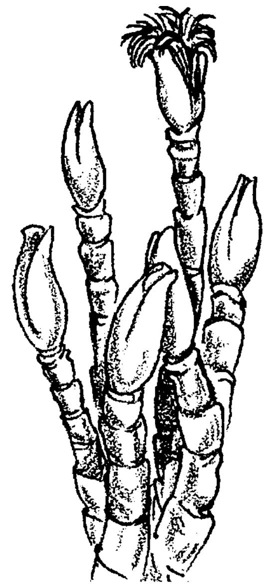
Cycling in the Hydrothermal Vents

Key Concepts

1. While the primary producers in sunlit areas of the ocean are green plants, the primary producers in hydrothermal vent communities are chemosynthetic bacteria.
2. A complex community of living things survives at hydrothermal vents without sunlight.
3. Energy flows through and matter cycles within the food structure of the hydrothermal vent community which is similar to other oceanic and terrestrial food webs.



Background

Scientific study of mid-ocean rifts, ridges, and hydrothermal vents has a relatively brief history. It was only in 1977 that a crew of two scientists and a pilot aboard the submersible *Alvin* were able to observe the vents directly. The crew made observations that shocked the scientific world: large, complex communities of never-before-seen animals living in a world of total darkness far removed from surface food sources.

The crew observed mineral laden hot water with temperatures of near 17°C, compared to 2°C for the surrounding seawater, issuing from the vents. Rocks near the vents were coated with chemical deposits rich in metals precipitated out of the vent waters. Scientists wondered from just where the water issuing from the vents came.

We now know that along the deep sea spreading centers where tectonic plates are moving away from each other, sea water seeps deep into cracks in the crust and down to the mantle, as far as 10-12 km. There, the water is superheated, perhaps as high as 1000°C. As the water is heated, it dissolves particles in the crust, mostly sulfides. The water eventually returns to the ocean floor through a restricted area called a vent or through diffuse, widely distributed seeps. The sulfides are carried back to the ocean with the rising water.

The water escaping through the vents is very hot. In fact, when the *Alvin* attempted to make initial temperature readings, the PVC housing for the thermistor melted when it came in contact with the water. Temperatures of

350°C at the vent openings are not unusual. This is considerably higher than the average water temperature of 2-4°C normally found at these depths. The turbulent nature of these hot water plumes, however, means that the hot water quickly mixes with the surrounding cold seawater. Within a few centimeters of the 350°C jets, the water temperatures are virtually that of the ambient ocean.

In addition to the metallic sulfides, the water escaping through the vent chimneys is rich in hydrogen sulfide gas (H_2S). Hydrogen sulfide is poisonous to virtually every animal. In the vent community, however, it is the basic source of energy which supports all life.

The vents dot the tops of the spreading zones and are separated by great distances. Many empty vents have been found, surrounded by dead organisms. It is estimated that individual vents may be active for only 20-30 years.

Hydrothermal Vent Communities

Hydrothermal vents would appear to present a hostile environment for living things. Yet, even though flooded with poisonous hydrogen sulfide, in extremely hot waters, with no light and no apparent source of food, a community of organisms flourishes. In what should be a deep-sea desert, populated by occasional scavengers finding bits of detritus floating down from the distant surface, hydrothermal vent communities thrive.

Hydrothermal vent organisms cluster near the vent. Masses of mussels, large white clams and blood-red tube worms cling to the outside edges. Surfaces on which to attach are scarce and competition for a “foothold” is as intense as in the intertidal zone. Mats of bacteria cover the shells of sessile animals and any open space. Limpets and snails graze on the bacteria mats. Crabs scavenge and prey upon tube worms and snails. Plume bacteria float in the nutrient rich water flowing through the vent opening. Microscopic zooplankton feed on the plume bacteria. How does this community survive?

Chemosynthesis Instead of Photosynthesis

Perhaps we can get an idea by looking at communities with which we are familiar on the earth’s surface. When we trace the energy source for these food chains and food webs, we can start with the higher order carnivores which eat the plant-eating herbivores. The plant-eaters get their food from the plants. The plants make their own food by using energy from the sun in a process called photosynthesis.

In photosynthesis, a water molecule is split apart in the presence of chlorophyll and sunlight. The energy released during that process powers the photosynthetic reaction which combines atoms from water and carbon dioxide to form sugar, the plant’s food, and oxygen, the plant’s waste product.

This process of photosynthesis produces ample food for the plant to use as it grows and reproduces. Plant eating animals then consume the plant or plant parts, and utilize, for the animal's life processes, the food that the plant made for itself to carry out its own life processes. Higher order consumers then eat the plant-eater, utilizing it as food to carry out their own life processes. Once the animals die and decompose, the minerals are returned to the soil where they can be recycled by the decomposers and reused by another generation of plants.

This basic food chain works very well on the surface of the earth, and even in the ocean down to about 100 meters, about as far as sunlight can penetrate. But photosynthesis cannot occur unless there is light, and there is no sunlight at the depths of the hydrothermal vents. Yet, life flourishes there.

So what is the source of energy that supports the food chain at the hydrothermal vents? It seems that the bacteria that populate the vent communities have evolved to carry out a process called chemosynthesis. In vent communities, bacteria are the primary producers - organisms like green plants that produce the energy containing substances on which all other organisms depend.

Vent community bacteria absorb the hydrogen sulfide into their cells where their enzyme system breaks the H_2S into SO_{4-}. They use the energy released from this reaction to power a chemosynthetic reaction. In chemosynthesis, the hydrogen from H_2S combines with carbon dioxide to form sugar, the bacteria's food, and sulfates, the bacteria's waste product.

Both plants and bacteria use energy, hydrogen and CO_2 to make sugar. The main difference between photosynthesis and chemosynthesis is in were the energy comes from.

In chemosynthesis, energy is provided by splitting the hydrogen sulfide molecules which come from the vents in the ocean floor. Enzymes in the bacteria cause the reaction which releases the energy. The energy is used to combine the hydrogen from the H_2S with CO_2 to form sugar.

In photosynthesis, energy is provided by splitting the water molecules. The chlorophyll and sunlight cause the reaction which releases the energy. The energy is used to combine the hydrogen from the H_2O with CO_2 to make sugar.

Hydrothermal Vent Community Food Web

In hydrothermal vent communities, chemosynthetic bacteria produce the food that sustains all other members of the community. There are three types of chemosynthetic bacteria in the vent community: plume bacteria, mat-forming bacteria, and symbiotic bacteria. These chemosynthetic bacteria are the producers for the entire hydrothermal vent community

Plume bacteria live in the cloud of water rich in hydrogen sulfide (H_2S), which comes from the vents. Filter-feeding shrimp and other animals that swim along the plume, as well as microscopic zooplankton, consume the plume bacteria.

Mat-forming bacteria coat every surface of the vent area. Wherever H_2S occurs, mat-bacteria grow. Snails, shrimp, and worms graze on the white, rusty, and brown mats.

The third group of chemosynthetic bacteria are symbiotic bacteria which live in the tissues of the tube worms, white clams, and mussels. About 75% of all the chemosynthetic bacteria in the vent communities are symbiotic bacteria.

The remaining inhabitants of the vent community do not have endosymbiotic bacteria and must obtain food by consuming mat or plume bacteria, eating particulate matter, scavenging, or preying upon one another.

The discovery of a complex biological community that can withstand the extreme environmental conditions found in the deep sea vents and based on bacteria which utilize chemicals considered poisonous to “all” living things gives us cause to consider the possibility that life may be found in other places that were previously considered too hostile.

Materials

For each group of 3-4 students:

- Hydrothermal Vent Critter Card set
- art paper
- miscellaneous art supplies

For each student:

- “Cycling in the Hydrothermal Vents” activity sheet

Teaching Hints

In Part I of “Cycling in the Hydrothermal Vents”, students make a food web diagram of the hydrothermal vent community. In Part II, they use the food web diagram to show food energy pathways.

You may elect to have students work individually or in groups of 3-4.

In Part II, you may choose to distribute the two animal cards or to have students select the top two cards from a strategically placed pile of cards.

Key Words

chemosynthesis - the process some bacteria use to make their own food using the energy from chemical reactions

community - a group of living things and the habitat in which they live

consumer - an organism that eats other organisms or food particles to survive

decomposer - an organism that obtains nourishment by breaking down dead organic matter

food web - a diagram showing the relationships among the producers, consumers, and decomposers of a community

hydrothermal - water heated by close contact with magma

hydrothermal vent - opening in ocean floor through which very hot water enters the ocean water

photosynthesis - the process plants use to make their own food using sunlight

producer - an organism, such as a green plant or certain algae or bacteria that makes its own food by photosynthesis or chemosynthesis and which are commonly a source of food for other organisms

zooplankton - animal plankton; weakly swimming animals, usually microscopic, which flow with the currents

Extensions

1. Have students build 3-dimensional, scale models of the vent community organisms using paper mache or art dough. Once completed, they may wish to create a model of the vent on which to place the animals.

2. Students can plan an excursion to a hydrothermal vent. They should design a vehicle that could transport them to the hydrothermal vent and a “habitat” to sustain them during their visit.

Answer Key

Text Questions

1. The top order consumer in the pond is the kingfisher.

2. A correctly labeled food chain is shown below:

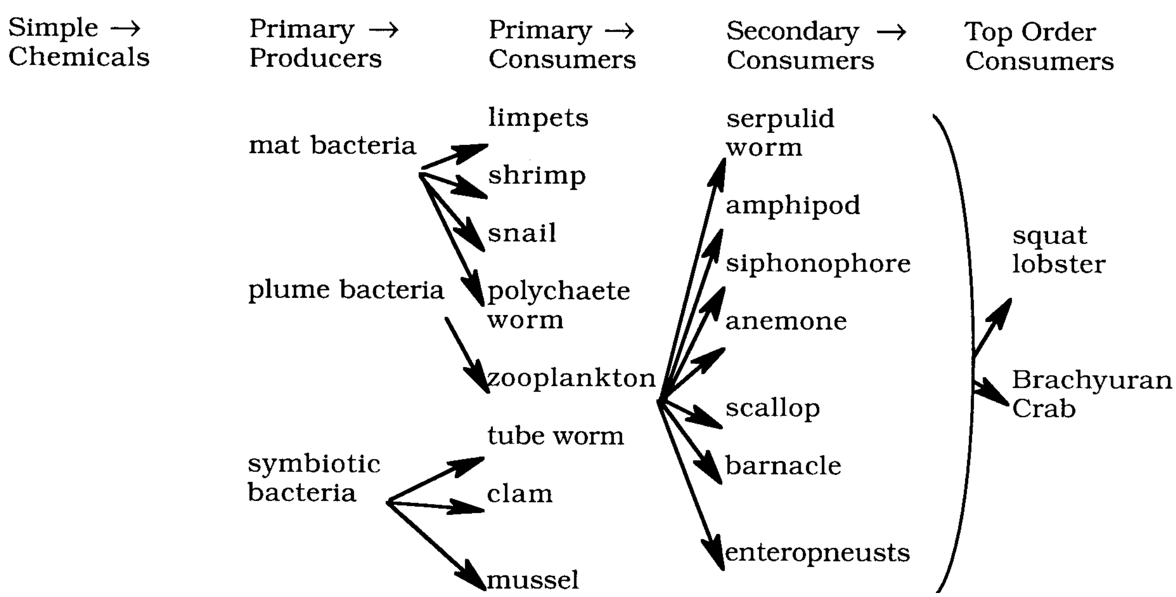
   simple chemicals + sunlight → pond weed → snail → perch → kingfisher

3. The arrow shows how matter and energy move along the food chain.

4. The energy for hydrothermal vent food chains comes from hydrogen sulfide. Vent community bacteria absorb the hydrogen sulfide into their cells where their enzyme system breaks the H_2S into SO_4^-. They use the energy released from this reaction to power a chemosynthetic reaction. In chemosynthesis, the hydrogen from H_2S combines with carbon dioxide to form sugar, the bacteria's food, and sulfates, the bacteria's waste product.

Part I

1. A correctly completed hydrothermal vent community food web is shown below:



2. Answers will vary. One possible food chain follows:

simple chemicals → plume bacteria → zooplankton → scallop → crab →

Analysis and Interpretation

Note: These questions are designed to be open-ended and encourage student thought and discussion. At this time, not even the experts know all the answers.

1 a. The bacteria is the first member of the community affected, since they need the hydrogen sulfide from the vents to carry out chemosynthesis. The tube worms, crab, and mussels, who depend entirely upon the bacteria for their food would probably die out next, with the rest of the food web collapsing quickly thereafter.

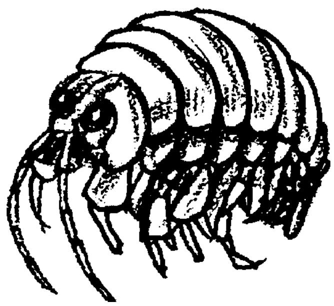
b. Answers, which are opinions, will vary. It is not known whether the animals in this community have a way to sense the location of a hydrothermal vent.

c. Answers, which are opinions, will vary. Even if the animals in the community could sense the location of a hydrothermal vent, many adults (e.g., tube worms and mussels) are attached while others (e.g. clams, scallops, and worms) can only travel limited distances.

d. The organisms might possibly get from one vent to another in their larval stage. The drifting animals could locate a vent and attach themselves.

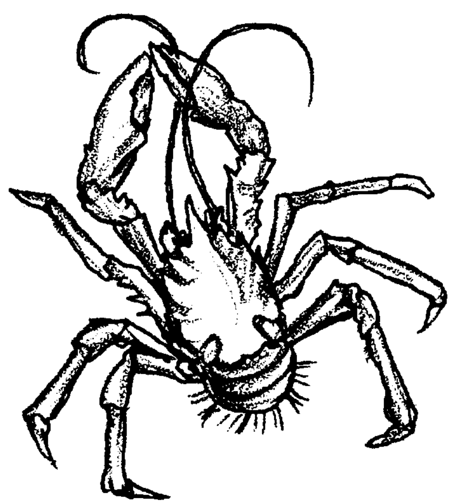
2. Shifting of the plates, movement of rocks deep within the crust may close off certain vents and open others.

3. The discovery of a complex biological community in the deep sea vents has given scientists cause to consider the possibility that organisms may be able to survive in habitats we once thought incapable of supporting life.

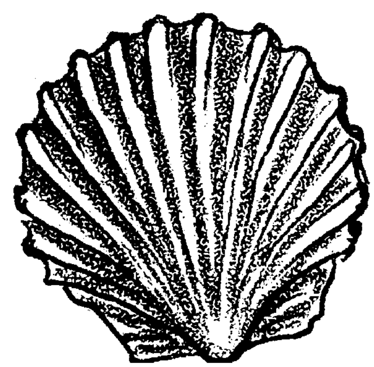


amphipod
Amphipods are related to crabs and shrimp. This one grows to about 5 mm in length. It is gray in color. It is found crawling around in the mats. It may feed on zooplankton.

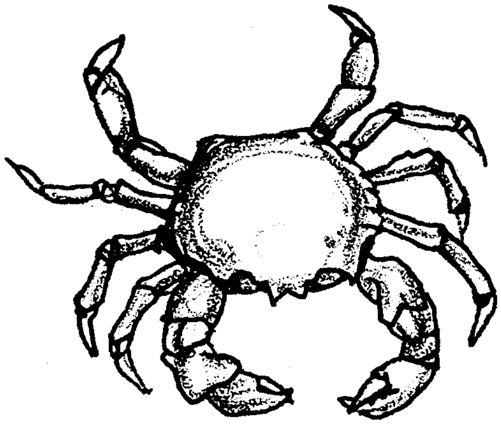
anemone
This white anemone lives on rocks at the edge of the hydrothermal vent community. This anemone is similar to those found in tidepools. It uses its tentacles to capture zooplankton.



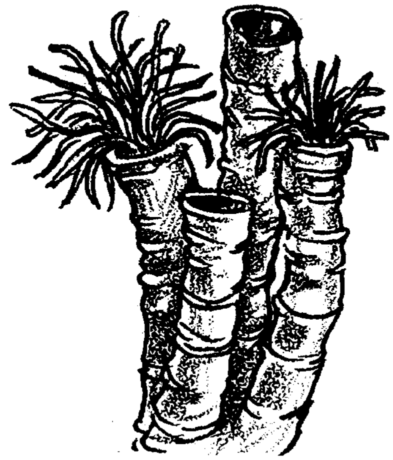
squat lobster
The squat lobster is really a crab. It grows up to 50 cm wide. It eats dead animals. It is found all over the vent community.



scallop
These scallops only grow to about 3 cm in length. They are found in many colors. They use their gills to filter particles of food floating in the water.

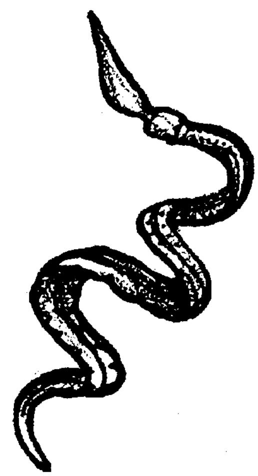


brachyuran crab
This crab is found all over the vent community. It eats whatever dead animals it can find. It may also eat tubeworms and other animals.
It grows to 20 cm wide.

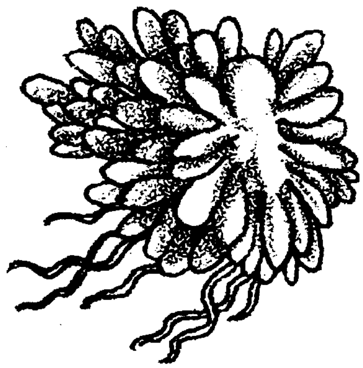


serpulid worms
Serpulid worms are tiny. They are only 5 mm long. These worms live in tubes on the rocks of active hydrothermal vents. They filter particles of food out of the water. These worms are whitish in color.

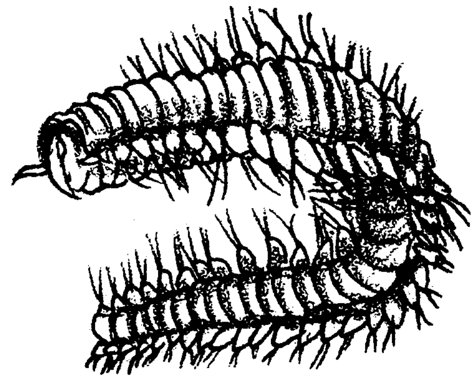
barnacles
These gray barnacles live on rocks at the edge of the vent community. They look like rocky shore barnacles. These barnacles are filter -feeders. They grow to about 2 cm in size.



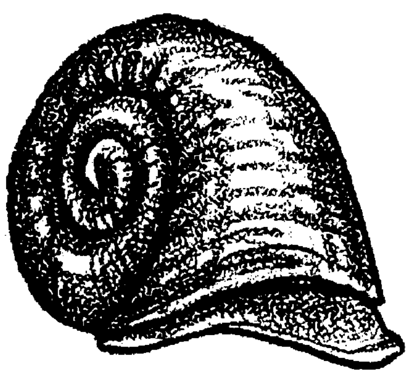
enteropneusts
Enteropneusts are also called spaghetti worms. They are thin and light-colored. They look just like spaghetti. They grow to 30 cm in length. A spaghetti worm will drape itself over rocks. Its head end drifts freely as it filter-feeds on zooplankton.



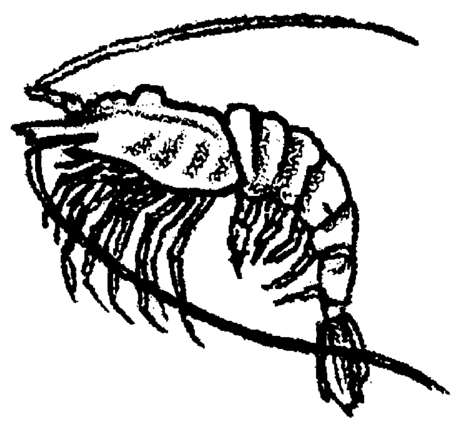
siphonophore
The siphonophore is related to the Portuguese man-of-war. It is actually a colony of many separate animals. it resembles a dandelion in its color, shape, and size. It can grow to 5 cm. A siphonophoreuses its tentacles to catch zooplankton.



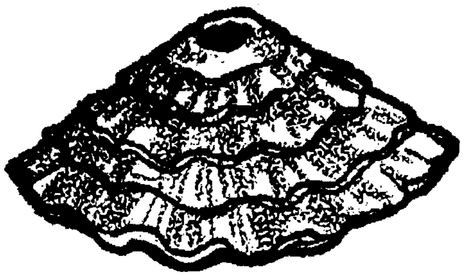
polychaete worm
Polychaete worms are tiny. They only grow to 2 mm in length. They are segmented. The segments have bristles on them. These red worms feed on mat bacteria.



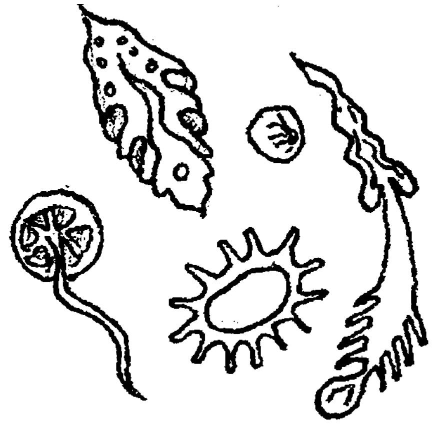
coiled snail
The coiled snail clings to the rocks near the vents. It eats mat forming bacteria which it scrapes from the rocks. It grows to about 2.5 cm. Coiled snails are found in many colors.



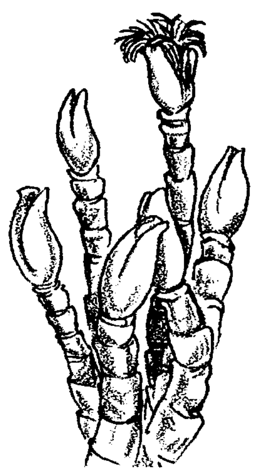
shrimp
These pink shrimp cluster around the vents. They feed mostly on mat-bacteria. They are 5 to 12 cm in length.



limpets
These limpets are very much like those found in tidepools. They grow to about 3 cm in diameter. They cling to the rocks near the vents. Limpets eat mat-forming bacteria.



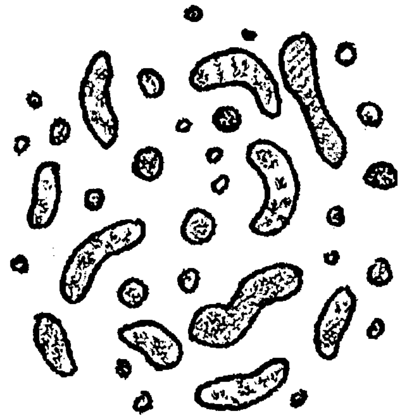
zooplankton
Zooplankton, tiny animals, drift in the plume waters. They feed on plume bacteria. They also eat other zooplankton.



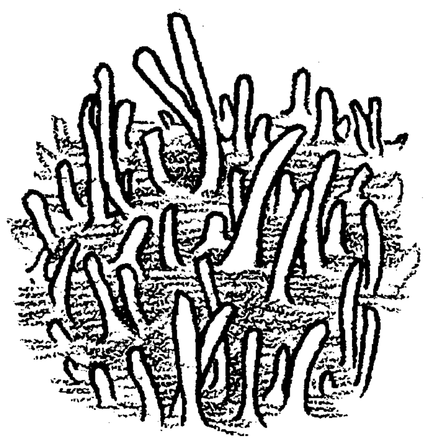
tube worms
These tube worms can grow to 2 meters in length! They have bright red soft bodies and white tubes. The tubes hold the worms upright. They have no mouth, no gut, and no digestive system. They absorb H_2 S from the vent waters. The H_2 S is used by symbiotic bacteria living inside the worms. The bacteria make the food the tube worms need.

mussels
These rust-colored mussels grow in clusters around the vents. They may reach 19 cm in length. They grow rapidly. Their food is made for them by symbiotic bacteria living in their gills.

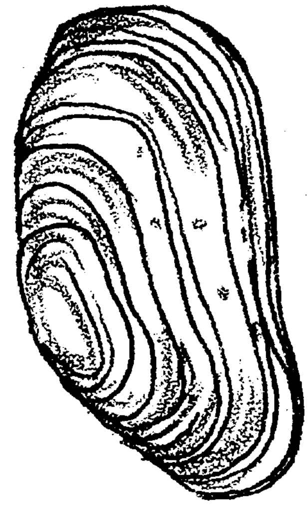
symbiotic bacteria
These bacteria are ball-shaped. They live inside tube worms, clams, and mussels. They get their energy from H_2 S. They use that energy to make food for themselves and hosts.



plume bacteria
These bacteria are peanut-shaped. They live in the plume. Water in the plume is warm. They get their energy from H_2 S. They use that energy to make food for themselves.

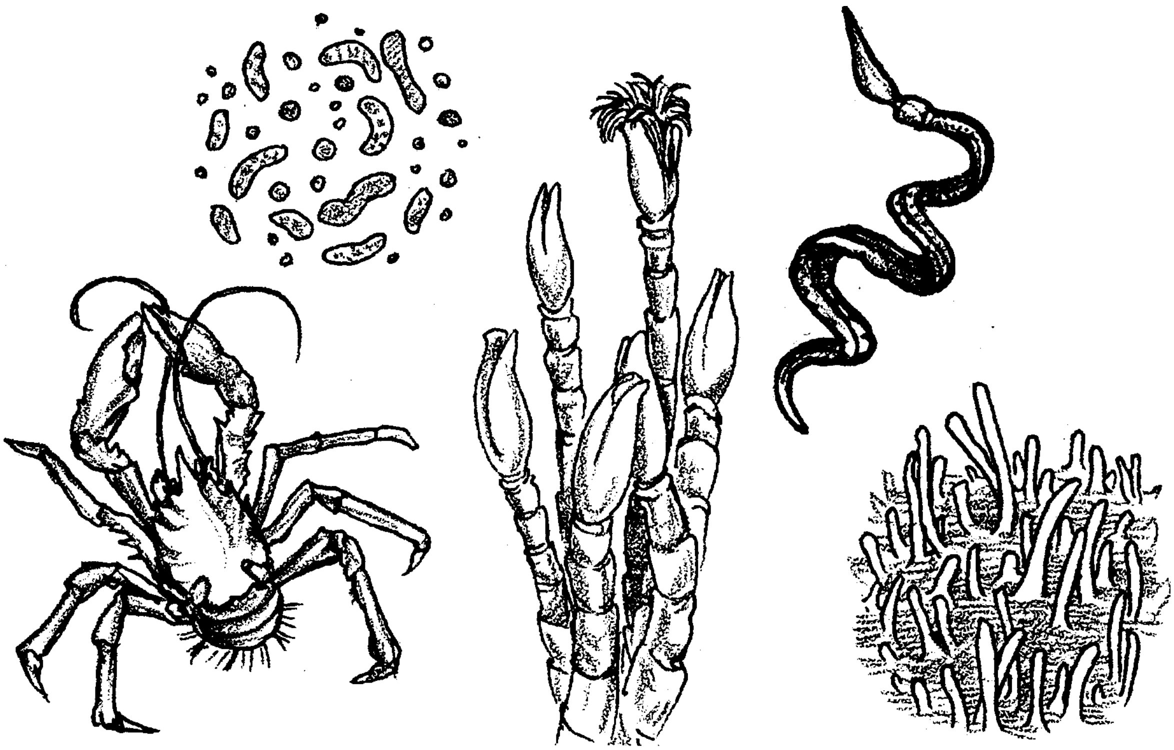


mat-forming bacteria
These bacteria live on most surfaces around the vents. They form slimy mats. These bacteria grow in “strings”. They get their energy from H_2 S. They use that energy to make food for themselves.



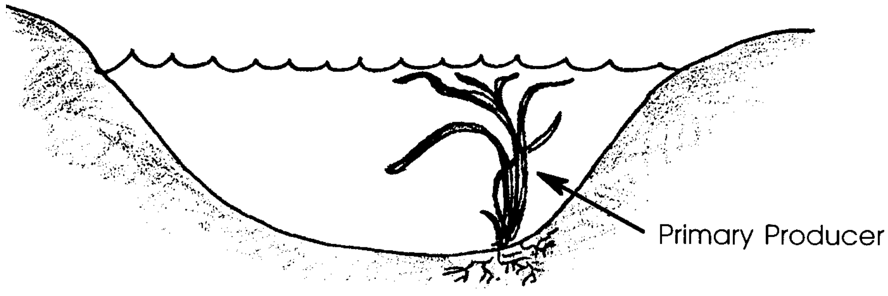
giant clam
This large white clam lives along cracks at vents. It can grow up to 24 cm (10") in length. It grows rapidly. Its food is made for it by symbiotic bacteria living in its gills.

Cycling in the Hydrothermal Vents

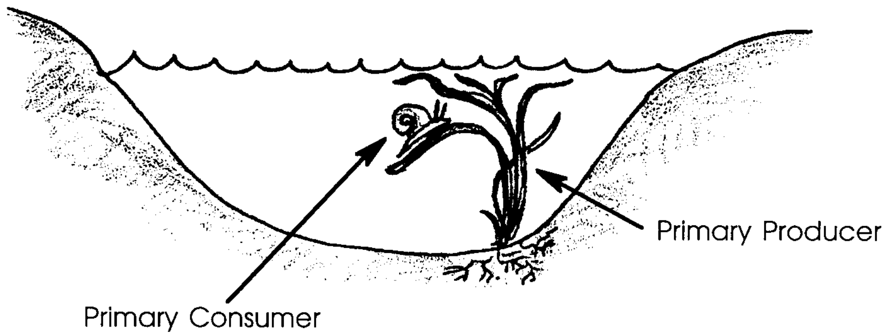


To grow and survive, living things need energy and matter. In a living community, energy and matter move from one living thing to another. We call a picture of these moves a "food web". What does the hydrothermal vent food web look like?

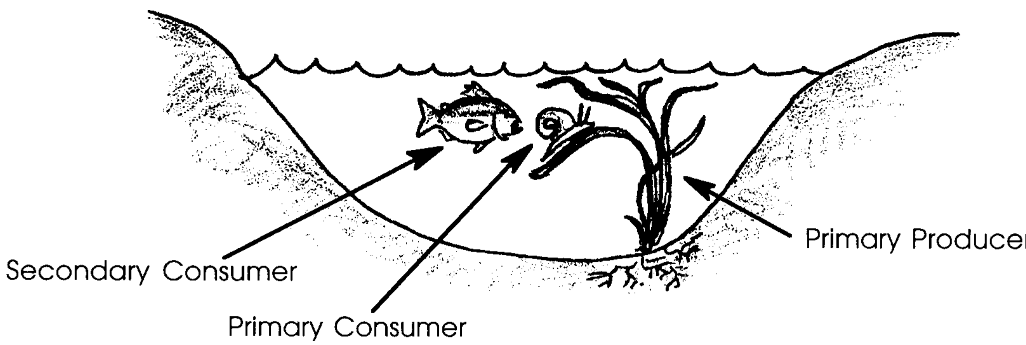
Perhaps we can get an idea by looking at communities we know. Think of a pond. Let's trace the movement of "food" (energy and matter). We can start with pond weed. This plant makes its own food. It uses energy from the sun and water. The process is called photosynthesis. The plant also needs some simple chemicals. It gets them from the soil at the bottom of the pond.



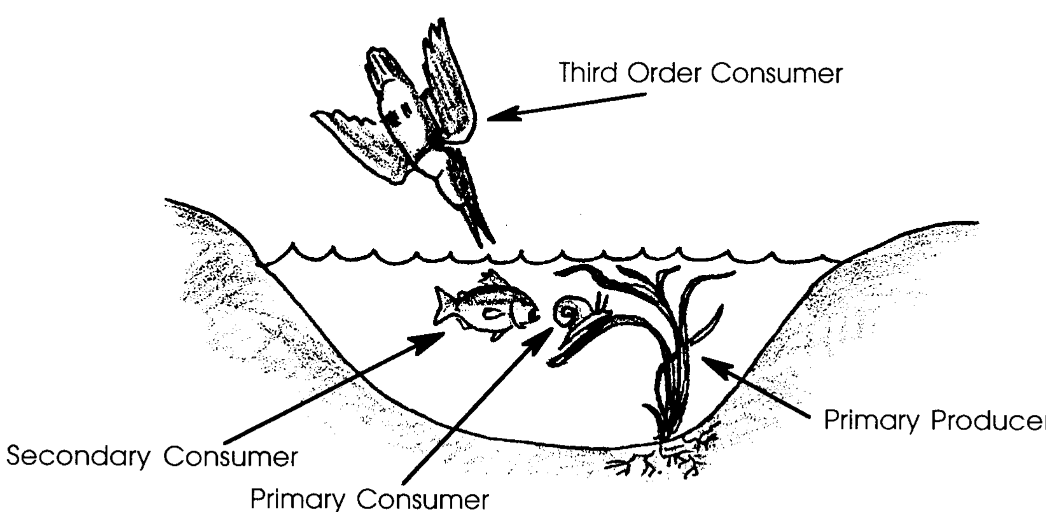
Pond snails eat the pond weed. The snails get their food from the plants. Plant eaters are called primary consumers. They are the first animal to eat the plants. Primary consumers use the energy and matter of the plant to grow and live.



The snail is eaten by a perch. What do you think scientists call animals that eat primary consumers? Right, secondary consumers. The perch is a secondary consumer.



A kingfisher swoops down and catches the perch. The perch has become food for a third order consumers. The kingfisher is a third order consumer.



Each time an animal eats another, some energy is lost. Because of this loss, food chains are often do not have fourth order consumers. The last consumer in a food chain is also called the top consumer. When plants or animals die they are eaten by decomposers. Decomposers return the plants and animals to simple chemicals. Decomposers are recyclers. They provide the simple chemicals needed by the plants. The cycle of matter starts again.

1. What is the top order consumer in the pond?

2. Use arrows to connect the pond food chain below. The tip of the arrow points **to** the eater.

simple chemicals + sunlight   pond weed   snail   perch   kingfisher

3. What does the arrow show?

This basic food chain works very well on the surface of the earth. It even works in the ocean down to about 100 meters. That's about as far as sunlight can reach. But green plants need sunlight. There is no sunlight at the depths of the hydrothermal vents. Yet, there is lots of life.

So where does the energy come from for hydrothermal vent food chains? Special bacteria play the role of green plants in the vent communities. These bacteria are the primary producers. They produce the energy rich food on which all other life depends. Instead of sunlight, the bacteria use a chemical called hydrogen sulfide.

4. Where does the energy come from for hydrothermal vent food chains?

Materials

- Hydrothermal Vent Critter Cards set
- art paper
- crayons, marking pens

Part I

In Part I, you will make a food web diagram of the hydrothermal vent community.

1. Obtain a set of “Critter Cards”. The cards show living members of the hydrothermal vent community. Read the cards. Place the members of the community in their correct food web “roles”.

Simple---> Chemicals	Primary ---> Producers	Primary ---> Consumers	Secondary ---> Consumers	Top Order Consumers
	________		________	
		________	________	
		________	________	________
	________	________	________	
		________	________	________
		________	________	
	________	________	________	

2. Some of these community members eat each other. Draw arrows connecting each member with the animals that eat it. The tip of the arrow points **to** the “eater”. The arrow shows how matter and energy move.

3. Look at the food web you have drawn. Use it to illustrate a simple food chain. Begin with simple chemicals. Include one primary producer, one primary consumer, one secondary consumer and one top order consumer. End with an arrow back to “simple chemicals”. This last arrow shows the decomposers.

Part II

In Part II, you will use the food web diagram from Part I to show food energy pathways.

1. You will receive two cards. Each card represents an animal in the hydrothermal vent food web.

2. Here is your task. Find and illustrate four different pathways that connect your two animals.

3. What if you find that there is no direct path connecting your two animals? Here’s how to solve this problem. Cycle your “food/energy” through the food web one or more times. Keep going until your two animals are connected.

4. Complete your four different pathways. Select one of the more complex cycles. Illustrate it for the class.

Analysis and Interpretation

1. Hydrothermal vents seem to last 20 or 30 years. At some point the vent stops releasing hot, sulfide-rich water. When a vent stops, the living community faces big changes.

   a. Which is the first member of the community affected?

   b. Do you think that tube worms, clams, or crabs can find a new hydrothermal? Why or why not?

   c. Hydrothermal vents are not found close to one another. Do you think that tube worms, clams, or crabs can move to a new hydrothermal? Why or why not?

   d. How might they get from one vent to another?

2. What do you think might cause a hydrothermal vent to stop?

3. Scientists were amazed when they found the hydrothermal vent communities. They have begun to think that life might be able to exist in areas they thought were too hot or too cold. What might this mean in terms of seeking life on other planets?