, including decaying plant or animal material

science literacy, n. the ability to read, hear, and comprehend information about scientific topics and demonstrate understanding in discussion and through writing

social media, n. websites and applications that allow users to participate in sharing content on the internet

spawn, v. to produce offspring through the release of eggs

species, n. a group of organisms that is identified by its ability to reproduce with each other and, in some cases, its distinct characteristics

starch, n. a polymeric carbohydrate consisting of numerous joined glucose units

sucrose, n. a sugar formed when one molecule of glucose bonds with one molecule of fructose

umami, n. a savory category of flavor

vascular tissue, n. tissue that functions to circulate fluids in an organism

vitamin, n. an organic molecule that serves as a nutrient necessary for an organism's development and function

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