Tennessee-Alabama-Georgia (TAG) Cave Teaching and Learning Module

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Cave Conservancy Foundation

Dear Educator,

We are pleased to present you with a TAG (Tennessee – Alabama – Georgia) cave-themed teaching and learning module. This module aims to engage Kindergarten through 5th grade students in subterranean biology, while fostering awareness and positive attitudes toward cave biodiversity. We have chosen cave fauna for this teaching module because students have a fascination with atypical organisms and environments. Moreover, little attention has been given to subterranean biodiversity in public outreach programs. Many students will likely be intrigued by the unique fauna and composition of subterranean landscapes. Therefore, we hope these lessons enable teachers to introduce students to the unique organisms and habitat below their feet.

The module presents students with background information and outlines lessons that aim to reinforce and discover aspects of the content. Lessons in this module focus primarily on habitat formation, biodiversity, evolution, and system flows in subterranean landscapes. We intend for this module to be a guide, and, thus, we have included baseline material and activity plans. Teachers are welcome to use the lessons in any order they wish, use portions of lessons, and may modify the lessons as they please. Furthermore, educators may share these lessons with other school districts and teachers; however, please do not receive monetary gain for lessons in the module. Funding for the TAG Cave module has been graciously provided by the Cave Conservation Foundation, a non-profit 501(c)3 organization dedicated to promoting and facilitating the conservation, management, and knowledge of cave and karst resources.

The cave module was created and disseminated by Drs. K. Denise Kendall, Matthew L. Niemiller, and Annette S. Engel. An electronic version of the module, as well as additional images, can be found on Dr. Niemiller's website http://www.speleobiology.com/niemiller/tag-education/. Additional teaching lessons and resources will also be posted on this website as they become available.

Sincerely,

K. Denise Kendall, Ph.D.
Matthew L. Niemiller, Ph.D.
Annette S. Engel, Ph.D.

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- K-ESS3-1. Use a model to represent the relationship between the needs of different plants or animals (including humans) and the places they live.

Evolution

- K-LS1-1. Use observations to describe patterns of what plants and animals (including humans) need to survive.
- K-ESS2-2. Construct an argument supported by evidence for how plants and animals (including humans) can change the environment to meet their needs.
- K-ESS3-1. Use a model to represent the relationship between the needs of different plants or animals (including humans) and the places they live.

Cave Water Cycle

- K-LS1-1. Use observations to describe patterns of what plants and animals (including humans) need to survive.
- K-ESS3-1. Use a model to represent the relationship between the needs of different plants or animals (including humans) and the places they live.
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Evolution

- 1-LS1-1. Use materials to design a solution to a human problem by mimicking how plants and/or animals use their external parts to help them survive, grow, and meet their needs.
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Evolution

- 2-LS4-1. Make observations of plants and animals to compare the diversity of life in different habitats.

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- 3-LS3-2. Use evidence to support the explanation that traits can be influenced by the environment.
- 3-LS4-3. Construct an argument with evidence that in a particular habitat some organisms can survive well, some survive less well, and some cannot survive at all.
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- 5-ESS2-2. Describe and graph the amounts and percentages of water and fresh water in various reservoirs to provide evidence about the distribution of water on Earth.

Background for Teachers

This background material provides an overview of cave habitats, biodiversity, and conservation efforts to protect these unique environments and their fauna. Cave systems of the Valley and Ridge of eastern Tennessee, northwestern Georgia, and northeastern Alabama are emphasized. Teaching about cave systems can help students appreciate these local places for their biological, cultural, and geological resources. For instance, caves and other subterranean cavities are estimated to store over 94% of all unfrozen freshwater globally. In the United States, an estimated 40% of all accessible groundwater that is safe for drinking comes from aquifers where there are caves. Many people in this region drink cave spring water at home or for perceived medicinal purposes. The background material reviews different types of caves, how caves form, the relationship of caves to the local water table and groundwater, and typical geological features found in caves.

Caves are characterized by generally constant temperature and humidity and the complete lack of sunlight. Photosynthesis, which sustains most of the planet's ecosystems on the surface, does not occur in absolute darkness. These habitats are among some of the most challenging and demanding environments for life on the planet, yet many unique and fascinating organisms survive and thrive in the inhospitable conditions. Life in caves primarily depends on receiving organic matter and other energy and nutrients brought in from water, air, or animals from the surface. Many subterranean species possess unusual and highly specialized adaptations associated with living in darkness and when food resources are limited. Cave organisms are viewed as interesting models to address fundamental questions in ecology, evolution, and other fields of biology, such as developmental biology and behavior. This teaching material describes the types of cave life commonly encountered in caves, from bacteria to invertebrates and vertebrates, how life has adapted to living in caves, and examines cave habitats in the context of ecological zonation.

Despite increased interest and study in recent years, subterranean biodiversity remains one of the most poorly known and studied faunas on the planet. Many species may be rare and have very small geographic ranges and narrow habitat requirements. The distribution and occurrence of cave animals is lacking, which means that cave life is at an elevated risk of extinction. The background material also covers threats to and conservation of caves and cave life. Understanding more about subterranean biodiversity is important because the organisms that live in caves and other subterranean habitats provide important ecosystem services for the whole planet, not just for caves. For example, groundwater microorganisms help to break down organic wastes to purify groundwater used for drinking. Cave-roosting bats are important for insect control, seed dispersal, and pollination in agriculture. In addition, caves contribute to the carbon cycle. As caves form in limestone, calcium carbonate is broken down. Calcium eventually returns to the ocean where it used by marine organisms, while some of the carbon in the form of carbon dioxide is transferred back to the atmosphere.

What are caves and how do they form?

Caves are natural openings in the ground that are large enough for a human to enter. However, with that being the criteria, a "cave" can vary from person to person. Some state cave research groups, like the Tennessee Cave Survey, have a specific length requirement or depth requirement for vertically oriented caves (i.e., pits). Other research groups require that a cave can be counted in a regional survey if total darkness can be obtained after entry.

As such, caves can vary in length from a few yards in length to over 644 kilometers (400 miles) of passage, like the Mammoth Cave System in Kentucky. However, most caves are less than 100 meters (328 feet) in length. Caves also vary greatly in depth. For example, the Ellison Cave system in northwest Georgia has a depth of almost 305 meters (1,000 feet). The sizes of individual rooms and passages are also variable. Some passages are so small that only the smallest humans can crawl through them. In contrast, the Big Room in Carlsbad Caverns in New Mexico is approximately 549 meters (1,800 feet) long, up to 335 meters (1,100 feet) wide, and up to 68 meters (225 feet) in height. The floor of the room is nearly 5.7 hectares (14 acres)!

There are four primary types of caves: solution caves, lava caves, sea caves, and glacier caves. **Solution caves** are the most prevalent throughout the world, including the Valley and Ridge region of TAG. They are typically developed in carbonate (limestone, dolomite, and marble) and sulfate (gypsum) rocks. Some of the largest and longest solution caves are developed in the carbonate rocks limestone or dolomite, with the dominant minerals being calcite [$CaCO_3$] or dolomite [$CaMg(CO_3)_2$], respectively.

Solution cave formation starts when rain water droplets absorb a small amount of carbon dioxide from the atmosphere as they fall to the land. Once in soil, water continues to absorb even more carbon dioxide from decaying organic matter. When water reacts with carbon dioxide, a weak acid forms called carbonic acid. The weakly acidic water percolates into pores, hairline fractures, and crevices in soil and carbonate rock, and slowly dissolves the soluble minerals. This process is known as **dissolution**. As the water continues to flow through the rock, the carbonate rock dissolves slowly and pores, fractures, and crevices get progressively larger. More water begins to flow through the rock and more dissolution results. Eventually, after thousands to millions of years, enough carbonate rock is dissolved to result in a complex network of enlarged fractures and crevices. These passages join to form flow channels and can become that are large enough for a human to pass through them.

Water continues to flow through the carbonate rock, dissolving the rock over time, until the water reaches a level where all cracks and pores in the rock are filled with water. This level is referred to as the **water table**, and represents the upper surface of groundwater in the **saturated zone**. The **unsaturated zone** is the region above the water table but below the land surface. Caves forming at or below the water table will remain filled with water if the water table is high. These caves are only accessible by humans through the use of diving gear.

Changes in the climate and surface landscape over time can decrease the elevation of the water table. Water then makes its way to lower elevations, and cave formation continues at the lower elevations. This process results in complex solution caves that usually have several elevation levels of passages. Each cave level represents a former water table elevation. For these systems, the oldest dry, air-filled passages are higher in elevation and the youngest, sometimes water-filled, passages are lower in elevation at the present water table. Formation of large, multilevel cave systems can take hundreds of thousands to millions of years.

Cave passages and voids in the rock may become large enough that the rock layers above them collapse. This results in the formation of a **sinkhole**. Sinkholes typically need some type of trigger to cause the collapse of the rock, such as heavy rainfall and flood conditions. Drought conditions can also result in sinkhole formation, as groundwater can often help to support the ceiling of a subterranean passage. Humans also can cause sinkholes to form through land use changes, such as by creating ponds and building, causing vibrations from heavy traffic, altering local hydrology during land development, and withdrawing groundwater. Sinkholes are often points of entry into cave systems.

Solution caves and sinkholes are dominant features of **karst**, a landscape that forms by the dissolution of soluble rocks at the surface. Other karst features include disappearing streams, springs, dry valleys, and rock outcrops. Karst springs mark the points on the surface where groundwater returns to the surface after passing through subterranean passages.

A significant portion of the United States is underlain by karst. The Valley and Ridge region is characterized by folded and faulted rocks that formed from tectonic mountain building associated with the uplift of the Appalachian Mountains over hundreds of millions of years. The series of upland ridges separated by deep valleys are caused by different rock types, with the less soluble rock (sandstone) forming the ridges and more soluble rock (limestone and dolomite) layers occurring in valleys. Karst in the Valley and Ridge is found inside or along the margins of valleys.

The other types of caves that exist around the world do not exist in the Valley and Ridge region. **Lava caves** are tubes that form in basalt lava when the outer surface of a lava flow cools and hardens, while molten lava continues to flow and ultimately drains out of the newly formed tube. Unsurprisingly, lava caves are found in regions with volcanic activity, such as in Hawai'i. **Sea caves**, also called littoral caves, form through the constant action of waves that erode weaker rock layers. They can form from along the shores of oceans, seas, and large lakes. Most sea caves are small but some can reach up to about 300 meters (1,000 feet) in length. **Glacier caves** form by melting ice and flowing meltwater within and beneath glaciers. Glacier caves are sometimes confused with ice caves. However, ice caves are actually solution caves formed in bedrock or lava caves that contain year-round ice formations. Other types of caves include talus caves and anchialine caves. **Talus caves** are openings among large boulders that have broken off from the sides of cliffs and mountains. **Anchialine caves** form where freshwater from inland rivers and groundwater mix with ocean salt water around coastal areas.

What features are found in caves and how do they form?

Rock formations in caves are referred to as **speleothems**, which form after a cave passage had already formed. Most speleothems develop from the deposition of calcite from water saturated with dissolved calcium carbonate. The calcium in the mineral comes from the progressive dissolution of carbonate rock caused by carbonic acid in the water. As the slightly acidic water continues to dissolve rock while flowing to the water table, the concentration of dissolved calcium carbonate can become saturated in the water. At this point, the water can no longer dissolve any more rock, but the water continues to flow through fractures and cracks until it reaches a larger, air-filled opening like a cave passage. Unsaturated zone water can have up to a 250 times higher carbon dioxide concentration than air. So, the carbon dioxide in the percolating water will diffuse out of solution into the cave air, through a process called **degassing**. This is analogous to what happens when you open a can of soda. The carbon dioxide in the soda is at a higher concentration than the air and will degas from the soda to the air, which is observed as fizzing. For the percolating water, without the presence of carbon dioxide, calcium carbonate can no longer remain in solution. The chemical reaction reverses, and the result is the precipitation of the solid mineral **calcite**. This is a cycle, as calcite was also the original mineral that dissolved from the carbonate rock at the surface, due to water charged with carbonic acid from elevated carbon dioxide concentrations. Calcite in carbonate rock at the surface dissolves and then calcite reprecipitates as speleothems within usually air-filled cave passages.

There are several different types of calcite speleothems, which take various forms and colors depending on the action of water, amount of carbonic acid in water, presence of other minerals, temperature and humidity of the cave passage, and air currents. The most familiar speleothems are **stalactites** and **stalagmites**. These are also referred to as **dripstones**. Stalactites extend downward from the ceiling of a cave passage, and form along fractures or other features in the rock where water can flow into the passage. Most stalactites form initially as a soda straw that results from single drops of percolating water, rich with dissolved calcium and carbon dioxide. The carbon dioxide in a droplet diffuses into the cave air and calcite precipitates in a ring around the droplet on the surface of a previous layer of calcite. Each time this occurs, the next droplet of water flows a little more away from the cave ceiling, and calcite is deposited in another ring. Eventually this results in a series of calcite rings that form a cylinder with hollow center where the percolating water flows. Soda straw stalactites can reach up to a meter in length. If more water starts to flow through along the fracture supplying the soda straw, then the water will start to flow on the outside. Carbon dioxide degasses from the water and new calcite is deposited on the outside of the speleothem. The familiar cone-shaped stalactite forms because deposition occurs predominately near the ceiling.

Other types of speleothems can form on cave ceilings and walls, and can have interesting shapes due to how carbon dioxide degasses from the water or from the evaporation of water itself. Water does not always drip from the ceiling of a cave passage. Sometimes, rock fractures are small enough for water to flow very slowly and essentially be squeezed from the rock. This results in calcite that forms twisted or spiraling cylinders or needles, called **helictites**. Cave corals or cave popcorn are small clusters of individual calcite knobs that form from slowly seeping water or from evaporation. Water can also trickle or flow down the surface of a rock, such as a cave passage wall, and calcite is deposited as another type of speleothem called **flowstone**.

Stalagmites extend upward from the floor of a cave passage, as a result of water dripping from overhanging stalactites above them. The droplets may not have deposited all of the calcite they could as a stalactite. So, as the water falls through the cave air, it can continue to degas carbon dioxide. When the degassed water makes contact with the floor, calcite precipitates. Over time, and if enough calcite deposition occurs, a stalactite and stalagmite continue to grow towards each other and may ultimately join to form a column.

Calcite speleothems also form in pools of water. **Rimstone** can form along the margins of pools that have fluctuating water levels. Calcite forms either as vertical walls around the edge of the pool or as water overflows a pool. **Shelfstone** typically develops under still and constant water conditions and levels, along the margins of pools or along existing dripstone formations. Another speleothem that forms in pools of water is a cave pearl. Cave pearls are spherical formations found in saturated pools where calcite is deposited around a tiny pebble or grain of sand that acts as a nucleus. As the water in the pool is agitated (e.g., from a drip above), calcite builds on the developing pearls. Constant movement of the pearl in the pool keeps it from becoming attached to the bottom.

The size of a speleothem is not a good gauge for the relative age of a formation. The rate of speleothem formation and growth depends on the amount of calcium in solution and how fast water flows. Most speleothems grow slowly, at a rate around 0.13 millimeters (0.005 inches) per year, or 12.7 millimeters (0.5 inch) per century. However, some stalactites have been estimated to grow at 3 millimeters (0.12 inches) per year, or up to 30.5 centimeters (1 foot) per century.

Other features commonly found inside cave passages include **breakdown** and **cave fill**. Breakdown forms from the collapse of the ceiling or walls of a passage. Breakdown can range from the size of dinner plates to massive blocks larger than a house, depending on the rock formation and size of the passage. Most breakdown present in caves likely reflects collapse that occurred hundreds to thousands of years ago. Cave fill represents deposits of material that washes in from the surface, such as sand, gravel, clay and other fine sediments, and organic matter. These deposits can be particularly interesting, as their study can yield insights into past geological events from volcanic ash deposits, flood deposits, or charcoal from fires, ancient life in a region from fossil teeth and bones, and climate from pollen and organic material.

What is TAG and where are caves found?

TAG is the geographic region that includes the states of Tennessee, Alabama, and Georgia. In particular, TAG refers to the specific region where the three state borders meet near the city of Chattanooga. The tri-state region is renowned for its concentration, variety, and quality of caves. Over 15,000 caves have been officially reported from TAG, and new caves are reported every year. TAG caves are associated with two primary karst regions: the **Interior Plateau** and the **Appalachians**. Caves in Interior Plateau are typically associated with horizontal limestone bedrock exposures along the escarpments of the **Cumberland Plateau**, **Highland Rim**, and **Nashville Basin**. In the Appalachians karst region, caves are developed in exposed carbonate rocks that were faulted and folded during the building of the Appalachian Mountains. Most caves in the Appalachians karst region occur in the **Valley and Ridge** physiographic province.

What ecological zones are found in caves?

Subterranean habitats are classified based on their vertical extent, starting from the surface and moving into the subsurface. The **epikarst zone** includes the soil and unsaturated rock above the water table and consists of a network of air-filled, partially water flooded, to flooded small cracks, fractures, and conduits in the bedrock. Water percolates from the surface through the epikarst zone and eventually flow into the cave system below. A cave stream may be entirely fed by water that flows through the epikarst. Generally, human exploration of the epikarst is rare because openings in the rock are too small. The **vadose zone**, which includes the unsaturated area of the epikarst zone and the water table below, consists of air-filled passages that can be explored by humans. Vertical cave passages, called pits or shafts, connect the epikarst and vadose zones. Both terrestrial and aquatic habitats are found in the vadose zone. Cave passages formed in the vadose zone tend to be more canyon-like in shape from the dissolution and physical erosion of rock caused by the action of flowing water.

The water table marks the boundary between the vadose zone above and the phreatic zone below. The **phreatic zone** is permanently saturated with water below the water table and human exploration requires SCUBA gear. Cave passages that formed via phreatic action (i.e., formed below the water table) are typically circular or oval in cross section, but because of changes in the water table over time, many cave passages are shaped by both phreatic and vadose actions. These passages have a keyhole-shaped cross section, with a circular section at the top of the passage formed during phreatic conditions and a canyon-like trench at the bottom of the passage formed during vadose conditions as the water table lowered.

Within a typical cave system, there are three major ecological zones based on differences in abiotic conditions, such as light level, temperature, and humidity, which influence the diversity and abundance of species that occur in a zone. Although most caves with obvious ecological zonation are those entered by human through entrances on the surface, even caves forming in the phreatic zone and explored with SCUBA gear have ecological zonation.

The **entrance zone**, also known as the light zone, marks the boundary between the surface and subterranean environments. The entrance zone is confined to where light penetrates in the area immediately around cave entrances. Light levels can be high enough in the entrance zone that some plants, mosses, and lichens can be found. The entrance zone often has more species than the other cave ecological zones, as this zone is influenced the most by surface ecological conditions and processes. The entrance zone typically experiences the greatest variation in temperature and humidity compared to other zones.

Continuing deeper into a cave, the **transition zone**, also called the twilight zone, is encountered. The transition zone is characterized by decreasing light levels and marks the interface between surface and subterranean habitats. This zone connects the entrance, which is greatly influenced by the surface, and the dark zone where no light occurs and where surface influences are minimal. Depending on the size of an entrance, the transition zone can vary in length, such that larger entrances tend to have larger transition zones and smaller entrances can have unperceivable transition zones. Habitats in the transition zone are influenced by surface environmental conditions to a lesser extent than those in the entrance zone. Few plants grow in the transition zone, but many species of animals occur here.

The **dark zone** is the section of a cave that completely lacks light and where surface environmental conditions are minimized. Plants do not grow in the dark zone. This zone has perpetual darkness, relatively constant temperature, and relative humidity almost always near saturation. The animals found in this zone are adapted to living in these harsh environmental conditions. Generally, animal species lacking such adaptations must return to the surface or will ultimately perish.

What habitats are found in caves?

Cave habitats can be either terrestrial or aquatic, and most cave systems have a mixture of terrestrial and aquatic habitats. Terrestrial cave habitats include all habitats not submerged or saturated with water. This includes the walls and ceilings of cave passages, as well as breakdown, sediments, mud banks, and other dry to moist habitats. Common aquatic cave habitats include drip pools, cave streams, rimstone and other pools, and phreatic lakes. Cave streams contain similar features found in surface streams, such as pools, riffles, runs, and waterfalls. Some deep phreatic habitats can only be accessed by wells or by SCUBA diving in completely submerged passages. In addition to aquatic habitats found in caves, aquatic animals can also be found in other subterranean habitats, such as seepage springs, small water-filled areas of the epikarst, and interstitial habitats along rivers and streams.

Microhabitats are habitats that are small or of limited extent, which differ in character from the surrounding and more extensive terrestrial or aquatic habitat. Examples in caves include an area underneath a rock in an otherwise dry and dusty passage. Moisture and humidity levels are often greater underneath rocks, particularly in cave passages with significant air flow.

The range of microhabitats in terrestrial habitats, based on the nature and amount of available food resources, can also be classified as low-energy and high-energy habitats. For example, piles of leafy detritus that collect on a mud bank or piles of guano are considered high-energy microhabitats. Guano from bats and scat from raccoons and other mammals are important sources of energy in some cave systems. In some tropical caves, whole communities of organisms associated with guano are known, including some species that complete their entire life cycles in or around piles of guano. These organisms are called **guanobionts**.

To determine what species live in caves, biologists who study caves (**biospeleologists**) search and sample as many types of habitats and microhabitats as possible when conducting a comprehensive biological inventory. Cave biologists often must employ different cave exploration techniques to search and sample the different habitats, from walking, crawling, and climbing, to technical rope work, to SCUBA. Additionally, cave biologists also collect information about the chemistry and mineralogy of the habitats and microhabitats. This can include determining the water quality of aquatic habitats, from pH, temperature, concentrations of dissolved compounds, and even concentrations of pollutant, to understand the types of habitat and microhabitat conditions that subterranean life must adapt to and survive, and how variable those conditions are through time.

How do cave ecosystems function?

An **ecosystem** is a community of organisms living together with the inorganic components of their environment, such as rock, water, and air. On the surface, nearly all ecosystems depend on energy provided from the sun. Organic matter is made by plants, algae, and bacteria through the metabolic process of photosynthesis. But, photosynthesis is not possible in the dark zone of caves. Therefore, most cave ecosystems need organic material brought into the subsurface by wind, speleothem drip waters, streams, or as guano. This washed-in or brought-in organic matter is ultimately sourced from photosynthesis, and cave ecosystems the develop based on this type of organic matter are sometimes referred to as **top-down ecosystems** because energy, carbon, and food comes from the surface downwards into the subsurface. Microorganisms like bacteria and fungi, called **heterotrophs**, live in water or sediments and decompose or break down this organic matter for energy and cellular growth, and they produce new organic compounds that can be used by other microorganisms or even animals.

Microorganisms can also convert inorganic carbon like carbon dioxide into organic carbon, and these microbes are referred to as **autotrophs**. These microorganisms use a process called chemosynthesis to extract chemical energy from rocks and water, including methane, hydrogen sulfide, hydrogen, iron, manganese, nitrate, ammonium, among others compounds and elements. Chemosynthetic microbes found in caves are called *chemolithoautotrophs*, meaning "self-feeding rock-eaters." They are important for the development of cave ecosystems that are closed off from the surface and surface-derived organic matter, referred to as **bottom-up ecosystems** because energy, carbon, and food comes from geological sources (i.e., rocks and water) due to chemical transformations completed by microorganisms.

All ecosystems are structured like a pyramid, with a large base and smaller levels of fewer and fewer organisms at each successive level up the **food chain**. This is because of the amount of carbon and energy needed to support each of the food chain levels. Predator populations are generally smaller than their **prey** populations, as more prey is needed to support few **predators**. Microorganisms serve as the base of all ecosystems, regardless if an ecosystem is based on photosynthesis or chemosynthesis. This is because microbial cells themselves can serve as food for small, microscopic animals, which serve as food for larger animals, and because microbial biomass can outweigh all other biomass within an ecosystem.

Microorganisms can have exceptionally fast rates of reproduction that can match rates of consumption. Consumers or **grazers** are close to the base of an ecosystem because they consume a mix of smaller organisms than themselves, microorganisms, and even raw organic material. Consumers become the prey for predators.

Because of the lack of primary producers (i.e., plants), and often harsh environmental conditions, conventional wisdom would suggest that caves are depauperate ecosystems. However, this generalization is not the case, as many microbial and animal species are found in caves and other subterranean habitats. Any animal found on the surface could be found in a cave system if it accidentally wandered, fell, or washed into a cave.

How is cave and subterranean life classified?

Many different types of animals can be found in caves and other subterranean habitats. These species are classified based on the primary reasons why they are found in the habitat and what length of time they reside in the habitat. Several classification schemes have been proposed, but a general ecological classification of organisms found in caves recognizes four classes: accidentals, trogloxenes, troglophiles, and troglobionts. The etymology of these words comes from Greek, whereby *troglo*- means "one who creeps into holes." In reality, cave use and inhabitation fall along a gradient rather than in discrete categories, from entirely surface-dwelling to obligate cave-dwelling.

Most animal species found on the surface are not adapted to living underground. However, they may fall or wander into cave systems. If these species, called **accidental species**, cannot find their way back to the surface, they will ultimately perish. Other species visit caves on an occasional or seasonal basis. These species, called **trogloxenes**, utilize caves for some aspect(s) of their life histories, such as for shelter, to raise offspring, to feed, or to hibernate. In Greek, -*xenos* means "stranger." As such, trogloxenes cannot permanently survive in caves and must return to surface habitats to complete their life cycle. Examples of trogloxenes include cave-roosting bats and cave crickets. Many species of bats roost in caves and mines during the summer to raise young or in the winter to hibernate. Bats must exit caves each night to feed when they are active. Likewise, cave crickets return to the surface when environmental conditions warrant feeding, but then they return to caves during the day. Several species of salamanders seek shelter in caves when surface environmental conditions are too inhospitable. Most species that are considered trogloxenes are most abundant within the entrance and transition zones, but can sometimes be found in the dark zone.

Some animals can be found more permanently in subterranean habitats, either exclusively within the entrance and transition zones or only in the dark zone. But, because these species can also be regularly found in surface habitats, they are called **troglophiles**, from the Greek word –*philos* meaning "loving." Unlike trogloxenes, troglophiles can complete their life cycles within caves. But, troglophiles often do not exhibit the morphological adaptations typically associated with life in perpetual darkness, such as the degeneration of eyes and reduction of pigmentation. Examples of troglophiles in Valley and Ridge caves in TAG include the Cave

Salamander (*Eurycea lucifuga*) and the Banded Sculpin (*Cottus carolinae*).

Troglobionts are the final group of organisms found in cave and other subterranean habitats. The root -*biont* stems from the Greek word *bion*, meaning "to live." These species permanently live in subterranean habitats and possess morphological, physiological, and behavioral adaptations, termed **troglomorphy**, to survive in complete darkness. Examples of troglomorphic characteristics include the degeneration of eyes and complete loss of vision, reduction in pigmentation to the point skin appears white or transparent, elongation of appendages, enhancement of nonvisual sensory systems, decreased metabolism, and increased longevity compared to their surface relatives.

The terminology presented above can be used to refer to cave animals specifically found in terrestrial versus aquatic habitats. Typically, the prefix **troglo-**, which can refer to all organisms found in subterranean places, is used specifically to denote terrestrial species that can complete their life cycles both on the surface and within subterranean habitats. The prefix **stygo-** is used to denote species that live in water. The root of the word, from Greek, means "horrible," as in the reference to the River Styx or Hell. In the cave biology literature, stygobionts are aquatic species that are obligate inhabitants of caves and other subterranean habitats.

Some 350 species of troglobionts and stygobionts have been described from TAG caves, and many more species are awaiting formal taxonomic descriptions. This diversity includes four phyla and 10 classes of organisms. Arthropods are the most diverse group found in caves, comprising many species of arachnids (spiders, pseudoscorpions, harvestmen, and mites), crustaceans (crayfishes, isopods, amphipods, shrimp, copepods, and ostracods), millipedes, springtails, diplurans, and insects (beetles and flies). Other invertebrate troglobionts include flatworms, segmented worms, and snails. Only two vertebrates in TAG caves are considered troglobionts: Southern Cavefish (*Typhlichthys subterraneus*) and Berry Cave Salamander (*Gyrinophilus gulolineatus*). The Berry Cave Salamander is a close relative of the Tennessee Cave Salamander (*Gyrinophilus palleucus*), which is recognized as the official state amphibian in Tennessee.

What kinds of subterranean life are found in caves?

In addition to microorganisms, which are found in every types of cave habitat (even the cave air), many different types of animals regularly or permanently use caves during their lives. The vast majority of these animal species are invertebrates.

Most troglobionts and stygobionts have very small ranges, known only from a few cave systems. Some species have only been documented from a single cave. Consequently, troglobiotic biodiversity is characterized by high levels of endemism. **Endemism** refers to being unique to a particular geographic location or ecological zone or habitat. Species that are highly endemic have very specific, often small, ranges compared to species that are not considered endemic that may be found over a wide geographic region.

Below, we briefly introduce and discuss several groups of organisms and species that are most commonly encountered in caves of TAG. This includes microorganisms and animal fauna that are not troglomorphic and are considered troglo-/stygoxenes and troglo-/stygophiles, as well as those considered to be troglobionts and stygobionts. For more information about particular organisms, we encourage exploration of the articles, books, and other literature listed in the Resources section at the end of this module.

Bacteria and Fungi

Probably the most recognizable microbiological features that can be seen in caves with the naked eye are shiny gold, white, pink, blue-gray, or brown patches. These microbial colonies can start as very small dots and become as large as 5 centimeters (2 inches) in diameter, and even combine to cover an entire rock or cave wall surface. Colonies form on moist cave passage ceilings and walls, or on mud surfaces that has been left undisturbed for long periods of time.

These pigmented colonies are mostly dominated by Actinobacteria, a phylum within the kingdom Bacteria. This group is commonly and historically referred to as **actinomycetes**. The shininess or sparkle commonly observed with these colonies is due to water droplets that condense onto the colony surface, as cell membranes are hydrophobic. Condensation occurs because the cave walls and colonies are cooler than the cave air, which has a relative humidity near saturation. Some actinomycetes produce compounds that give off an odor, including geosmin. This compound has an earthy smell that most people associate with basements, cellars, and caves.

Research done to investigate other groups of microorganisms requires the analysis of DNA by using molecular genetics methods. By comparing DNA sequences of samples collected from caves, biologists can determine which group of organisms may dominate a community or be rare community members. It is also possible to study how microorganisms impact animals, such as through species interactions like symbiosis. However, of the hundreds of thousands of caves known in the world, and from the over 15,000 caves in TAG, only a handful of caves have been investigated for their microbial diversity. At present, although we know that microorganisms are extremely important and essential to cave ecosystems, we know almost nothing of TAG cave microbial diversity. This is an exciting area for new research.

Invertebrates

In TAG, stygobiotic representatives of flatworms (phylum Platyhelminthes) include four species in the genus *Sphalloplana*. These species all are small, white, and eyeless relatives of the planarians that a student might dissect in a biology lab in high school. Flatworms lack a body cavity and are unsegmented. Species that have been found in subterranean habitats are free-living, although many parasitic taxa are known from surface habitats. They have been found sporadically throughout TAG in a variety of habitats, including cave streams, rimstone pools, and drip pools. They are often located adhering to the undersides of rocks. Several other species considered stygophiles or stygoxenes also have been reported from caves.

Segmented worms (phylum Annelida) can be quite abundant in caves, and some species are even obligate inhabitants of caves and groundwater. Earthworms and other segmented worms can be found in a variety of terrestrial and aquatic habitats, living in sediments that they ingest and from which they extract nutrients. Some species found in caves are not native to the United States, having been brought here by Europeans over the past 300 years. Branchiobdellid worms are annelids that are ectosymbionts on the exoskeleton or in the gill chamber of crayfishes. Some of these worms are thought to be stygobionts.

Terrestrial snails (phylum Mollusca) are commonly encountered at the entrance and in the twilight zone of caves. There are several species of aquatic snails that have been reported from caves. Troglobiotic and stygobiotic snails are small, generally <4 millimeters, with some species as small as 1 mm. In the Valley and Ridge of TAG, three terrestrial cave snails are known from just a handful of records. Only one aquatic cave snail has been described from TAG, the Manitou Cave Snail (*Antrorbis breweri*). This blind and depigmented species is transparent and reaches a maximum size of 2 millimeters (0.08 inches). At least two undescribed species of aquatic cave snails have been discovered in the last three years in east Tennessee, some in urban watersheds. This is an interesting and important area of research when considering water quality issues and conservation efforts in the region.

The vast majority of invertebrate fauna found in caves belong to the phylum Arthropoda. Arthropods include insects, arachnids, myriapods (millipedes and centipedes), and crustaceans. Arthropods are characterized by their jointed appendages, segmented body, and exoskeleton made of chitin. Over 80% of all known living animal species on Earth are arthropods. Consequently, it comes as little surprise that this group is also diverse in cave ecosystems.

Crustaceans are a very diverse group of arthropods, which includes crabs, crayfishes, lobsters, shrimp, barnacles, isopods, amphipods, and others. Although most crustaceans are aquatic, some are terrestrial, and others are parasitic or even sessile organisms. In caves, the major crustacean fauna includes crayfishes, shrimp, isopods, amphipods, copepods, and ostracods.

Crayfishes and shrimp are decapods, which have five sets of appendages on the last five thoracic body segments. In general, the front three pairs function as mouthparts. They are omnivores that opportunistically feed on other aquatic invertebrates, carcasses of dead organisms, organic matter, and even bat guano. In some species, such as crayfishes, a pair of appendances is modified into enlarged pincers called chelae. More appendages are found on the abdomen. Cave crayfishes lack eyes, are depigmented, and have elongate appendages and antennae. Caves with prominent streams typically have crayfish. Two stygophilic species are particularly common: the Cavespring Crayfish (*Cambarus tenebrosus*) in the Interior Plateau and the Appalachian Brook Crayfish (*C. bartonii*) in the Valley and Ridge. Eleven species of stygobiotic crayfish are known from the Interior Plateau of TAG. No cave crayfishes are known from the Valley and Ridge of TAG. The Alabama Cave Shrimp (*Palaemonias alabamae*) is the only cave shrimp currently known from just a few caves in northern Alabama in TAG. However, a related undescribed cave shrimp species inhabits a few caves along the Tennessee River in northwestern Alabama. Cave shrimp have not yet been discovered in the Valley and Ridge.

Isopods are perhaps the most common cave animals in aquatic habitats of TAG caves, where they can be found in cave streams, rimstone pools, and drip pools. Cave species lack eyes and pigment and have dorsoventrally compressed bodies, which gives them a flattened appearance. Twelve species in the genus *Caecidotea* have been described and are known from TAG. In addition to aquatic taxa, there are half a dozen terrestrial cave isopods from TAG. Terrestrial isopods are also sometimes called pill bugs, woodlice, and roly-polies, terms students may already know.

Amphipods are aquatic crustaceans that resemble shrimp. They are sometimes referred to as freshwater shrimp or scuds. Amphipods differ from shrimp by having eight pairs of appendages that issue from the thorax and being laterally compressed. Several species of amphipods that are common in seeps, springs, and spring runs are also found in caves. These species are considered stygoxenes or stygophiles, possess eyes, and are pigmented. Several stygobiotic species are known, and found in a variety of aquatic habitats that range from the interstices of cobble and gravel to large phreatic lakes. These species lack eyes and are depigmented. Some cave amphipods are quite small and reach only 3 millimeters (0.12 inches) in body length.

Ostracods are very small, flattened crustaceans that have a two valve body that resembles the shell of a clam. They are sometimes called seed shrimp. They are difficult to identify without a microscope, but are found in nearly every aquatic habitat. Most species reported from caves are commensals on cave crayfishes. Commensal is in reference to commensalism, which is a symbiotic association between two organisms where one organism benefits (the ostracod) and one organism derives no benefit or harm (the cave crayfish).

Copepods are even smaller (<1.5 millimeters or <0.06 inches) crustaceans found in almost every aquatic habitat, as well. The cuticle of the exoskeleton in most species is very thin, making them transparent. Copepods typically have a short, cylindrical body, with a rounded head that is fused with the first one or two thoracic body segments. Because of their small size, most species have no heart or circulatory system, or even gills. Instead, they rely on gas exchange directly into and out of the body. Several species have been reported from caves, and they represent an important food source for larger, aquatic predators, such as cavefishes.

Spiders are common inhabitants of caves. Spiders, along with pseudoscorpions, scorpions, mites, ticks, and some other groups, are terrestrial arachnids. All arachnids have eight legs and lack antennae or wings. Many species have been reported from TAG caves. Larger species can be found around cave entrances, and smaller (1–3 millimeters, 0.04–0.12 inches) species are found in moist microhabitats among rocks and cobble in the dark zone. All spiders are predatory, and many species are important components of cave ecosystems. The Cave Orb Weaver (*Meta ovalis*) is not a troglobiont, despite its common name. This medium-sized spider is conspicuous in the large orb webs they construct at a cave entrance in the twilight zone. Several species of troglobiotic spiders are known from TAG, including 10 species of cobweb spiders in the genus *Nesticus*. The Subterranean Sheet-Web Spider (*Phanetta subterranea*) is the most widespread spider in TAG, known from more than 150 caves.

Pseudoscorpions are small terrestrial arachnids (0.08–0.31 inches, 2–8 millimeters) that resemble scorpions but lack a tail with a stinger. They are active predators of smaller invertebrates, such as mites and springtails. Several species of pseudoscorpions have been reported from caves in TAG, including more than 50 troglobiotic taxa. The largest and most commonly observed cave pseudoscorpion in TAG is the Southeastern Cave Pseudoscorpion (*Hesperochernes mirabilis*), which is often found in association with bat guano and woodrat nests. This species has been found in over 100 caves. However, most cave pseudoscorpions are endemic to a single or just a few cave systems, and species identification of newly discovered endemic populations is ongoing.

Harvestmen, also referred to as daddy longlegs, are omnivorous arachnids that feed on small invertebrates and organic debris. Most species found in caves are not troglomorphic. Species in the genus *Leiobunum* often aggregate in large numbers on cave walls or ceilings during winter months, and then return to the surface during warmer parts of the year. Three troglobiotic species of harvestmen are known from TAG, but none from the Valley and Ridge as of yet.

Another group of arachnids found in caves are mites. Cave mites have been particularly poorly studied, likely because many species are extremely small (<1 millimeter, <0.04 inches). Mites live in a variety of terrestrial and aquatic habitats. Some species live freely in the environment, while others are parasites of other animals.

Many species of millipedes can be found in caves. They are elongate arthropods (class Diplopoda) with typically cylindrical bodies and two pairs of legs on most body segments. Millipedes most often found in damp and moist microhabitats, where they feed on decaying wood, leaves, scat, and guano. Several troglobiotic millipedes are known from TAG caves. Most are small, reaching no more than 20 millimeters (0.8 inches) in length, although the genus *Tetracion* can reach over 80 millimeters (3 inches) in length. Troglobiotic millipedes are depigmented and either lack or have reduced eyes. Several millipedes are considered trogloxenes and troglophiles. For example, the Greenhouse Millipede (*Oxidus gracilis*), also called the Hothouse Millipede, has been widely introduced around the world and has colonized caves in North America. This invasive species can sometimes be found in great numbers throughout TAG caves, especially around animal scat.

Springtails, also called collembolans, are a diverse but poorly studied group of small, terrestrial, and wingless invertebrates. Like insects, they are hexapods and possess three pairs of legs and antennae. Springtails are found in moist microhabitats in surface habitats, such as soil, forest leaf litter, and other decaying plant matter. Several species are common in caves. Trogloxenic and troglophilic springtails are typically pigmented grayish or purplish and have conspicuous eyes. Troglobiotic species typically lack eyes, are depigmented, and have elongated antennae. Springtails possess a forked structure called a furculum at the end of their abdomen. The furculum functions like a catapult that allows springtails to jump up to 20x their body length to escape from predators and other threats.

A third of all troglobionts in TAG caves are beetles. Ground beetles are particularly successful in cave habitats. The genus *Pseudanophthalmus* is the most diverse group of cave beetles, with 145 described species and another potentially 80 species that remain to be formally described. Most cave beetles have small ranges, including several that are endemic to a single cave system. These beetles either lack or have extremely reduced eyes and vestigial wings. They are active predators that feed on small invertebrates, such as springtails and millipedes. Some species are even adapted to feed on cave cricket eggs that are laid in sediments. Several other troglobiotic beetle species are known from TAG caves, including species of fungus beetles and rove beetles. Many of these species are not troglomorphic but still regularly occur in caves. For example, rove beetles are scavengers that are often found feeding on raccoon scat and bat guano. Rove beetle species that are trogloxenes or troglophiles possess functional eyes.

Cave crickets are common in TAG caves, and are often found on the walls and ceiling of cave passages in the twilight zone but also the dark zone. Although some cave cricket species may have reduced pigmentation and elongated limbs and antennae, they are not considered troglobionts. This is because they regularly travel to the surface on warm, humid nights to feed. Almost all of their food is derived from feeding at the surface, where they are omnivores and scavengers. Consequently, cave crickets are considered trogloxenes. By traveling back and forth into caves, they provide important sources of energy into cave ecosystems. Cave cricket guano, as well as eggs that are laid in cave sediments and carcasses when they die, provide important sources of food for many other invertebrates.

Several flying invertebrate species are commonly encountered in TAG caves. However, only one species, the Cave Dung Fly (*Spelobia tenebrarum*), is a troglobiont. This species is widely distributed throughout the Interior Plateau and Appalachians karst regions of TAG. All other flying invertebrates are either accidentals, trogloxenes, or troglophiles. Mosquitos, which often overwinter in caves, heleomyzid flies, fungus gnats, and phorid flies are also common in caves. Some moths overwinter in caves, such as the Herald Moth (*Scoliopteryx libatrix*).

Nymphs of mayflies, stoneflies, and caddisflies are occasionally found in cave streams but are not troglomorphic.

<u>Vertebrates</u>

Several families of fishes have colonized caves in TAG, but only two species are currently considered stygobionts. Alabama Cavefish (*Speoplatyrhinus poulsoni*) and Southern Cavefish (*Typhlichthys subterraneus*) belong to the family Amblyopsidae. They both have degenerate eyes, are depigmented, and have a hyper-developed lateral line system, as well as other sensory papillae that contain neuromasts arranged in ridges on the head and sides of the body. To compensate for lack of vision in the darkness of caves, these cavefishes rely on detecting subtle vibrations in water using their lateral line system and sensory papillae to locate food, members of the same species (conspecifics) and predators, and even their surroundings, like rocks and the edges of pools. Alabama Cavefish are known only from a single cave in Lauderdale Co., Alabama, and is federally endangered. Southern Cavefish are considerably more common and widespread, occurring throughout the Interior Plateau of central Tennessee, northern Alabama, and northwestern Georgia. Until very recently, this species was not known from the Valley and Ridge. However, cave biologists discovered a new population in 2015 in the heart of the Valley and Ridge in Catoosa County, Georgia. It also appears that the Southern Cavefish is not actually a single species. Instead, molecular evidence suggests that this species is a complex of ten or more morphologically indistinguishable species that are each genetically distinct.

Mottled Sculpin (*Cottus bairdii*) and Banded Sculpin (*C. carolinae*) are frequently observed in caves. These bottom-dwelling stygophiles have flattened bodies and enlarged pectoral fins that help them remain on the bottom in fast-flowing water. A related species in Missouri, the Grotto Sculpin (*C. specus*), was recently described and is a stygobiont with reduced eyes and pigmentation. Several other fishes have been reported from caves in TAG, although most are either accidentals or possibly stygoxenes, such as Green Sunfish (*Lepomis cyanellus*), Bluegill (*L. macrochirus*), and Yellow Bullhead (*Ameiurus natalis*).

Salamanders are important components of cave ecosystems and several species regularly occur in caves. Some species reproduce in caves while other species utilize caves on a seasonal basis to escape harsh conditions in surface habitats. Two closely-related species in TAG are permanent cave-dwellers and are considered stygobionts: the Tennessee Cave Salamander (*Gyrinophilus palleucus*) and the Berry Cave Salamander *(G. gulolineatus*). Both of the species are neotenic, meaning that they attain sexual maturity in the larval stage and retain larval traits, such as gills. They also have reduced eyes and an enhanced lateral line system compared to other related salamanders. Berry Cave Salamanders are known from only a few caves in the Valley and Ridge of east Tennessee. Tennessee Cave Salamanders are more common and occur in caves of south-central Tennessee, northern Alabama, and northwestern Georgia. The Cave Salamander (*Eurycea lucifuga*) is the most commonly encountered salamander in TAG caves. This troglophile can be found around entrances, but also in the dark zone of caves where it is most often found on cave walls and within crevices.

Several other salamander species are commonly observed in caves of TAG. Most are considered trogloxenes, although some species lay eggs and tend to nest in cave habitats and are considered troglophiles. This includes Northern Slimy Salamanders (*P. glutinosus*), Zigzag Salamanders (*P. dorsalis* and *P. ventralis*), Red Salamanders (*Pseudotriton ruber*), and Spring Salamanders (*G. porphyriticus*). All of these species are lungless and belong to the family Plethodontidae. Northern Slimy Salamanders and Zigzag Salamanders are unusual in that they lay terrestrial eggs that then hatch out as miniature adults, bypassing the aquatic larval stage typical of most other salamander species in the egg.

Most frog species do not inhabit caves, although three ranid species are considered trogloxenes: the Pickerel Frog (*Lithobates palustris*), American Bullfrog (*L. catesbeianus*), and Green Frog (*L. clamitans*). These species are most often observed around the entrances and twilight zones of caves with prominent streams. Pickerel Frogs and Green Frogs are known to congregate in caves during periods of extreme drought and cold.

Reptiles are infrequently encountered in caves. No species in TAG are even considered trogloxenes. This is likely because caves are too cool to support prolonged activity for our native turtles, snakes, and lizards. However, several species of snakes and the Eastern Box Turtle (*Terrapene carolina*) have been reported from TAG caves. Most of these reports represent individuals that fell into a pit or sinkhole and could not climb out of the cave.

Few birds are encountered in caves, and no species are considered troglobionts. The Eastern Phoebe (*Sayornis phoebe*) is often observed during the spring and summer months at the entrances of caves, where it builds nests. Both Black Vultures (*Coragyps atratus*) and Turkey Vultures (*Cathartes aura*) are known to infrequently nest at the entrances of caves and can be found within the twilight zone.

Several mammals are regularly encountered in caves, but no troglobiont species are known in North America. Although Raccoons (*Procyon lotor*) are seldom seen, evidence of activity in the form of scat and tracks is abundant in many caves. Raccoons use caves for shelter, but may also occasionally try and feed on crayfish in cave streams and pools. Woodrats, also called pack rats, utilize caves for shelter. They live in and around the entrances of caves and construct nests, called middens, which are comprised of twigs, leaves, grasses, stones, bones, and other litter and objects. They also store caches of food and nesting materials, hence the common name "pack rat." Two species closely related species occur in TAG, the Eastern Woodrat (*Neotoma floridana*) and Allegheny Woodrat (*N. magister*). The Allegheny Woodrat occurs in the Valley and Ridge. Other rodents, such as White-Footed Mouse (*Peromyscus leucopus*), are known to nest in caves. North American Beavers (*Castor canadensis*) even construct their lodges at the entrances of caves with prominent springs.

Several species of bats roost or hibernate in caves in TAG. All species found in TAG caves are insectivorous and use echolocation to navigate and locate prey. The Tri-Colored Bat (*Perimotis subflavus*), the smallest species, is the most frequently encountered bat in caves. This species can be found all months of the year in caves, but are most abundant during the winter months when they hibernate either alone or in small clusters. In addition to Tri-Colored Bats, several other species are regularly encountered in TAG caves. Gray Bats (*Myotis grisescens*) roost in caves during the summer months and hibernate in caves during winter. In summer, females form maternity colonies in caves while males form separate bachelor colonies in caves. During winter, this species hibernates in large colonies of up to 500,000 bats in only a few caves. Other bats that are often observed in caves include Big Brown Bats (*Eptesicus fuscus*), Little Brown Bats (*M. lucifugus*), Indiana Bats (*M. sodalis*), Northern Long-Eared Bats (*M. septentrionalis*), and Rafinesque's Big-Eared Bats (*Corynorhinus rafinesquii*). Gray Bats and Indiana Bats are federally endangered species, and Northern Long-Eared Bats are federally threatened.

Are any cave animals at risk of extinction?

Many species of cave fauna are of conservation concern. This is because many species have very small ranges, very specific habitat requirements, low reproductive rates, and are thought to have limited dispersal abilities. Consequently, the cave organisms may be particularly vulnerable to any threats that result in further reductions in available habitat or that degrade their habitat. In addition, because we know very little about the ecology and life history of most cave species, this has hampered conservation efforts. For instance, we often do not know exactly how long particular species may live or how many offspring they might produce during their lifetimes. Such information is important to determine how threatened a species may be and to estimate how long it may take for a population to recover after experiencing a decline.

Cave organisms face a variety of threats. Some threats are universal, such as climate change and groundwater pollution, while other threats vary considerably in scope and severity. For example, mining and quarrying can completely destroy cave systems at a local, or perhaps limited regional, scale. Hydrological modifications, which can include water extraction and impoundment construction, can be a local threat and result in cave passage flooding. Other threats on a local scale include tourism and visitation, and even scientific and amateur collection. But, karst landscapes are particularly susceptible to contamination, due to low potential for auto-depuration or self-purification, and greater probability of retention of contaminants in passages with odd shapes, pockets, and deep trenches. Groundwater pollution is among the most common threat to cave ecosystems, across an entire watershed, and even extending across a karst region. Sources of groundwater contamination are many, but commonly include septic systems, sewage, urban stormwater runoff, industrial wastewater, mining operations, and pervasive and widespread agricultural runoff (e.g., herbicides and pesticides). Such pollution can be a high-severity, acute event, such as a chemical spill that feeds directly into a sinkhole on a timescale of hours or days, or be a chronic, slowly but continually sourced pollutant that occurs over months to years.

Unfortunately, the conservation status of only a few troglobionts and stygobionts has been assessed. Many species are thought to be of conservation concern, but most species have not been studied with enough intensity or regularity to ascertain if populations are in decline. In such cases, there simply is not enough information yet to make a determination. However, some of the more charismatic groups, such as cavefishes, salamanders, crayfishes, and bats, have been assessed. Several species are at an elevated risk of extinction. They are included on TAG state lists of rare, threatened, and endangered species.

Thirty-five cave faunal species are listed as threatened or endangered under the U.S. Endangered Species Act (ESA). This includes seven species of cave beetles, seven cave spiders, three cave harvestmen, one cave pseudoscorpion, two cave crayfish, three cave shrimp, four cave amphipods, two cave isopods, one cave snail, three cavefish, and two cave salamanders. However, only the Alabama Cavefish (*S. poulsoni*) and Alabama Cave Shrimp (*P. alabamae*) are listed under the ESA in the TAG region. Both species are federally endangered. The ESA prohibits taking listed species, as well as interstate and international trade. The act of taking includes such actions as harassing, harming, hunting, trapping, capturing, killing, or collecting. Protections also include prohibition of activities that result in significant habitat modification or degradation to cause death or injury of wildlife.

Six species of bats are listed under the ESA, including three species that are found in TAG: the

Gray Bat (*M. grisescens*), Northern Long-Eared Bat (*M. septentrionalis*), and Indiana Bat (*M. sodalis*). Gray Bats and Indiana Bats have been listed since 1976 and 1967, respectively. Gray Bats form large colonies during hibernation, which makes them especially vulnerable to population decline due to human disturbance, which is a significant threat implicated in population declines. It is estimated that 95% of all Gray Bats hibernate in one of 11 major hibernacula. Indiana Bats also hibernate in large numbers but not nearly to the same degree as Gray Bats. However, Indiana Bats have also suffered population declines due to several factors, including human disturbance, loss of summer habitat, and pesticides. To help protect Gray Bat and Indiana Bat colonies, many caves have been gated to reduce human impacts.

Unfortunately, a new threat has emerged that not only affects Gray Bats and Indiana Bats, but several other species, as well. This threat is called White-Nose Syndrome (WNS), which is caused by the fungus, *Pseudogymnoascus destructans*. The fungus was likely introduced from Eurasia in 2006 to the bats in a cave in New York state, and WNS has since spread to 29 U.S. states and five Canadian provinces (as of July 2016). Knowledge of the distribution of *P. destructans* in TAG caves is unknown, and it is unclear whether this fungus, which tends to prefer to live at cooler temperatures, can survive for long periods of time in somewhat warmer TAG caves.

The fungus infects the skin of the muzzle, ears, and wings of hibernating bats. The fungus disrupts bat hydration and hibernation cycle. WNS causes bats to awake repeatedly from hibernation during the winter, which causes them to metabolize limited fat reserves. Consequently, bats often then leave hibernacula in late winter, already dehydrated, to search for food. Most bats succumb to the elements or starve, as flying insects typically are inactive. WNS is known to affect seven bat species in North American, and has been detected in another five bat species, although these have not yet developed the disease. Millions of bats have already been died from WNS. One bat species, the Northern Long-Eared Bat (*M. septentrionalis*), was listed in 2015 as threatened under the United States ESA because of dramatic population declines associated with WNS. Transmission of the fungus is predominately from bat-to-bat contact, particularly in species that form tight clusters during hibernation. Research continues to understand the fungus responsible for WNS, WNS transmission, and possible ways to kill the fungus by many different government agencies, organizations, and scientists. For cave explorers, there are protocols in place to reduce the potential for fungal transmission from an infected cave to an uninfected cave in cave equipment and clothing. Additionally, the spread of WNS throughout the U.S. and Canada continues to be monitored, and many different solutions to manage and ultimately cure the disease are being researched.

Cave Landscape Formation

Objective

- Students will learn about how caves form.
- Students will learn about rock formations (speleothems) found inside of caves.

Next Generation Science Standards

- 2-ESS1-1. Use information from several sources to provide evidence that Earth events can occur quickly or slowly.
- 2-ESS2-2. Develop a model to represent the shapes and kinds of land and bodies of water in an area.
- 4-ESS1-1. Identify evidence from patterns in rock formations and fossils in rock layers to support an explanation for changes in a landscape over time.

Student Information Sheets

- What is a Cave
- Cave Formations
- Cave Rock Formations

Activities

- Dissolution
- Speleothems

Handouts

- Speleothems experiment design. This handout is designed to allow students to predict what they think will happen, and then follow-up by reporting what actually happens. A follow-up to this would be to have students write a description of why think their results are as expected or different than expected.
- A writing exercise for Kindergarten is included. This one-page handout includes four 4-letter traceable words related to caves. This is a great bell-ringer handout.
- Cave exploration mazes. Four mazes of varying difficulty have been provided for students to trace their way through or to the center. This is a great handout for early finishers or as a bell-ringer.

Activity One - Dissolution

Materials: *White vinegar, baking soda and/or calcium carbonate chalk.*

Before performing this demonstration, have your students predict what will happen when the vinegar is poured over the baking soda. They can do this verbally, or through drawings and writing.

Dissolution caves, especially in karst landscapes, form by weak carbonic acid dissolving calcite rocks. Calcite is a mineral made of calcium and carbonate ions. While commonly used to portray volcanic activity, a mixture of baking soda and white vinegar can also be used to demonstrate carbonic acid dissolving calcite rock. The chemical reaction taking place in a baking soda and white vinegar mixture is much stronger than what one would actually witness when carbonic acid dissolves calcite rock, but it provides a visualization.

Alternatively, to visualize this process pour white vinegar over Calcium Carbonate Chalk (do NOT use dustless chalk, as this will not work). The vinegar will "dissolve" holes into the chalk providing a demonstration of the process that forms dissolution caves. This demonstration may take a bit longer to produce results than the baking soda demonstration, but provides a more accurate visual for cave formation.

Activity Two - Speleothems

Materials: *Cups, small plates or aluminum foil, plastic spoons, paper clip or washers, thread (wool or cotton), hot water, and Epsom salt (or baking soda).*

The necessary supplies for each set-up are: 2 foam cups, 1 small plastic plate (or square of aluminum foil), 1 plastic spoon, 2 paper clips, thread (wool or cotton), and Epsom salt (or baking soda).

This activity allows students to make their own rock formations (stalactites, stalagmites, and possibly columns) over a period of a few days. Students can work in groups, pairs, or individually for this activity.

Students should fill each cup 3/4 full with hot tap water. Then, have students add Epsom salt to each cup until no more salt dissolves. The cups should be placed in a warm place, such as near a window with sunlight. Next, students should twist a couple strands of thread together (these strands can also be prepared ahead of time). A paper clip should be attached to each end of the string to weigh it down and then an end of the string should be placed in each cup leaving the thread dangling between the cups. Place the plate or aluminum under the dangling thread. The solutions will migrate up the thread until they meet in the middle at which point they will drip down. Allow students to observe what happens over the next few days until no solution remains. Students should see the formation of "stalactites" and "stalagmites." If enough Epsom salt solution was present, and the rate of migration was ideal, then students could also see a column form. Additional solution can be added if evaporation is too quick and only little solid formation occurred on the string.

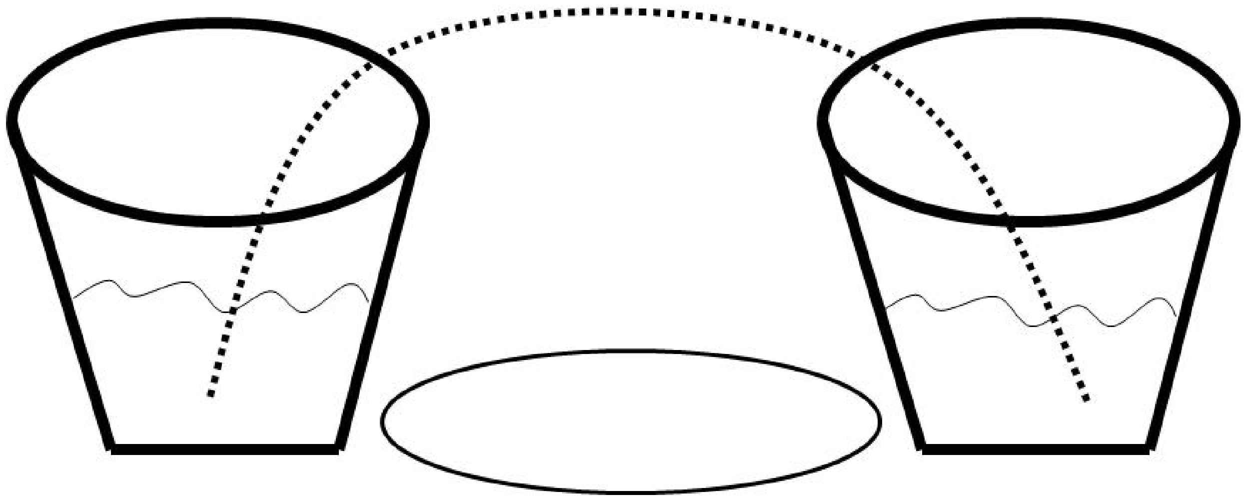
Students may encounter some challenges in this experiment, and below are some helpful comments. These comments can be used to guide student experimental set-up, can be used after the fact to explain differences in student results, or can be used to modify the experimental design (e.g., students can construct an experiment to compare two set-ups with difference solution concentrations while predicting what they will see, or students can determine how the level or length of dangling string impacts results for stalagmite/stalactite/column formation).

Comments:

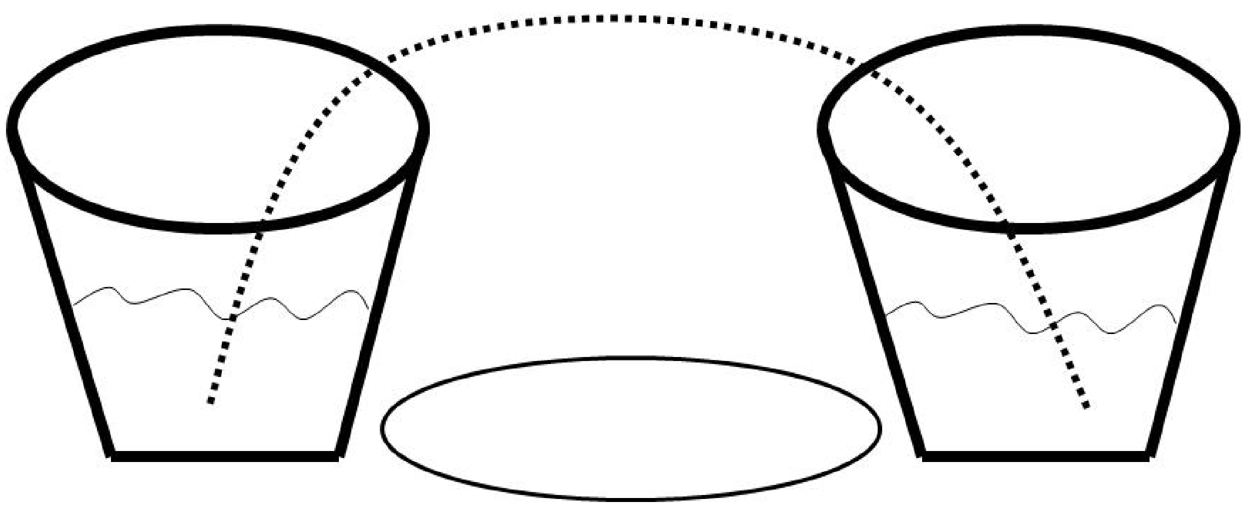
1. Baking soda can be substituted for Epsom salt (or be used for a comparison experiment).
2. Keep the dangling string above the level of water in the cups or else you will merely see a pool form on the plate.
3. Dampen the string in the solution prior to dangling it so migration is more efficient.
4. Cups should be moved closer together if there is no dripping and the string becomes dry.

Name: ______________________________

Draw what you think will happen in your experiment.



Draw what happens in your experiment.



What is a Cave?

Speleology is the study of caves that includes many subjects, such as biology, geology, chemistry, and anthropology. What other subject areas do you think would study caves?

Caves are natural openings in the ground that contain a **dark zone** (place where no light is present) and are large enough to allow a human to enter. Cave openings can form in many ways, for example some caves form at sinkholes while others are weathered into rocks by water or wind.

Caves vary in size. Some can be small like a closet while others are interconnected mazes with many pathways like a school. Features called speleothems can be inside a cave, such as stalagmites or stalactites. Caves can also have waterfalls, underground streams, pools, and chambers.

Scientists often make maps of caves when they explore them, and then they use features found inside of the cave to document locations of what they discover.

Cave Formation

Caves can form due to many natural forces. Most caves form in karst landscapes. Karst landscapes are made up of soluble rocks, such as limestone, dolomite, and gypsum. As rain falls onto these landscapes, carbon dioxide from the atmosphere mixes with water and forms a weak acid solution that dissolves the minerals in the rocks. Typical caves form in carbonate rock and the main mineral is calcite. Caves that form by dissolving of minerals are called **dissolution caves**.

Caves form in other ways, too. **Sea caves** develop when waves break apart rocks along a lake or ocean coastline. Waves are able to carve out caves because they exert pressure on the rock and carry sand and gravel that also physically wears away the rocks. **Glacier caves** form in glaciers by flowing water melting tunnels throughout the ice. **Lava caves** are volcanic in origin and form when the outside of a lava flow from a volcano cools while the inside is still hot and flows like a stream or river. The surface cools faster than the inside, leaving a tube.

Cave Rock Formations

Have you ever wondered about the amazing rock formations found inside of caves? Cave rock formations are called **speleothems** and they form when the carbon dioxide in the water escapes from dripping water into the cave atmosphere. When this happens, calcite precipitates into rock formations.

Stalactites hold tight to the ceiling. Calcite forms when carbon dioxide is released into the cave air as water drips from the cave ceiling. They look almost like icicles.

Stalagmites form when water drips off of stalactites and a little bit more calcite can form when the water hits the ground., They resemble upside-down icicles.

When stalactites and stalagmites join together, they form **columns**. As columns get larger, they grow wider and wider.

Sometimes we see twisting or spiraling structures that look like spiral noodles or wiggling worms. These are called **helictites.**

Name: ________________________________

CAVE

ROCK

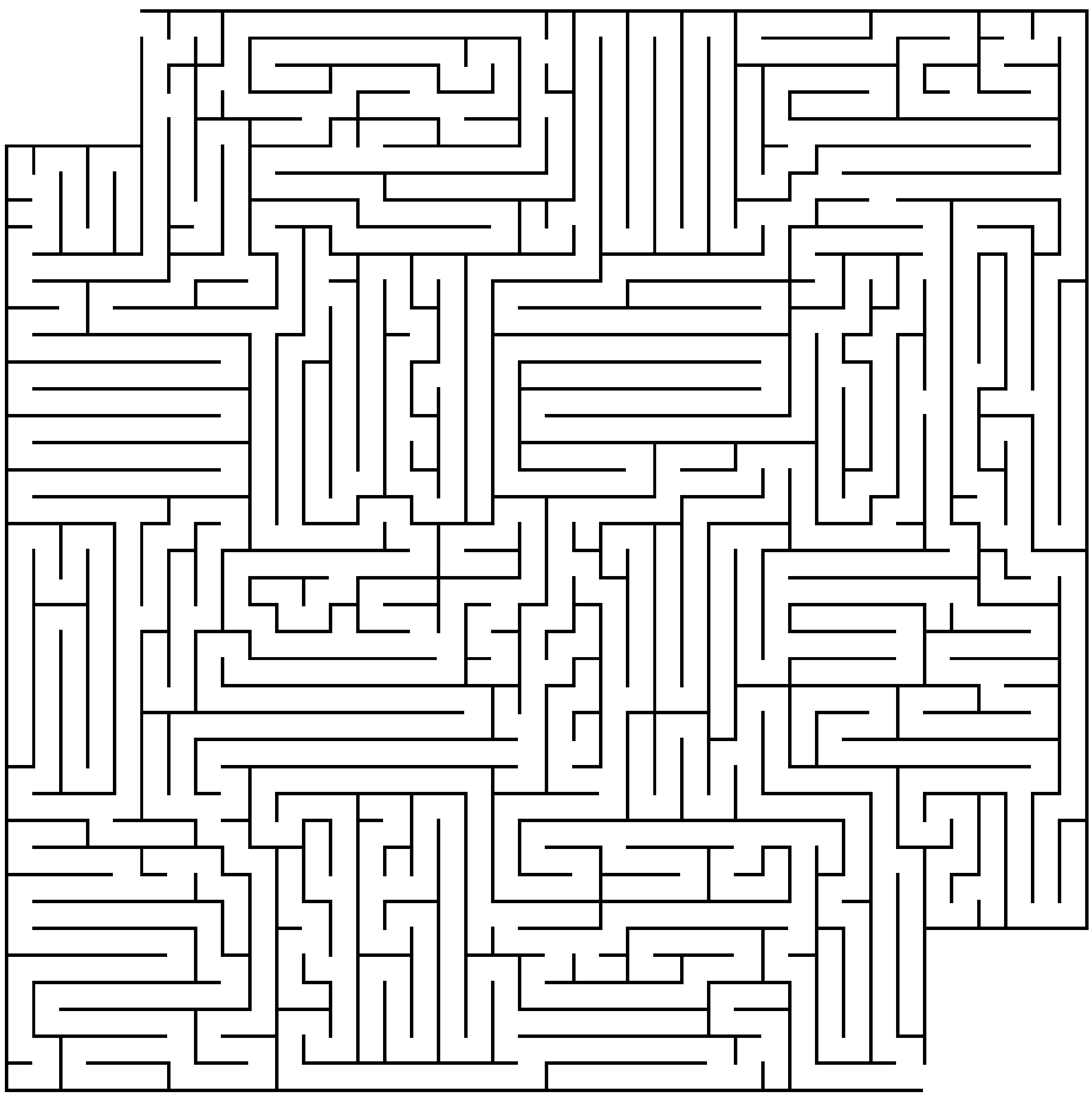
HOLE

MAZE

Name: ______________________________

Some caves have more than one entrance. Find your way from one side of the cave to the other!

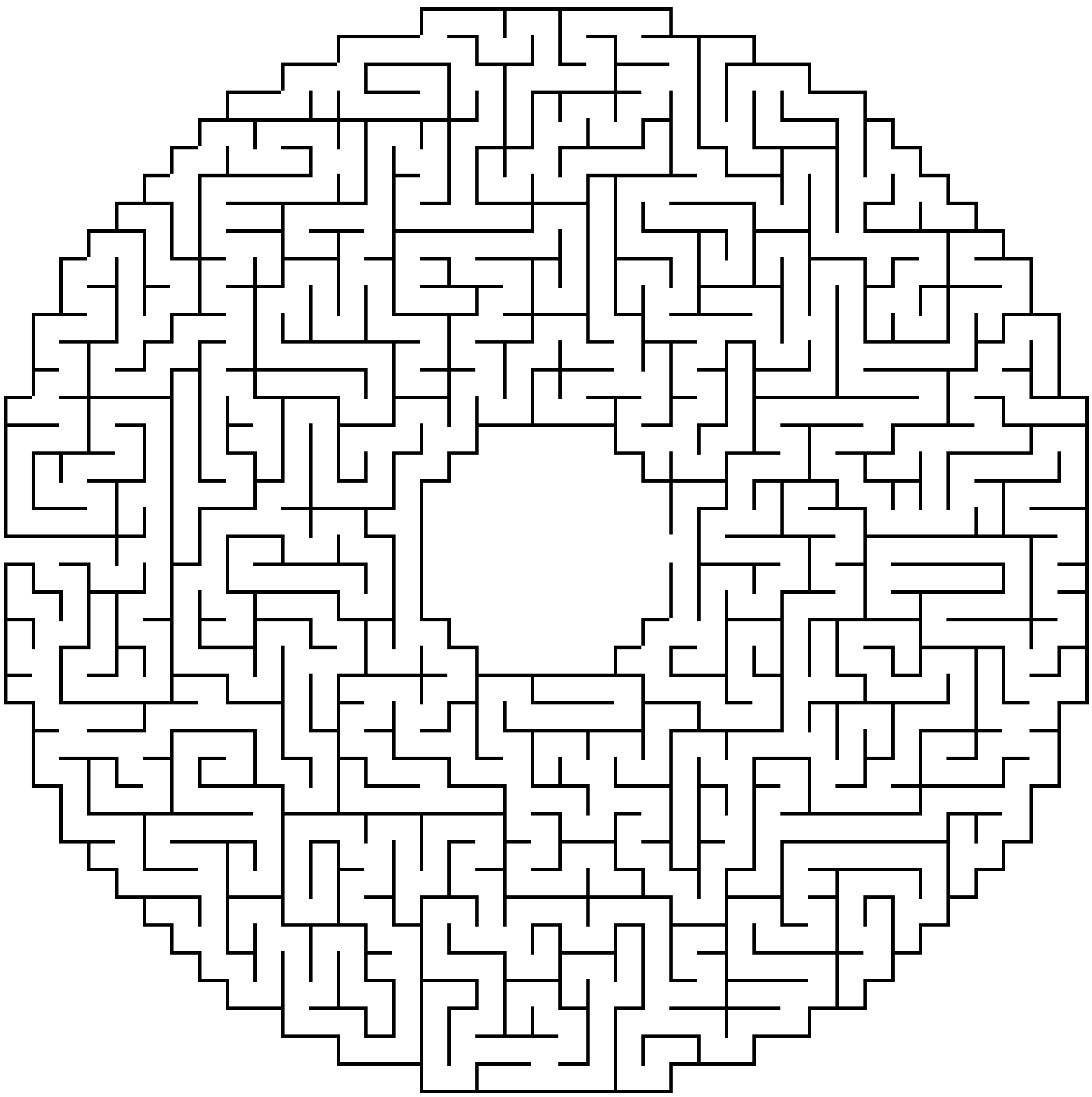
Cave Exploration!



Name: ______________________________

This cave has a large room at the center. Find your way to the middle of the cave! Draw a picture in the middle of an animal you see!

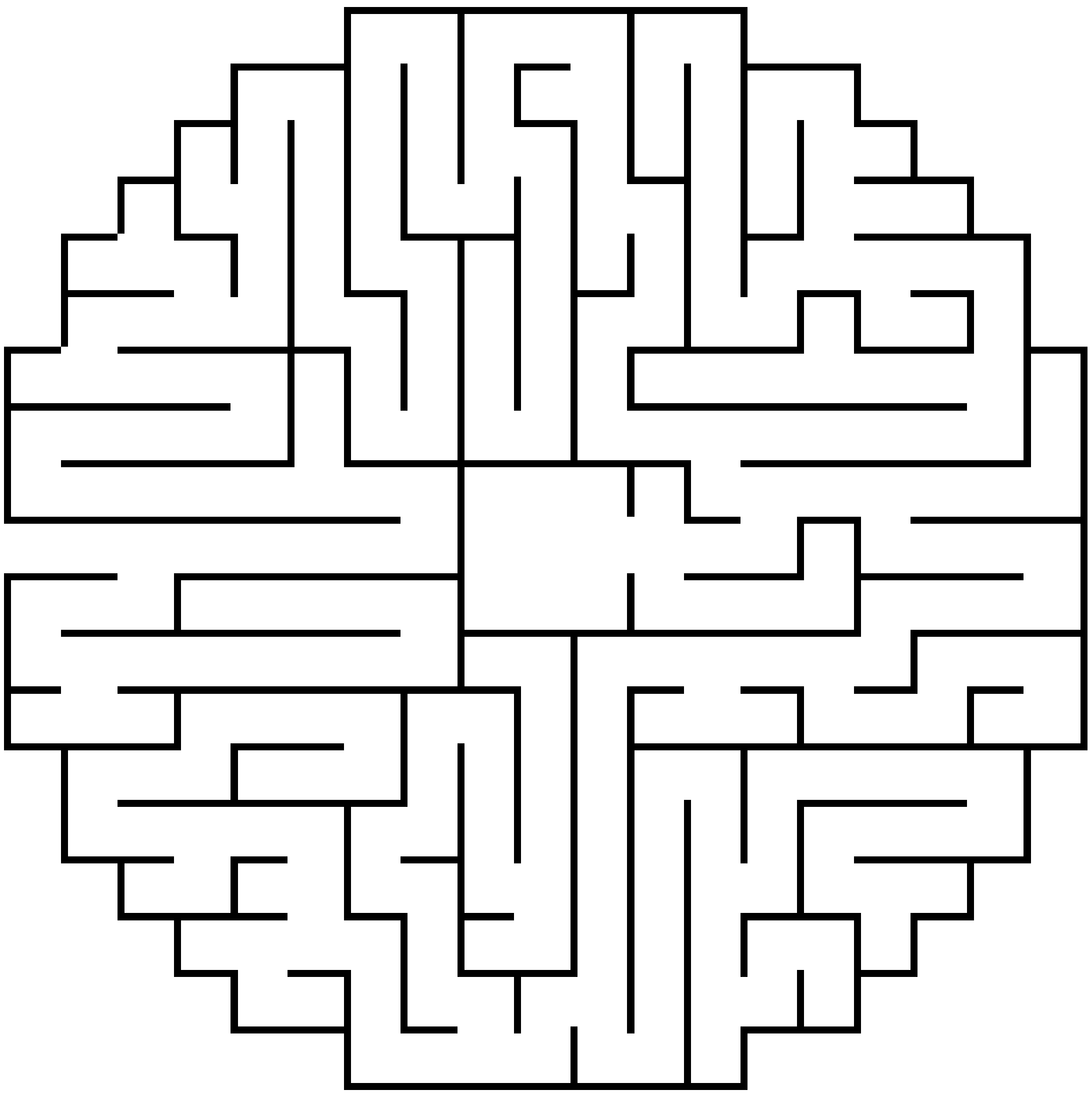
Cave Exploration!



Name: ______________________________

Can you find your way to the middle of the cave? What do you see? Draw a picture of a cave animal in the center of the cave!

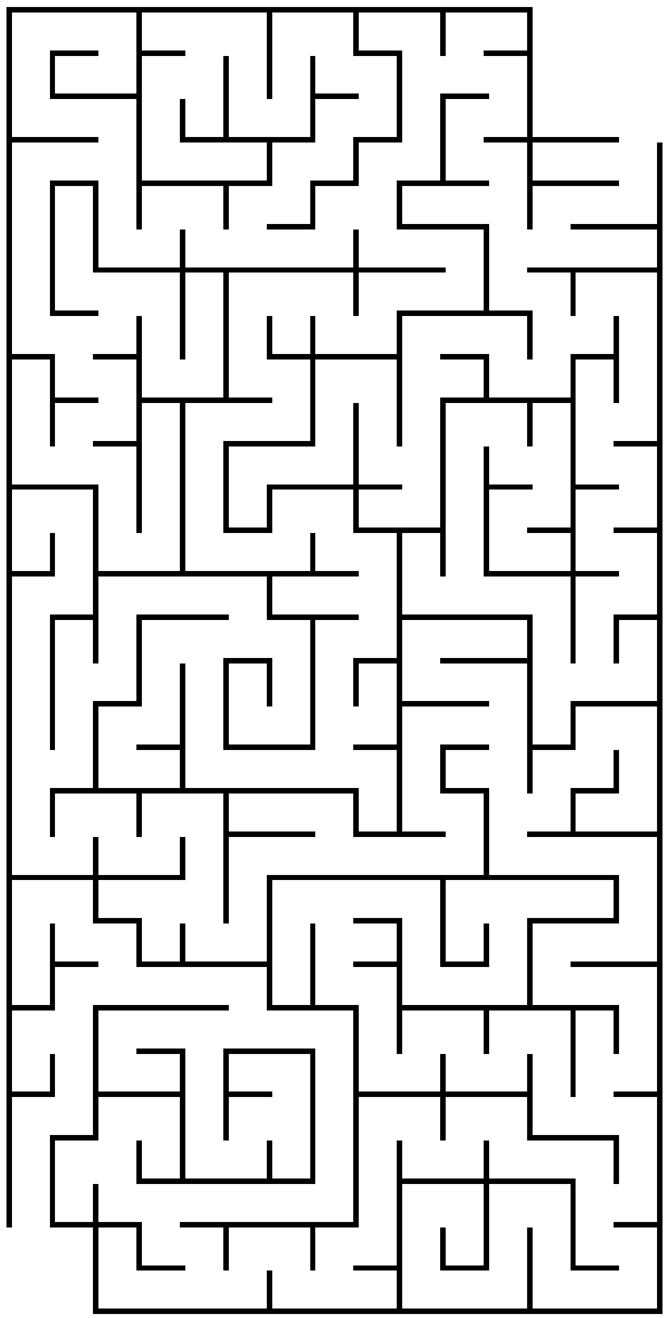
Cave Exploration!



Name: ______________________________

Some caves have more than one entrance. Find your way from one side of the cave to the other!

Cave Exploration!



Cave Ecosystem Dynamics

Objectives

- Students will be able to explain the three main ecological zones of cave habitats.
- Students will be able to explain the three main zones of a cave associated with hydrology.
- Students will be able to organize animals by their cave classifications.
- Students will attain an understanding regarding the flow of energy through a cave ecosystem.

Next Generation Science Standards

- K-LS1-1. Use observations to describe patterns of what plants and animals (including humans) need to survive.
- K-ESS2-2. Construct an argument supported by evidence for how plants and animals (including humans) can change the environment to meet their needs.
- K-ESS3-1. Use a model to represent the relationship between the needs of different plants or animals (including humans) and the places they live.
- 1-LS1-1. Use materials to design a solution to a human problem by mimicking how plants and/or animals use their external parts to help them survive, grow, and meet their needs.
- 2-LS2-1. Plan and conduct an investigation to determine if plants need sunlight and water to grow.
- 2-LS4-1. Make observations of plants and animals to compare the diversity of life in different habitats.
- 3-LS3-2. Use evidence to support the explanation that traits can be influenced by the environment.
- 3-LS4-3. Construct an argument with evidence that in a particular habitat some organisms can survive well, some survive less well, and some cannot survive at all.
- 5-LS2-1. Develop a model to describe the movement of matter among plants, animals, decomposers, and the environment.

Information Sheets

- Caves as Habitats
- Cave Animal Classification
- Flow of Energy

Activities

- Classroom Cave
- Cave Flipchart
- Cave Art
- Energy Flow

Handouts

- Cave Food Web Wordlist. This list is just a sampling of the diversity of organisms that can be found in a cave. You and your students are welcome to add to this list as you work through the activities in this module.
- Cave critter images. We suggest printing these images in color and laminating the images. These images can be used for many of the activities in this module.

Activity One - Classroom Cave

Materials: *Classroom with windows, organism images (cutouts, free drawn images).*

For this activity, students will learn about the cave habitat through exploration of the different ecological zones of a cave established in a classroom setting. In order to complete this activity, teachers will need access to a classroom or hallway with windows, it would be ideal that this location can have some area where no sunlight will reach, if shades are closed. Turn off all the lights and ask students to define the ecological zones of the classroom based on the three main cave ecological zones (entrance, transitional, and dark zone). Ask students to articulate what defined these three zones, specifically based on the amount of light that delineates the zones.

Once students have an understanding of the three main ecological zones in a cave, numerous extensions can take place to understand ecosystem dynamics of the cave landscape. Students can be given cut-outs of various organisms or free draw organisms that are found inside caves. Ask students to put their organism into the appropriate zone. For instance, a cave-obligate organism would be placed in the classroom dark zone and plants would be placed in the entrance zone.

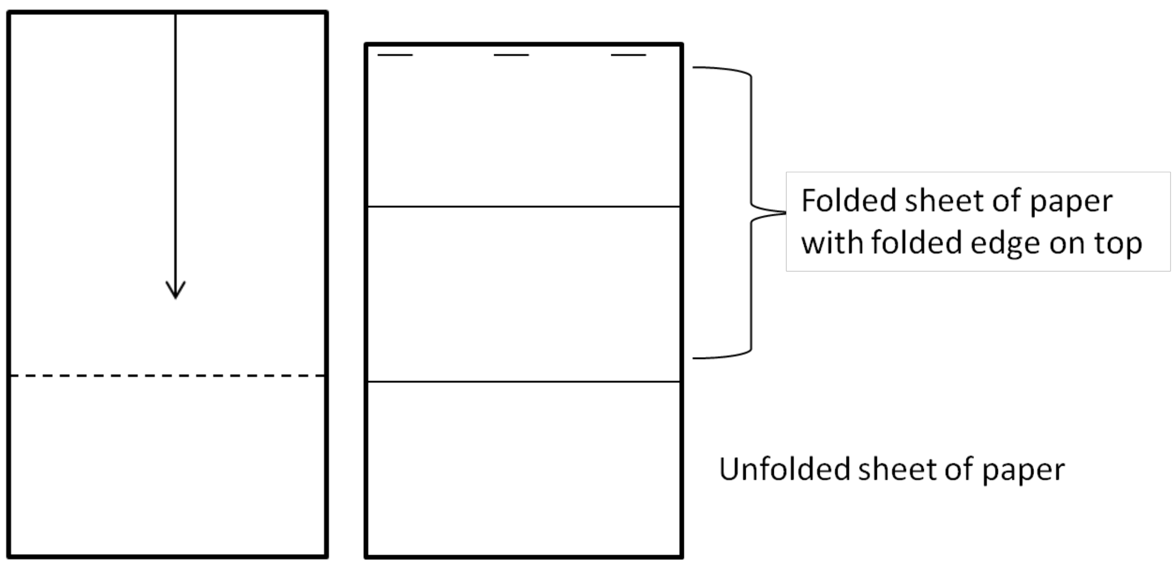
The placement of the various organisms can be used to prompt follow-up questions as to the classification of the organisms and the survival necessities for organisms. For instance, students can be asked to consider where plants are most likely to be found in a cave habitat. This can lead to inquiry based experimentation about plant survival, for example. Do plants need sunlight for survival? Likewise, exploration of temperature can take place. Can plants tolerate variations in temperature? Would plants be able to survive in ambient cave temperature (typically 12-14^{o}C)? What are the impacts of these and other abiotic factors on plant growth and development?

Activity Two - Classroom Flipchart

Materials: *Paper, art supplies, stapler.*

This flipchart activity can be used in interactive science notebooks or it can be used as a standalone activity. This activity can be teacher or student centered. In a teacher-centered activity, the teacher can lead a class discussion of the cave zones. Students can take notes and then complete their flipcharts. Alternatively, in a student-centered activity, students can be given a reading assignment and self-identify key descriptions of each zone.

The base of the flipchart is put together by stacking the three full sheets of paper. Fold the top of one sheet of paper approximately 2/3 of the way down the page to create a small flap. Then place this folded sheet on top of the two unfolded sheets of paper with the folded side flush with the top. Now, use three staples to secure the layers along the top edge. You now have a flip chart with three layers and a sheet below for writing. Alternatively, if you do not want to include writing space below each zone for notes/descriptions, then two sheets can be used and the bottom writing sheet can be left off. See diagram below for visualization.



This flipchart can be used either horizontally or vertically to draw different cave zones. With horizontal use, students can draw the entrance, twilight, and dark zones associated with ecological delineations. In this way, it would appear as if they are crawling into a cave. With vertical use, students can draw the epikarst, vadose (unsaturated zone), and phreatic (water table) zones associated with karst hydrology. In this orientation, it would appear as if students are descending from the surface toward the groundwater table. Students can make two flipcharts to compare the two cave dimensions (horizontal and vertical orientations), and both orientations represent the different dynamic principles of cave ecology and cave formation.

On the top of each layer, students should draw something that visualizes each zone. This visual can be a composite of what the entire zone would look like or it can simply be a representative organism or structure (Figure 1).

Then, students should flip up the layer and provide a written description of each zone (if the writing sheet was included). Students can write a descriptive paragraph, key words, or single sentences that describe the different zones. Discussion can be fostered throughout the activity by having students brainstorm together and peer critique the flip charts. Students should provide only constructive criticisms. Some examples should be provided to guide the students in constructive review procedures that also reveal correct technical information.

Alternatively, students can draw the zones on a single sheet of paper with boundaries outlined.

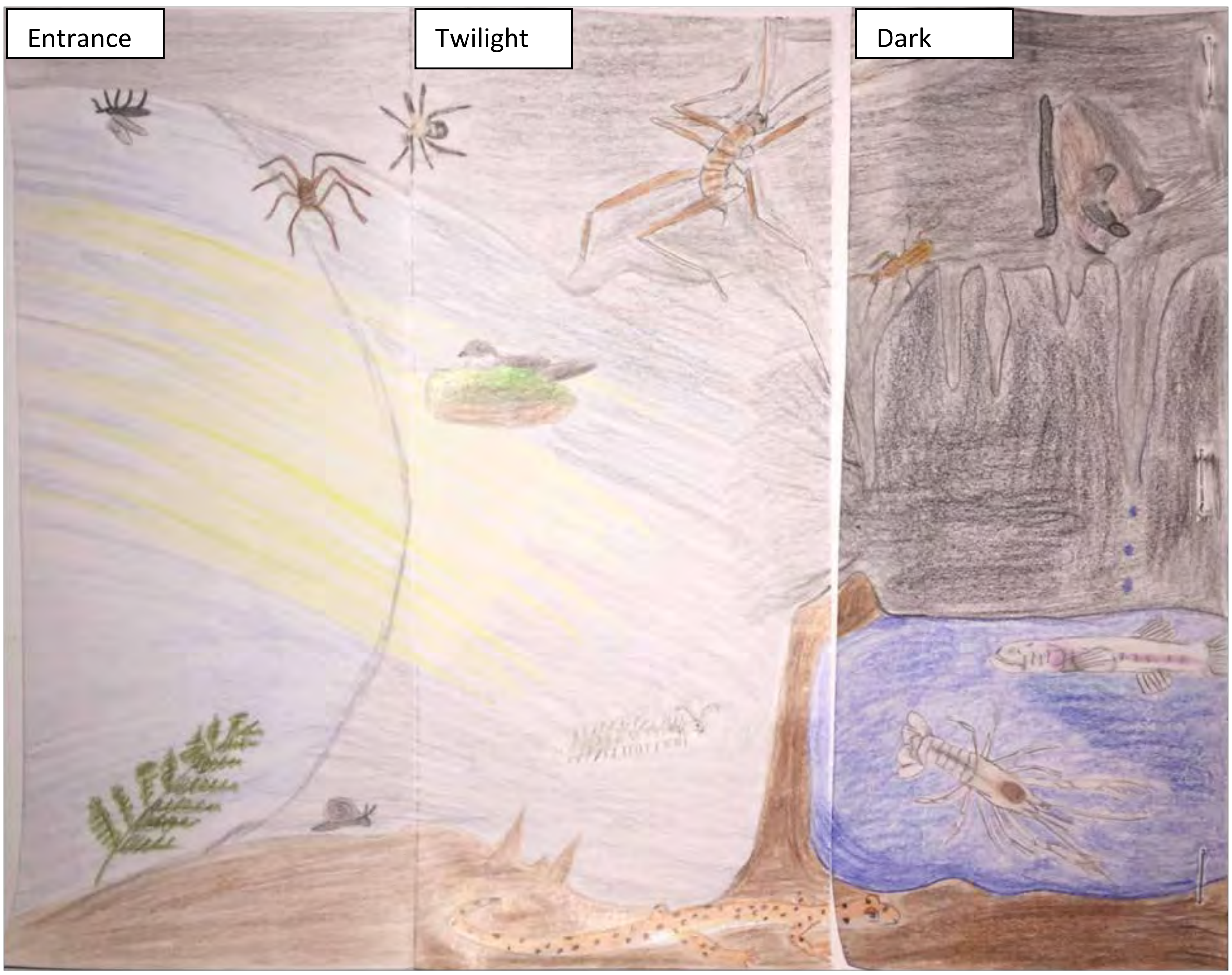


Figure 1. Example flipchart depicting entrance, twilight, and dark zones associated with ecological delineations.

Activity Three - Cave Art

Materials: *Art supplies.*

Students can be asked to complete draw images or complete a 3-D diorama of the cave habitat. This activity is a great way to intertwine the visual arts with science education. After students have completed their artwork, they should be asked to explain the ecological zones depicted in their artwork.

Activity Four - Energy Flow

Materials: *Art supplies, word list.*

Just as in surface habitats, there is a food web present in cave habitats. This activity asks students to paste together a cave food web using images provided in this module or to free draw a cave food web. Additionally, a word list is provided that students can use to generate a food web without images.

Cave Food Web Word List

Create a food web that includes the following terms:

Amphipod
Bacteria
Bat
Beetle
Cavefish
Crayfish
Cricket
Flatworm
Fly
Frog
Guano
Harvestman
Isopod
Millipede
Organic Matter
Phoebe
Pseudoscorpion
Salamander
Sculpin
Snail
Spider
Springtail
Woodrat

Caves as Habitats

Most cave habitats can be divided into three main ecological zones. These zones are defined by their **abiotic** (chemical and physical) factors. The **entrance zone**, sometimes called the **light zone**, is the region between surface and subterranean habitats. The entrance or light zone is the area around the cave entrance where light penetrates the cave. This zone usually has great variation in abiotic factors, such as temperature and humidity. Further into the cave is the **transition zone**, also called the **twilight zone**. This zone connects the entrance zone to the dark zone. In the transition zone, we see decreasing light levels. The **dark zone** is the deepest of the main ecological zones and completely lacks light. In this area, cave temperature and humidity conditions are usually constant.

Cave Animal Classification

The distribution and abundance of organisms found in a cave depends on the temperature, humidity, and food supply from organic matter. Cave animals are classified by their ability to survive in cave environments. Some animals thrive in cave environments and are able to live there for most or all of their lives. Sometimes, animals are found in caves that have been accidentally washed in by heavy rains, or perhaps they wandered in a cave on their own to seek shelter. Some animals can complete their entire life stages in a cave, while others are unable to do so.

Trogloxenes are animal that must return to surface habitats at some point in their life cycle. They are most often found in the entrance and transition zones of caves. For example, cave-roosting bats are trogloxenes because they may use caves for shelter, but must come to the surface to feed. Permanent cave residents can be found in all ecological zones of the cave. Organisms that are able to spend their entire lives in caves, but can also be found in surface habitats, are called **troglophiles**. Examples of troglophiles include the Cave Salamander and Cavespring Crayfish. There are two names for organisms that must spend their entire lives in a cave habitat. These organisms are called **cave-obligate**. The terrestrial species (such as the Cave Harvestman) are **troglobionts** and the aquatic species (such as the Southern Cavefish) are **stygobionts**. Both troglobionts and stygobionts are only found in the dark zone and have evolved characteristics that are associated with life in constant darkness. For example, they have increased ability of non-visual senses and are generally white or transparent due to lacking pigmentation.

Southeastern Bats (left) and a Tennessee Cave Salamander (right).

Flow of Energy

Energy flows through ecosystems from the habitat, from abiotic conditions and chemicals to organisms and from organism to organism. On the surface, most food webs start with sunlight and green plants that use sunlight to make food. But, in caves, there are very few plants because it is dark and photosynthesis is not possible. This is why most plants are found in the entrance zone and a few can also grow in the twilight zone depending on light penetration levels. No plants can grow in the dark zone of a cave.

So, if no sunlight and no green plants are found in the dark zone, then how do do so many different types of cave organisms survive living in the dark zone? Organisms in the dark zone depend on organic material washed into the subsurface by water and wind during storms. Also, organic material can be carried into the caves by animals or left by animals as waste.

Most cave organisms are decomposers. **Decomposers** break down and feed on organic material (like decaying animals or plant material) or they feed on guano (like bat scat). Cave decomposers include fungi and microbes. Higher in the food web, we see millipedes and little crustaceans that feed on the decomposers. **Predators** include cave spiders, centipedes, salamanders, and cavefish.

Less energy is available for each higher step up in the food web. So, in caves, we see more decomposers than we see predators.

Cave Salamander (top left), cave cricket (top right), spring amphipod (bottom left), and annelid worm (bottom right).

Rafinesque's Big-Eared Bat (top left), a cave amphipod (top right), Big Brown Bat (bottom left), and an aquatic annelid worm (bottom right).

A cave carabid beetle (top left), Prickly Cave Crayfish (top right), cave fungus beetle (bottom left), and Barr's Cave Crayfish (bottom right).

A cave cricket (top left), Southern Cavefish (top right), Spring Cavefish (bottom left), and a cave flatworm (bottom right).

A cave flatworm (top left and right), Pickerel Frog (bottom left), and a harvestman (bottom right).

A cave harvestman (top left and right), a troglophilic terrestrial isopod (bottom left), and a cave terrestrial isopod (bottom right).

A cave isopod (top left), Greenhouse Millipede (top right), Barr's Cave Millipede (bottom left), and a cave millipede (bottom right).

A snout-nosed moth (top and bottom left), Herald Moth (top right), and a Southeastern Cave Pseudoscorpion (bottom right).

A Long-tailed Salamander (top left), Cave Salamander (top right), Tennessee Cave Salamander (bottom left), and Grotto Salamander from Oklahoma (bottom right).

Variation in pigmentation in an aquatic snail from the same cave stream population.

A nesticid cave spider (top left), a cave spider (top right), Cave Orb Weaver (bottom left), and Subterranean Sheet-web Spider (bottom right).

Various species of surface (top left) and cave (top right and bottom left) springtails and a Green Salamander (bottom right).

Evolution

Objective

- Students will gain an understanding of evolution through the use of cave-obligate organisms as examples.

Next Generation Science Standards

- K-LS1-1. Use observations to describe patterns of what plants and animals (including humans) need to survive.
- K-ESS2-2. Construct an argument supported by evidence for how plants and animals (including humans) can change the environment to meet their needs.
- K-ESS3-1. Use a model to represent the relationship between the needs of different plants or animals (including humans) and the places they live.
- 1-LS1-1. Use materials to design a solution to a human problem by mimicking how plants and/or animals use their external parts to help them survive, grow, and meet their needs.
- 1-PS4-4. Use tools and materials to design and build a device that uses light or sound to solve the problem of communicating over a distance.
- 2-LS4-1. Make observations of plants and animals to compare the diversity of life in different habitats.
- 3-LS3-2. Use evidence to support the explanation that traits can be influenced by the environment.
- 3-LS4-3. Construct an argument with evidence that in a particular habitat some organisms can survive well, some survive less well, and some cannot survive at all.
- 3-LS4-4. Make a claim about the merit of a solution to a problem caused when the environment changes and the types of plants and animals that live there may change.
- 4-LS1-2. Use a model to describe that animals receive different types of information through their senses, process the information in their brain, and respond to the information in different ways.

Information Sheets

- Cave Adaptations

Activity

- No Sight

Handouts

- Cave Organism Evolution

Activity - No Sight

Materials: *Classroom or fenced in outdoor area, soft obstacles, blindfolds, swimming noodles.*

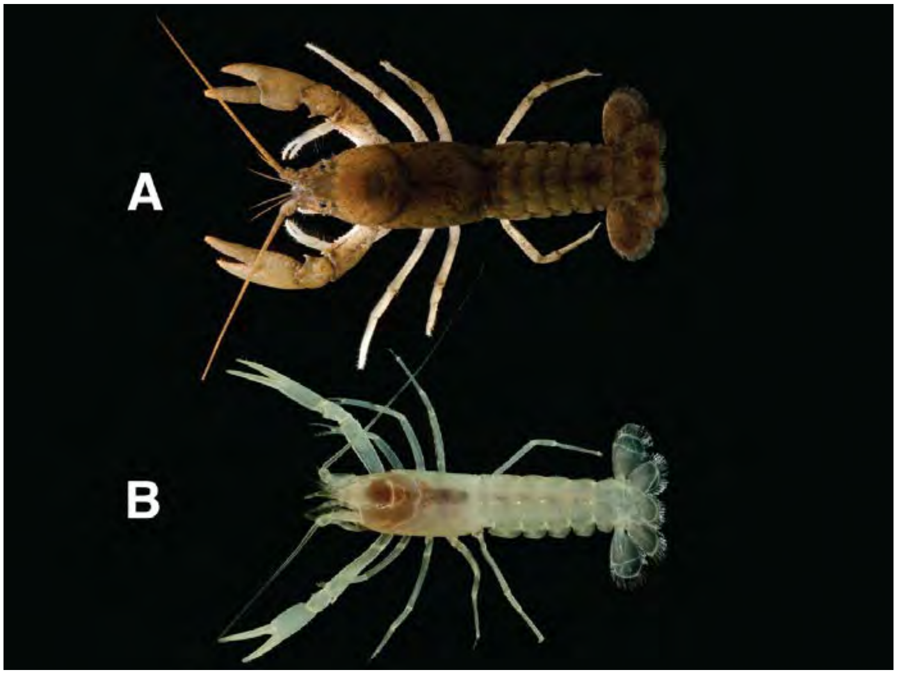
This activity should take place in an enclosed environment with a few scattered obstacles (it would be ideal if these are padded so students do not injure themselves if they bump into one). Students should be blindfolded to mimic degeneration of eyes. Students should be asked to find their way around the area without running into any of the obstacles or other students. Students can then be asked about how they found their way around while avoiding others, what cues did they use (e.g., noise, feeling)? How might the elongation of appendages seen in some cave organisms relate to what students experienced? Students can experience elongated appendages (e.g., holding swimming noodles in their hands to mimic elongated hands) to find their way around. How did this experience compare to the previous experience?

Extensions of this activity can include assigning students to being predators/prey and telling students that predators should seek out their prey while prey should do their best to avoid predators. Ask students if they can think of some other ways that cave organisms can locate their prey? Some cave organisms depend on vibrations. Take a cup of water and drop a penny into it, what happens to the surface? Do you see the ripples coming away from the point of entry?

Cave Adaptations

Cave organisms are adapted to their environment. **Adaptations** help an organism to obtain nutrients, enable an organism to survive in physical conditions of the environment (temperature, light, humidity), defend themselves, and to reproduce.

Evolution in cave organism is dominated by the loss of structures. **Evolution** results in the change or changes in inherited characteristics from one generation to another. Evolution occurs because genetic changes are passed from parent to offspring and through generations. For example, many cave organisms lose their skin color, referred to as a degeneration of pigmentation. We see this in the blind Mexican cavefish. The ancestors of the Mexican cavefish come from surface environments. Both the cavefish and surface ancestor are still classified as the same species because they still are able to breed with each other, but they are in the process of divergence. **Divergence** means the formation of a new species. The loss of pigmentation in the Mexican cavefish was not instantaneous and it took thousands to tens and hundreds of thousands of years. Scientists have found intermediate species that stillvhave varying amounts of pigmentation. We see the loss or degeneration of pigmentation (coloration) and eyes in many cave organisms. For most of the organisms, we do not see intermediates between the surface and subsurface. Research is on-going to determine the ancestors for these organisms.



Differences in morphology between related surface and cave crayfishes: Cavespring Crayfish (top) and Tennessee Cave Crayfish (bottom). Photographs by Dante B. Fenolio.

Name: ___________________________

Cave Organism Evolution

1. Why do you think we see changes and differences in the ways that cave organisms look?

2. How can cave animals find their way around the cave environment? How do they find food? How do they avoid predation?

3. Remember your five senses? Sight, touch, taste, hear, and smell. If you are not able to see, then what other senses do you think would help you find your way around? How would you find food?

4. Many cave organisms have longer limbs than surface organisms? How might this help them in the darkness of a cave?

Cave Water Cycle

Objective

- Students will learn about the flow of water through the cave ecosystem.

Next Generation Science Standards

- K-LS1-1. Use observations to describe patterns of what plants and animals (including humans) need to survive.
- K-ESS3-1. Use a model to represent the relationship between the needs of different plants or animals (including humans) and the places they live.
- K-ESS3-3. Communicate solutions that will reduce the impact of humans on the land, water, air, and/or other living things in the local environment.
- 2-ESS2-3. Obtain information to identify where water is found on Earth and that it can be solid or liquid.
- 5-ESS2-2. Describe and graph the amounts and percentages of water and fresh water in various reservoirs to provide evidence about the distribution of water on Earth.

Information Sheets

- Water Cycles

Activities

- Phases
- Complete the Cycle
- Contaminated

Handouts

- Root beer float

Activity One - Phases

Materials: *Cups, ice, sunlight or warm setting, boiling water, cold dish. Optional: root beer, cups, ice cream, straws.*

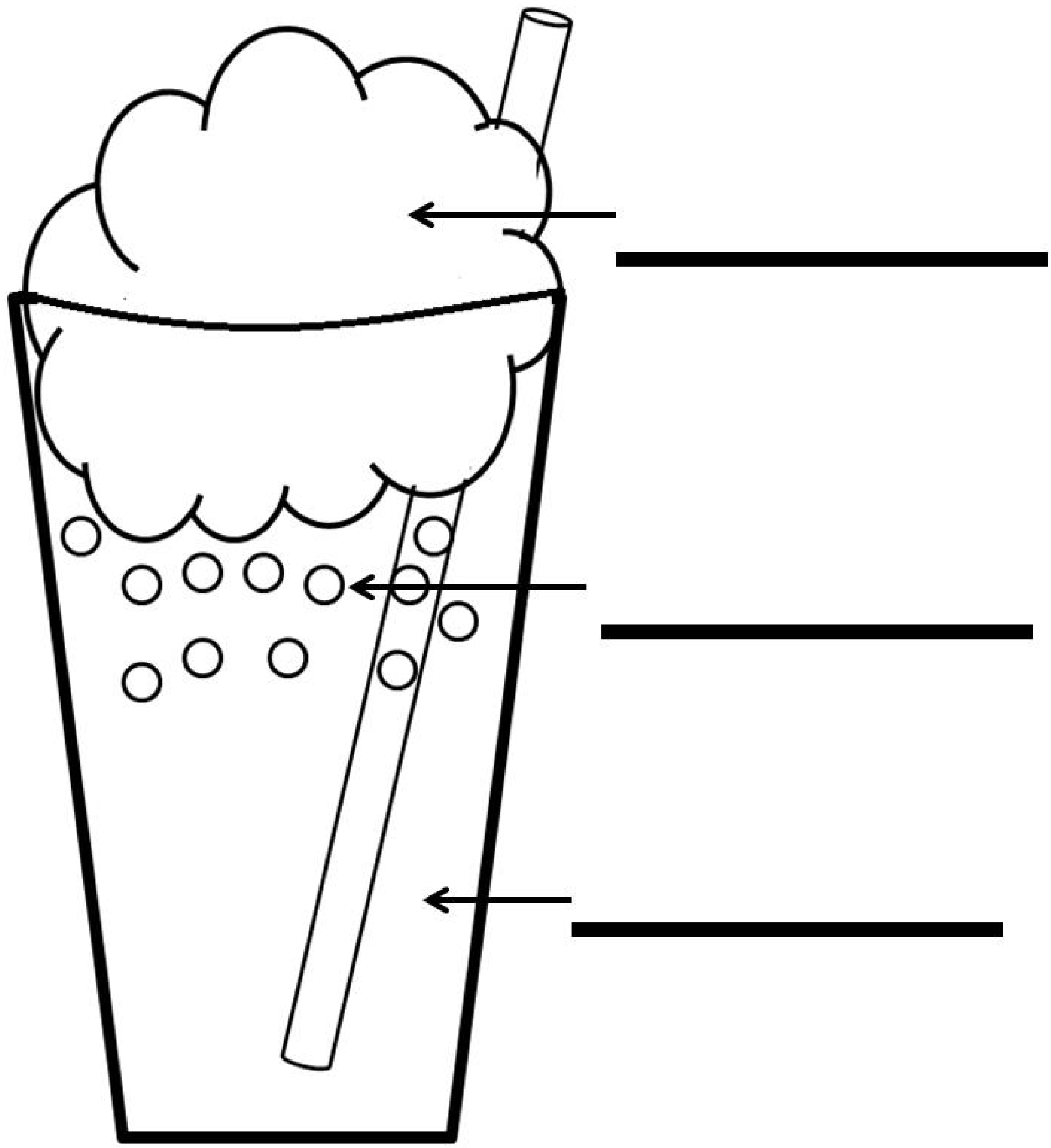
Introduce students to the chemical phases of water. Start the discussion by asking students what happens to the ice in their drinks. After engaging students in discussion, give each student an ice cube in a small cup and ask what they think will happen to it. Place the cup in a warm place (e.g., outside). Allow students to watch the ice melt. Ask them about the change in phases, and encourage them to use the proper terminology (solid to liquid). Then, allow the cups to remain sitting until all the liquid has evaporated and ask students what happened to the water. Discuss the chemical phase of a gas. Have students speculate what happens to the gas, can it return to a liquid or solid phase - how would this happen? Demonstrate to students how gas can change into a liquid drop of water (e.g., boil water until students see steam rise then place a cold dish above the steam and watch condensation form).

Lesson extension: Show students these three chemical phases in a different form. Make a root beer float! Ask students to tell you what they think is the liquid, solid, and gas components in the demonstration. The root beer serves as the liquid, the ice cream as a solid, and the bubbles formed when the ice cream is dropped into the root beer (or when the root beer is poured over the ice cream) are an exemplification of gas. Have students draw images of what they see and label the phases. Enjoy!

Name: _______________________________

Color the image. Label the liquid, solid, and gas.

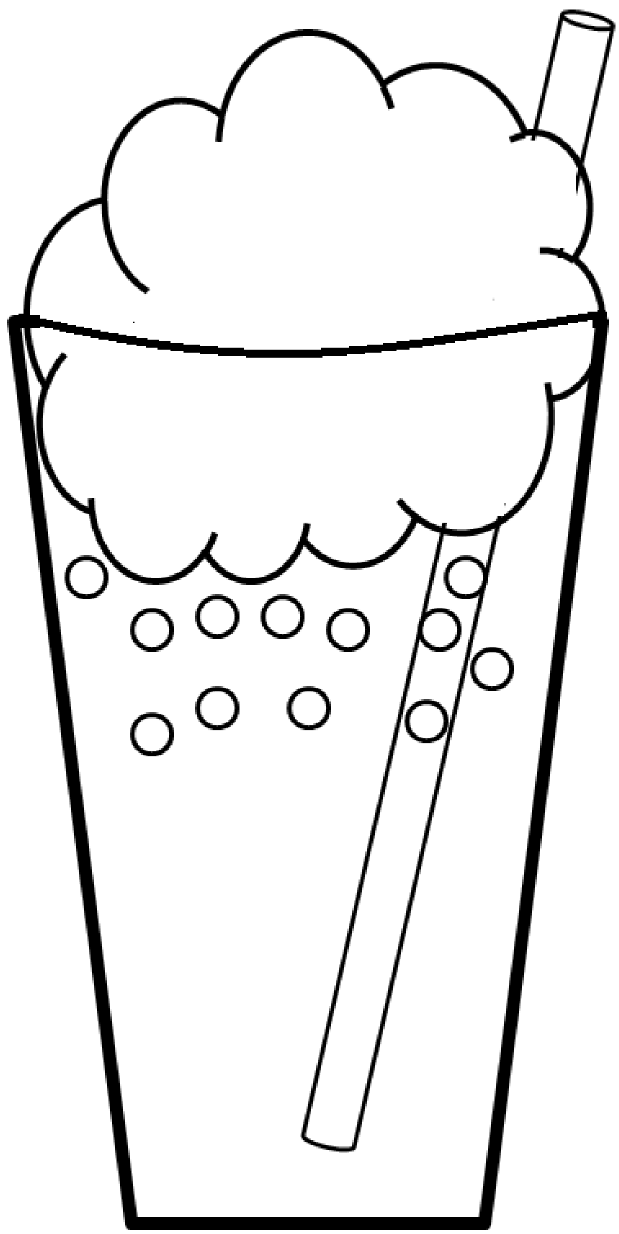
Root Beer Float!



Name: ______________________________

Color the image. Label the liquid, solid, and gas.

Root Beer Float!



Activity Two - Complete the Cycle

Materials: *Art supplies.*

Draw and label an image of the water cycle that includes cave habitats. Be sure to include groundwater.

Activity Three - Contaminated

Materials: *Soda bottle, ring stand, cheese cloth (or coffee filter), rubber bands, variety of rocks and soil types, bowls, and colored water.*

As water enters subterranean aquifers, it is filtered through a variety of rock types. In this activity, students will explore how water can be cleaned as it flows from the surface into subterranean systems and then when water returns to the atmosphere.

Prior to setting up this activity, cut off the bottom of each soda bottle. Attach the soda bottle upside down onto the ring stand (alternatively, prop the soda bottle upside-down). Remove the cap from the soda bottle and use a rubber band to attach cheese cloth (or coffee filter) over the opening. Then, allow students to fill the soda bottle with their choosing of rocks and soil types into the cutout bottom. Make sure a bowl is placed underneath the soda bottle, and then have students pour the colored water into the soda bottle from the cutout bottom. Students should compare the intensity of the color in the water in the bowl to what was initially poured into the bottle.

Comments:

1. This activity works best with 2-liter bottles.
2. Students can compare different rock and soil combinations to explore if certain substrates filter better than others.
3. This activity can be expanded by having students pour other substances into their soda bottle filters (e.g., coffee, car wash detergent, oil, etc).

Water Cycles

Did you know that over 94% of Earth's unfrozen freshwater can be found below the surface? Water moves, or cycles, around and throughout the Earth. The water cycle is often shown as just occurring in surface landscapes, but below ground areas also play a role in water cycling.

Water can seep into underground environments through gravitational forces. **Gravity** is the force that pulls objects downward. As water seeps downward into underground environments, much of the water is also filtered through soil and rock particles. The amount of time water spends underground depends on the solid composition of the particular area, such as the soil and rock types. Sometimes, water remains underground for long periods of times, but other times it may come to a cave. Some caves have flowing streams and the water only remains for a few hours or days before it resurfaces. Other caves do not have flowing streams so the water takes much longer to resurface.

Water takes on three chemical phases as it goes through the water cycle: liquid (water), solid (ice), and gas (vapor). Think about what happens when an ice cube melts. It changes from a solid (ice) to a liquid (water) and then it evaporates as a gas (vapor). Try it! As water changes chemical phases it goes through various physical processes including evaporation, condensation, precipitation, infiltration, run-off, and discharge.

Resources

Adult Books

Culver, D.C., and T. Pipan. 2009. The Biology of Caves and Other Subterranean Habitats. Oxford University Press. 256 p.

Engel, A.S. 2015. Microbial Life of Cave Systems. DeGruyter Publishing House. 435 p.

Fenolio, D. 2016. Life in the Dark: Illuminating Biodiversity in the Shadowy Haunts of Planet Earth. Johns Hopkins University Press. 312 p.

Fong, D.W., M.L. Porter, and M.E. Slay. 2012. Cave Life of the Virginias: A Field Guide to Commonly Encountered Species. Biology Section of the National Speleological Society. 42 p.

Niemiller, M.L, K.S. Zigler, and D.B. Fenolio. 2013. Cave Life of TAG: A Guide to Commonly Encountered Species in Tennessee, Alabama and Georgia. Biology Section of the National Speleological Society. 45 p.

Palmer, A. 2007. Cave Geology. Cave Books. 454 p.

Romero, A. 2009. Cave Biology: Life in Darkness. Cambridge University Press. 306 p.

Slay, M.E., M.L. Niemiller, M. Sutton, and S.J. Taylor. 2016. Cave Life of the Ozarks: A Guide to Commonly Encountered Species in Arkansas, Missouri, and Oklahoma. Biology Section of the National Speleological Society. 45 p.

White, W.B., and D.C. Culver. 2012. Encyclopedia of Caves, 2nd edition. Academic Press. 966 p.

Children Books

A selection of children books that can be used to support activities. Grade suggestions are based on publisher reported reading level.

- Caves (Nature in Action) by Stephen Kramer, 1995. (Grades 3-5)
- Caves and Caverns by Gail Gibbons, 1996. (Grades 1-5)
- Cave Animals (Animals in Their Habitats) by Francine Galko, 2002. (Grades 1-5)
- Cave (Landforms) by Cassie Mayer, 2006. (K-5)
- Caves: Mysteries Beneath Our Feet (Earth Works) by David L. Harrison and Cheryl Nathan, 2001. (Grades 1-3)
- Caves (Natural Wonders) by Kimberly M. Hutmacher, Kelly Garvin, and Gail Saunders-Smith, 2010. (K-5)
- Cave: Look Inside by Richard Spilsbury, 2013. (Grades 1-3)
- Caves (Early Bird Earth Science) by Sally M. Walker, 2007. (Grades 2-5)
- Exploring Caves: Journeys into the Earth by Nancy Holler Aulenbah, 2001. (Grades 3-5)
- Home in the Cave by Janet Halfmann and Shennen Bersani, 2012. (K-5)

TAG Cave Organizations

National Speleological Society (http://www.caves.org)
Tennessee Cave Survey (http://www.subworks.com/tcs/)
Alabama Cave Survey (http://www.alabamacavesurvey.org/main/index.php)
Georgia Speleological Survey (http://caves.org/survey/gss/GSSWebsite/Home.html)
Southeastern Cave Conservancy (http://www.scci.org)
Birmingham Grotto (http://www.bhamgrotto.org/)
Chattanooga Grotto (http://www.chattanoogagrotto.org/)
East Tennessee Grotto (http://caves.org/grotto/etg/)
Gadsden Grotto (http://caves.org/grotto/gadsdengrotto/index.html)
Huntsville Grotto (http://caves.org/grotto/huntsville/)
Montgomery Grotto (http://caves.org/grotto/montgomery/)
Nashville Grotto (http://www.nashvillegrotto.org/)
Sewanee Mountain Grotto (http://caves.org/grotto/sewaneemountaingrotto/)
Six Ridges Grotto (http://www.sixridgesgrotto.com/)
Smoky Mountain Grotto (http://smgrotto.wix.com/smg-webpage)
Spencer Mountain Grotto (http://caves.org/grotto/spencer/)
Upper Cumberland Grotto (https://www.facebook.com/ucgrotto)

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