



Lessons from the Deep: Exploring the Gulf of Mexico's Deep-Sea Ecosystems Education Materials Collection

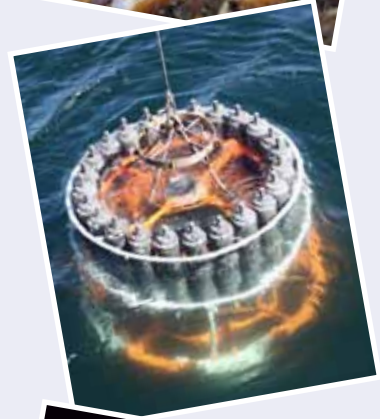


Image captions/credits on Page 2.

lesson plan

What's in That Cake?

(adapted from the Expedition to the Deep Slope 2006)

Focus

Exploration of deep-sea habitats

Grade Level

5-6 (Life Science)

Focus Question

How can scientists study organisms in deep-sea habitats in the Gulf of Mexico?

Learning Objectives

- Students will be able to explain what a habitat is, and describe at least three functions or benefits that habitats provide.
- Students will be able to describe some habitats that are typical of the Gulf of Mexico.
- Students will be able to describe and discuss at least three difficulties involved in studying deep-sea habitats.
- Students will be able to describe and explain at least three techniques scientists use to sample habitats such as those found in the Gulf of Mexico.

Materials

- At least two cakes or one cake for each student group, approximately 22 cm square or round
- Icing in various colors
- Candies or other edible materials for modeling habitat features
- Cardboard boxes large enough to cover cakes, one for each cake
- Piece of cardboard or foamcore, approximately 30 cm x 50 cm with a 3 cm x 22 cm "window" cut out of the center, one for each student group
- Large-diameter drinking straw (6mm or more), one for each

student group

- Tweezers, one for each student group

Audio/Visual Materials

- None

Teaching Time

Two or three 45-minute class periods, plus time for student research

Seating Arrangement

Classroom style

Maximum Number of Students

30

Key Words

Gulf of Mexico
Chemosynthetic
Cold-seep

Background Information

The Gulf of Mexico produces more petroleum than any other region in the nation, even though its proven reserves are less than those in Alaska and Texas. The *San Francisco Chronicle* reports that oil companies are spending billions to find more crude oil and drill more wells. Even with the threat of more hurricanes, the Gulf of Mexico has advantages: oil workers are not in danger of being kidnapped by armed insurgents as is the case in Nigeria; no foreign president threatens to raise oil companies' taxes, as has happened in Venezuela; and OPEC doesn't control oil production in the Gulf of Mexico. As of August 1, 2005, a total of 41,188 wells had been drilled in the Gulf, and 1,259 petroleum fields had been discovered.

Much of this new exploration is focused on some of the deepest regions of the Gulf, made possible by improved technology and increasing crude oil prices (which have doubled in the last three years). In addition to new petroleum fields, this exploration has led to other discoveries as well. Some of the same conditions responsible for petroleum deposits also provide the basis for biological communities that receive energy from chemicals through a process called chemosynthesis (in contrast to photosynthesis that provides energy to terrestrial and shallow-water communities through processes in which sunlight is the basic energy source).

Deepwater ecosystems in the Gulf of Mexico are often associated with rocky substrates or "hardgrounds." Most of these hard bottom areas are found in locations called cold seeps where hydrocarbons are seeping through the seafloor. Microorganisms are the connection

Images from Page 1 top to bottom:

A close-up mussel aggregation with *Chirodota heheva* sea cucumbers. Image courtesy of Expedition to the Deep Slope 2007.

http://oceanexplorer.noaa.gov/explorations/07mexico/logs/july3/media/cuke_600.html

A CTD rosette being recovered at the end of a cast. Note that the stoppers on the sample bottles are all closed. Image courtesy of INSPIRE: Chile Margin 2010.

<http://oceanexplorer.noaa.gov/explorations/10chile/logs/summary/media/2summary.html>

A methane hydrate mound on the seafloor; bubbles show that methane is continuously leaking out of features like this. If bottom waters warmed, this entire feature may be destabilized and leak methane at a higher rate.

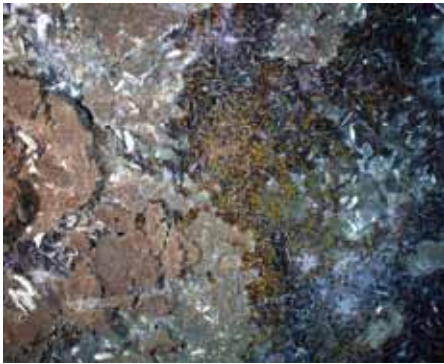
<http://oceanexplorer.noaa.gov/explorations/10chile/background/methane/media/methane4.html>

Lophelia pertusa create habitat for a number of other species at a site in Green Canyon. Image courtesy of Chuck Fisher.

http://oceanexplorer.noaa.gov/explorations/08lophelia/logs/sept24/media/green_canyon_lophelia.html



Chemical mapping during this cruise will help us better understand the role dissolved gases play in the distribution of chemosynthetic animals, such as these mussels and tubeworms. Image courtesy of Erik Cordes, Harvard University. http://oceanexplorer.noaa.gov/explorations/07mexico/background/gas/media/seep_600.html



Bacterial mats, mussels, and tubeworms are common at cold seeps. This image from Atwater Valley Site 340 in the Gulf of Mexico was captured with a downward-looking camera mounted on the deep submergence vehicle Alvin. Image courtesy of Expedition to the Deep Slope. http://oceanexplorer.noaa.gov/explorations/06mexico/logs/may16/media/seeps_600.html



The ROV manipulator arm allows scientists to collect and bring samples to the surface for closer study. Image courtesy of *Lophelia* II 2008: Deepwater Coral Expedition: Reefs, Rigs, and Wrecks. http://oceanexplorer.noaa.gov/explorations/08lophelia/logs/sept29/media/falcon_rov_arm.html

between hardgrounds and cold seeps. When microorganisms consume hydrocarbons under anaerobic conditions, they produce bicarbonate which reacts with calcium and magnesium ions in the water and precipitates as carbonate rock. Two types of ecosystems are typically associated with deepwater hardgrounds in the Gulf of Mexico: chemosynthetic communities and deep-sea coral communities. Hydrocarbon seeps may indicate the presence of undiscovered petroleum deposits, so the presence of these ecosystems may indicate potential sites for exploratory drilling and possible development of offshore oil wells. At the same time, these are unique ecosystems whose importance is presently unknown.

The first chemosynthetic communities were discovered in 1977 near the Galapagos Islands in the vicinity of underwater volcanic hot springs called hydrothermal vents, which usually occur along ridges separating the Earth's tectonic plates (visit <http://www.pmel.noaa.gov/vents/> for more information and activities on hydrothermal vent communities). Chemosynthetic communities in the Gulf of Mexico were found by accident in 1984. These communities are similar in that they are based upon energy produced by chemosynthesis; but while energy for the Galapagos communities is derived from underwater hot springs, deep-sea chemosynthetic communities in the Gulf of Mexico are found in the vicinity of cold seeps. Typical features of communities that have been studied so far include mounds of frozen crystals of methane and water called methane hydrate ice, that are home to polychaete worms and shrimp. Brine pools, containing water four times saltier than normal seawater, have also been found. Researchers often find dead fish floating in the brine pool, apparently killed by the high salinity.

Many species found in deepwater bottom communities are new to science, and may prove to be important sources of unique drugs for the treatment of human diseases. Because their potential importance is not yet known, it is critical to protect these systems from adverse impacts caused by human activities. Ironically, one of the most likely sources of such impacts is the same activity that led to the discovery of these systems in the first place: exploration and development of petroleum resources.

An essential part of strategies to protect deepwater ecosystems is describing deepwater biological communities and evaluating their sensitivity to impacts from human activities. A major challenge for scientists is how to accurately sample these habitats given the constraints of a hostile environment, as well as the need to minimize damage to the habitats caused by sampling. In this activity, students will create edible models of Gulf of Mexico habitats, and devise ways to study and sample these habitats under less-than-ideal conditions.

Learning Procedure

1. To prepare for this lesson:

a) Review the following essays:

Chemosynthetic Communities in the Gulf of Mexico

(<http://oceanexplorer.noaa.gov/explorations/02mexico/background/communities/communities.html>); and

The Ecology of Gulf of Mexico Deep-Sea Hardground Communities

(<http://oceanexplorer.noaa.gov/explorations/06mexico/background/hardgrounds/hardgrounds.html>).

(b) You may also want to review the following visual resources and consider presenting some of these to your students:

Image collections from Sulak, *et al.* (2008). Master Appendix D of this large report contains many images of deepwater coral communities. Download the pdf files "Master Appendix D - Megafaunal Invertebrates of Viosca Knoll, *Lophelia* Community Investigation," and "Key to Plates in Master Appendix D" from http://fl.biology.usgs.gov/coastaleco/OFR_2008-1148_MMS_2008-015/index.html

Video showing some of the extraordinary biological diversity of the Gulf of Mexico (http://oceanexplorer.noaa.gov/explorations/03mex/logs/summary/media/ngom_biodiversity_cm3.html)

Videos of deepwater corals and coral communities (<http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/photolog/photolog.html>)

Virtual tour of a cold seep community (http://www.bio.psu.edu/cold_seeps)

Slideshow of highlights from Expedition to the Deep Slope 2006 (<http://oceanexplorer.noaa.gov/explorations/06mexico/background/media/slideshow/slideshow.html>)

Slideshow of images from the Expedition to the Deep Slope 2007 (http://oceanexplorer.noaa.gov/explorations/07mexico/logs/summary/media/slideshow/html_slideshow.html)

(c) Prepare cakes and gather decorating materials. You may want to have students volunteer to bring their own cakes (be sure to specify the size!). A standard box of cake mix will make two

22 cm round or square cakes. If cakes are iced, the icing should be uniformly spread over the surface, and be a single color to provide a “clean slate” for the students to work from.

2. Briefly review and contrast chemosynthesis with photosynthesis. Point out that until recently it was well-accepted that photosynthesis was the basis of all major biological communities on Earth. Recognition of chemosynthetic communities has changed this view dramatically; indeed, many biologists now favor the idea that life on Earth may have begun in communities like those found near hydrothermal vents and cold seeps. You may want to show some of the visual resources referenced in Step 1 at this point.

Discuss deepwater reefs as an example of another type of deep-sea community. Be sure students understand that these reefs have a high diversity of species and large number of individual organisms like coral reefs in shallower water, but are virtually unexplored in the Gulf of Mexico.

Discuss the importance of the Gulf of Mexico to U.S. petroleum resources, as well as the potential importance of deep-sea biological communities that might be adversely affected by exploration and development of petroleum resources. Ask students to brainstorm steps that might be taken to avoid adverse impacts.

Discuss the concept of habitats. Have students brainstorm what functions or benefits an organism receives from its habitat. The students' list should include food, shelter (protection), and appropriate nursery areas. Tell students that detailed surveys of deep-sea communities in the Gulf of Mexico are just beginning, but we can have a general idea of what to expect based on explorations in other deepwater, hard-bottom habitats. Explain the concept of “microhabitat.” Be sure students understand how the combination of various rock formations and organisms with complex physical forms (like branching corals and sponges) can offer many different types of habitat and as a result can provide food, shelter, and nursery space for many different kinds of organisms.

Tell students that one of the challenges faced by scientists studying deep-sea communities is how to obtain information about the organisms living in the habitats without destroying the habitats or the scientists themselves. Point out that early scientific expeditions used dredges or trawls to sample deepwater areas, but that these techniques basically destroy whatever they

sample. Being able to use deep-diving submersibles to visit these communities in person has many advantages, but also puts the scientists in greater danger from the extreme conditions in the deep-sea environment. Ask students to list some of these dangers. Their list should include extreme pressure, low temperatures, and darkness.

Tell students that they are going to simulate some of these challenges in their classroom, and devise ways to study unfamiliar habitats under difficult conditions.

3. The first task for exploring new environments is to obtain a general idea of what types of habitats and organisms may be present. Tell student groups that they are to find out what sorts of habitats and organisms Ocean Exploration Expeditions have found in deep-sea communities of the Gulf of Mexico. Have students read relevant trip logs from the following expeditions, and find pictures or illustrations of these organisms (you may want to assign one or two expeditions to each student group):

- Chemosynthetic Life in the Gulf of Mexico (June 15–October 19, 2002) <http://oceanexplorer.noaa.gov/explorations/02mexico/welcome.html>
- Gulf of Mexico Deep-sea Habitats 2003 (September 21 - October 2, 2003) <http://oceanexplorer.noaa.gov/explorations/03mex/welcome.html>
- Expedition to the Deep Slope (May 7 - June 2, 2006) <http://oceanexplorer.noaa.gov/explorations/06mexico/welcome.html>
- Expedition to the Deep Slope 2007 (June 4 – July 6, 2007) <http://oceanexplorer.noaa.gov/explorations/07mexico/welcome.html>
- *Lophelia* II 2008: Deepwater Coral Expedition: Reefs, Rigs, and Wrecks (September 20 - October 2, 2008) <http://oceanexplorer.noaa.gov/explorations/explorations.html>
- *Lophelia* II 2009: Deepwater Coral Expedition: Reefs, Rigs, and Wrecks (August 19 - September 12, 2009) <http://oceanexplorer.noaa.gov/explorations/09lophelia/welcome.html>

In addition to printed reference books, the Ocean Explorer Gallery (<http://oceanexplorer.noaa.gov/>, click on "Gallery") has lots of images suitable for downloading.

4. Have each group present their research findings. Discuss and list the types of habitats found in deep-sea communities of the Gulf of Mexico, and the kinds of organisms that may be found in these habitats. Have students describe what functions or benefits organisms receive from each habitat type. Be sure students understand that previous expeditions have only identified a fraction of the organisms that are probably present, so their list should consider habitats that may not have been sampled as yet.
5. Tell students that each group is going to construct an edible model of some of the habitats and organisms found in the Gulf of Mexico. Their model should contain at least three habitat types and at least one organism that uses each of the three habitats. The base of the model will be a cake. Have students brainstorm what kinds of edible features can be added to the cake to make the habitat model. Mounds of icing can be used for boulders, and when hardened can be sculpted to form caves and overhangs. Sponges might be modeled with small pieces of sponge cake (of course), and strings of rock candy (made by hanging pieces of string in a saturated sugar solution) could represent branching corals. Of course, there are many more possibilities, and your students will probably have a pretty good idea of potential model elements.

Each group should prepare a written record of the habitats modeled, the organisms included for each habitat, and where the organisms are located. Be sure each group keeps their work out of sight of the other groups. When models are finished, they should be placed under a cardboard box so they cannot be seen.

6. Lead a discussion of techniques that could be used to sample organisms living in the eight major habitats found in the Gulf of Mexico. State the following ground rules for sampling:
 - All samples must be collected from the deep-diving submersible.
 - It is important to minimize damage to the habitats being sampled.
 - It isn't possible to sample every centimeter of a habitat, so sampling must be distributed over the entire study area.
 - Time is severely limited, so it is important to get as much information as possible in a short amount of time.

Photographic and video recordings are one of the most important sampling tools since they can cover large areas, cause no damage to the habitats (although bright lights may cause temporary or permanent blindness to light-sensitive organisms), and provide a permanent record of observations that can be studied in greater detail when scientists return from their dives.

When sampling unexplored areas, scientists often steer their submersible along a series of pre-determined paths called “transects” that cover the entire area. For example, this would be like sampling a football field at night by walking with a flashlight along every ten-yard line; the entire field would be covered, but only a small fraction would actually be seen. If a site has been previously visited, scientists may concentrate their sampling and observations on features of particular interest.

Samples of rocks and larger organisms such as corals and sponges can be collected with the submersible’s manipulator arm. Scoops, cores, and suction devices may also be used to sample organisms living on living and non-living surfaces, as well as organisms in soft bottom habitats.

Be sure students realize that regardless of the sampling techniques used, some organisms will almost certainly escape detection, particularly those able to move rapidly away from a source of disturbance, such as fishes, squids, and many burrowing animals.

7. Tell students that their challenge is to sample an unknown environment (cake) to determine the habitats and organisms present. Since we are working with deep-sea environments, there will be some constraints on the sampling:
- A total of two minutes will be allowed for the entire sampling program.
 - No more than 5% of the model may be damaged.
 - Samples may only be taken through a “window” 3 cm wide.
 - No more than 5 windows can be sampled.

Provide each group with a pair of tweezers (simulating the submersible’s manipulator arm), a large-diameter drinking straw (simulating a core sampler), and a piece of cardboard with a 3 cm x 23 cm slot (simulating the sampling window). Have each group write down their sampling strategy, indicating which students will be responsible for collecting each type of sample. One or two students may be assigned to record visual observations to simulate video recording.

Working with one group at a time, provide the group with an unknown cake. Signal the start of the two-minute sampling period, and allow the group to begin their sampling program. Be sure that no more than five windows are sampled. Call out elapsed time every 15 seconds so that the group can pace their sampling activities.

When all groups have completed their sampling, have each group prepare a written report on the habitats and organisms discovered in their model environment. Since they won't know what the various modeling materials are supposed to represent, they will have to identify the various features sampled by a description (red boulder, yellow gummy bear, or other collected objects).

8. Lead a discussion in which each group presents their report, and compares their findings with the records of the group that created the model. Have students verify that no more than 5% of the model has been damaged by the sampling procedure. Discuss ways in which sampling could be improved. Have students compare and contrast their sampling techniques with those actually used by scientists exploring deep-sea communities of the Gulf of Mexico. Point out that it would have been even more realistic if the entire sampling process were done in total darkness with only a small flashlight to guide the sampling effort.

Following this discussion (and depending upon the condition of the cakes), invite students to assume the role of top consumers and have a direct interaction with their model environments (they can eat the cake, after washing their hands).

The Bridge Connection

www.vims.edu/bridge/ – Click on “Ocean Science” in the navigation menu to the left, then “Habitats,” then “Deep Sea” for resources on deep-sea communities.

The “Me” Connection

Have students write a short essay on how explorations of areas like deep-sea communities of the Gulf of Mexico could be of direct benefit to their own lives.

Connections to Other Subjects

English/Language Arts, Physical Science, Life Science

Assessment

Reports and records prepared in Steps 4, 5, and 6 provide opportunities for assessment.

Extensions

See the “Resources” section of *Lessons from the Deep: Exploring the Gulf of Mexico's Deep-sea Ecosystem Education Materials Collection Educators Guide* for additional information, activities, and media resources about deepwater ecosystems in the Gulf of Mexico.

Multimedia Discovery Missions

<http://www.learningdemo.com/noaa/> Click on the links to Lessons 3, 5, and 6 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Chemosynthesis and Hydrothermal Vent Life, and Deep-Sea Benthos.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Let's Make a Tubeworm! (15 pages, 1946 KB)

<http://oceanexplorer.noaa.gov/oceanos/explorations/10index/background/edu/media/tubeworm.pdf>

Focus - Symbiotic relationships in cold-seep communities (Life Science)

Students describe the process of chemosynthesis in general terms, contrast chemosynthesis and photosynthesis, describe major features of cold-seep communities, and list at least five organisms typical of these communities. They will be able to define symbiosis, describe two examples of symbiosis in cold-seep communities, describe the anatomy of vestimentiferans, and explain how these organisms obtain their food.

Animals of the Fire Ice (5 pages, 364 KB)

<http://oceanexplorer.noaa.gov/oceanos/edu/lessonplans/media/09animalsoffireice.pdf>

Focus - Methane hydrate ice worms and hydrate shrimp (Life Science)

Students define and describe methane hydrate ice worms and hydrate shrimp, infer how methane hydrate ice worms and hydrate shrimp obtain their food, and infer how methane hydrate ice worms and hydrate shrimp may interact with other species in the biological communities of which they are part.

Microfriends (6 pages, 420 KB)

<http://oceanexplorer.noaa.gov/oceanos/edu/lessonplans/media/09microfriends.pdf>

Focus - Beneficial microorganisms (Life Science)

Students describe at least three ways in which microorganisms benefit people, describe aseptic procedures, and obtain and culture a bacterial sample on a nutrient medium.

Other Links and Resources

The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.

<http://oceanexplorer.noaa.gov/> – Ocean Explorer Web site

<http://www.uky.edu/KGS/education/cookbook.htm> – The Geologic and Paleontologic Cookbook

<http://www.piersystem.com/go/site/2931/> – Main Unified Command Deepwater Horizon response site

<http://response.restoration.noaa.gov/deepwaterhorizon> – NOAA Web site on Deepwater Horizon Oil Spill Response

http://docs.lib.noaa.gov/noaa_documents/NESDIS/NODC/LISD/Central_Library/current_references/current_references_2010_2.pdf – Resources on Oil Spills, Response, and Restoration: a Selected Bibliography; document from NOAA Central Library to aid those seeking information concerning the Deepwater Horizon oil spill disaster in the Gulf of Mexico and information on previous spills and associated remedial actions; includes media products (web, video, printed and online documents) selected from resources available via the online NOAA Library and Information Network Catalog (NOAALINC)

<http://www.gulfallianceeducation.org/> – Extensive list of publications and other resources from the Gulf of Mexico Alliance; click “Gulf States Information & Contacts for BP Oil Spill” to download the Word document

<http://rucool.marine.rutgers.edu/deepwater/> – Deepwater Horizon Oil Spill Portal from the Integrated Ocean Observing System at Rutgers University

http://www.darrp.noaa.gov/southeast/deepwater_horizon/index.html – Information about damage assessments being conducted by NOAA's Damage Assessment Remediation and Restoration Program

<http://response.restoration.noaa.gov/> – Click “Students and Teachers” in the column on the left for information, fact sheets, and activities about oil emergencies, habitats, and other ocean issues

<http://www.noaa.gov/sciencemissions/bpoilspill.html> – Web page with links to NOAA Science Missions & Data relevant to the Deepwater Horizon/BP Oil Spill

<http://ecowatch.ncddc.noaa.gov/jag/data.html> – Data Links page on the Deepwater Horizon Oil Spill Joint Analysis Group Web site

<http://ecowatch.ncddc.noaa.gov/jag/reports.html> – Reports page on the Deepwater Horizon Oil Spill Joint Analysis Group Web site

http://www.education.noaa.gov/Ocean_and_Coasts/Oil_Spill.html - "Gulf Oil Spill" Web page from NOAA Office of Education with links to multimedia resources, lessons & activities, data, and background information

<http://www.geoplatform.gov/gulfresponse/> - Web page for GeoPlatform.gov/gulfresponse—an online map-based tool developed by NOAA with the EPA, U.S. Coast Guard, and the Department of Interior to provide a "one-stop shop" for spill response information; includes oil spill trajectory, fishery area closures, wildlife data, locations of oiled shoreline and positions of deployed research ships

Fisher, C., H. Roberts, E. Cordes, and B. Bernard. 2007. Cold seeps and associated communities of the Gulf of Mexico. *Oceanography* 20:118-129; available online at http://www.tos.org/oceanography/issues/issue_archive/20_4.html

Sulak, K. J., M. T. Randall, K. E. Luke, A. D. Norem, and J. M. Miller (Eds.). 2008. Characterization of Northern Gulf of Mexico Deepwater Hard Bottom Communities with Emphasis on *Lophelia* Coral - *Lophelia* Reef Megafaunal Community Structure, Biotopes, Genetics, Microbial Ecology, and Geology. USGS Open-File Report 2008-1148; http://fl.biology.usgs.gov/coastaleco/OFR_2008-1148_MMS_2008-015/index.html

National Science Education Standards

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard C: Life Science

- Populations and ecosystems

Content Standard F: Science in Personal and Social Perspectives

- Populations, resources, and environments

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.

The Earth has one big ocean with many features.

Fundamental Concept h. Although the ocean is large, it is finite and resources are limited.

Essential Principle 4.

The ocean makes Earth habitable.

Fundamental Concept b. The first life is thought to have started in the ocean. The earliest evidence of life is found in the ocean.

Essential Principle 5.**The ocean supports a great diversity of life and ecosystems.**

• *Fundamental Concept b.* Most life in the ocean exists as microbes. Microbes are the most important primary producers in the ocean. Not only are they the most abundant life form in the ocean, they have extremely fast growth rates and life cycles.

Fundamental Concept c. Some major groups are found exclusively in the ocean. The diversity of major groups of organisms is much greater in the ocean than on land.

Fundamental Concept d. Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.

• *Fundamental Concept f.* Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is “patchy”. Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.

Fundamental Concept g. There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, and methane cold seeps rely only on chemical energy and chemosynthetic organisms to support life.

Essential Principle 6.**The ocean and humans are inextricably interconnected.**

Fundamental Concept b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.

• *Fundamental Concept e.* Humans affect the ocean in a variety of ways. Laws, regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise pollution) and physical modifications (such as changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.

Fundamental Concept g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Essential Principle 7.**The ocean is largely unexplored.**

Fundamental Concept a. The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.

Fundamental Concept b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.

Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.

Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

Send Us Your Feedback

We value your feedback on this lesson.

Please e-mail your comments to: oceaneducation@noaa.gov

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