Lessons from the Deep:

Exploring the Gulf of Mexico's Deep-Sea Ecosystems

Education Materials Collection

Image captions/credits on Page 2.

lesson plan

Entering the Twilight Zone

(adapted from the Expedition to the Deep Slope 2007)

Focus

Deep-sea habitats

Grade Level

5-6 (Life Science)

Focus Question

What organisms are typical of major deep-sea habitats, and how do they interact?

Learning Objectives

- Students will be able to describe major features of cold seep communities, and list at least five organisms typical of these communities.

- Students will be able to infer probable trophic relationships within and between major deep-sea habitats.

- Students will be able to describe the process of chemosynthesis in general terms, and will be able to contrast chemosynthesis and photosynthesis.

- Students will be able to describe major deep-sea habitats and list at least three organisms typical of each habitat.

Materials

- 5 x 7 index cards
- Drawing materials
- Corkboard, flip chart, or large poster board
- *Student Handout: Generalized Ocean Habitats*

Audio/Visual Materials

- None

Teaching Time

Two 45-minute class periods, plus time for individual group research

Seating Arrangement

Groups of 4 students

Maximum Number of Students

32

Key Words

Cold seeps
Methane hydrate ice
Chemosynthesis
Brine pool
Trophic level
Pelagic Zone
Epipelagic Zone
Mesopelagic Zone
Bathypelagic Zone
Hadopelagic Zone
Benthic Zone
Intertidal Zone
Subtidal Zone
Bathyal Zone
Abysal Zone
Hadal Zone
Hydrothermal vent

Background Information

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 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.

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

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.

An example of the Viosca Knoll 906 habitat. In part of this site, there are a series of mounds that appear to be composed primarily of dead Lophelia pertusa rubble. Image courtesy of *Lophelia* II Team 2009, NOAA-OER.
http://oceanexplorer.noaa.gov/explorations/09lophelia/background/plan/media/image_4.html

Deepwater coral reefs were discovered in the Gulf of Mexico nearly 50 years ago, but very little is known about the ecology of these communities or the basic biology of the corals that produce them. These corals are usually found on hardbottom areas where there are strong currents and little suspended sediment (but extremely strong currents may interfere with feeding and cause breakage). *Lophelia pertusa*, the best-known deepwater coral species, prefers water temperatures between 4-12 °C, dissolved oxygen concentrations above 3 ml/l, and salinity between 35 and 37 ppt. The influence of other factors, including pH, is not known.

Lophelia pertusa coral, with opened polyps, attached to an authigenic carbonate rock. Seep-dependent tubeworms are visible behind the coral. Image courtesy of, *Lophelia* II 2009: Deepwater Coral Expedition: Reefs, Rigs and Wrecks.
http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug25/media/lophelia_insitu_.html

Recent studies suggest that deepwater reef ecosystems may have a diversity of species comparable to that of corals reefs in shallow waters, and have found deepwater coral species on continental margins worldwide. One of the most conspicuous differences between shallow- and deepwater corals is that most shallow-water species have symbiotic algae (zooxanthellae) living inside the coral tissue, and these algae play an important part in reef-building and biological productivity. Deepwater corals do not contain symbiotic algae (so these corals are termed "azooxanthellate"). Yet, there are just as many species of deepwater corals (slightly more, in fact) as there are species of shallow-water corals. Sulak (2008) provides extensive information on deepwater hard bottom coral communities at Viosca Knoll in the Northern Gulf of Mexico, including illustrations of fishes, benthic invertebrates, and typical biotopes associated with these communities.

The major deepwater structure-building corals belong to the genus *Lophelia*, but other organisms contribute to the framework as well, including antipatharians (black corals), gorgonians (sea fans and sea whips), alcyonaceans (soft corals), anemones, and sponges. While these organisms are capable of building substantial reefs, they are also quite fragile, and there is increasing concern that deepwater reefs and their associated resources may be in serious danger. Many investigations have reported large-scale damage due to commercial fishing trawlers, and there is also concern about impacts that might result from exploration and extraction of fossil fuels. These impacts are especially likely in the Gulf of Mexico, since the carbonate foundation for many deepwater reefs is strongly associated with the presence of hydrocarbons. Potential impacts include directly toxic effects of hydrocarbons on reef organisms, as well as effects from particulate materials produced by drilling operations. Since many deepwater reef organisms are filter feeders, increased particulates could clog their filter apparatus and possibly smother bottom-dwelling organisms.

These deepwater ecosystems are fundamentally different from other biological systems, and there are many unanswered questions about the individual species and interactions between species found in these communities. These species include some of the most primitive living organisms (Archaea) that some scientists believe may have been the first life forms on Earth. Many species are new to science, and may prove to be important sources of unique drugs for the treatment of human diseases. Organisms from hydrothermal vent communities, for example, have proven to be useful in treating bone injuries and cardiovascular disease, copying DNA for scientific studies and crime scene investigations, and making sweeteners for food additives. Because their potential importance is not yet known, it is critical to protect deepwater ecosystems from adverse impacts caused by human activities.

Deepwater coral reefs and cold seep communities are surrounded by a much larger ocean environment. Very little is known about interactions between these communities and organisms in other ocean habitats. This activity focuses on major ocean habitats, organisms typically found in these habitats, and the interactions that take place within and among these habitats.

Ocean habitats are usually categorized into zones:

I. Pelagic zones are found in the water column above the bottom. Organisms that inhabit pelagic zones are divided into plankton that drift with the ocean currents and nekton that can swim and control their motion in the water (at least to some extent).
   A. **The Epipelagic Zone** includes surface waters where light is adequate for photosynthesis (about 200m, maximum). Phytoplankton are the dominant primary producers in this zone.
   B. **The Mesopelagic Zone** (about 200m-1000m) is the twilight

zone. Because there is not enough light for photosynthesis, much less energy is available to support animal life. Bacteria and detritus (pieces of dead plants and animals that slowly settle to the bottom) are the primary sources of food for animals like jellyfishes that are confined to this zone. Other animals, including squids, fishes, and shrimps can move up and down through the water column, and have a wider range of food available to them.

C. **The Bathypelagic Zone** (sometimes divided further into an additional Abyssopelagic Zone) has no light at all, with the exception of light produced by bioluminescent organisms. Deep-sea organisms are dependent upon production in other zones. The base of bathypelagic food chains may be primary production in shallower water (obtained by feeding on detritus or on other animals feeding in shallower water) or chemosynthetic communities like hydrothermal vents or cold seeps.

D. **The Hadopelagic Zone** is sometimes used to include the water column in deepest ocean trenches (about 11,000 m).

II. Benthic zones are areas on or in the ocean bottom. Animals that swim near the bottom are called "benthopelagic."

A. **The Intertidal Zone** is on the shore between the level of high and low tide.

B. **The Subtidal Zone** includes the ocean bottom on continental shelves down to about 300 m. Green plants are the base of food chains in shallower waters, but bacteria and detritus are the primary energy source below about 200 m.

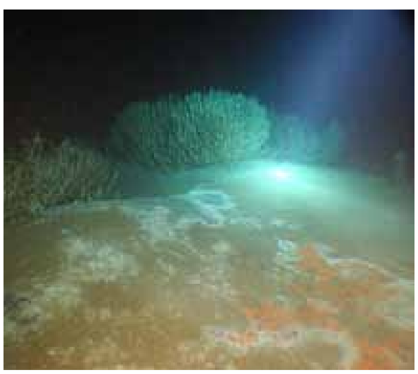
C. **The Bathyal Zone** includes the rest of the continental shelf (between about 300 m and 3,000 m).

D. **The Abyssal Zone** is the ocean bottom between 3,000 m and 6,000 m. The bottom is primarily muddy and flat in most places (hence the common term "abyssal plain"). This is the largest benthic zone and covers about half of the Earth's surface.

E. **The Hadal Zone** is sometimes used to describe the very deep ocean bottom between 6,000 m and 11,000 m.

F. **Vents and seeps** are unusual deep-water habitats that support communities of living organisms whose food chains are based on chemosynthetic bacteria, rather than photosynthetic activity near the surface. Vent and seep communities may, in turn, be a significant energy (food) source for organisms living in other benthic habitats nearby.

This picture illustrates four common types of hard substrate at seeps: clams (white and black shells; Solemyidae: *Acharax* sp.), mussels (brown shells; Mytilidae: *Bathymodiolus* sp.); vestimentiferan tube worms (*Lamellibrachia* sp.); and carbonate rocks, precipitated by methanotrophic archaea. Photo courtesy of CRROCKS/NSF.
http://oceanexplorer.noaa.gov/explorations/10chile/background/habitats/media/habitats2.html



Large tubeworm aggregations composed of Lamellibrachia luymesi and Seepiophila jonesi from 530 m depth at a seep site on the Upper Louisiana Slope of the Gulf of Mexico. In the foreground are mats of sulfide-oxidizing bacteria. Image courtesy of Ian MacDonald.
http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/tubeworm_600.html

Learning Procedure

1. To prepare for this lesson, 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).
   You may want to visit http://www.bio.psu.edu/cold_seeps for a virtual tour of a cold seep community.

2. Lead a discussion of the major categories of ocean habitat. Introduce the recently-discovered deep-sea chemosynthetic communities (hydrothermal vents and cold seeps). Emphasize the contrast between communities that depend upon chemosynthesis with those dependent upon photosynthesis. You may want to point out that through both processes, organisms build sugars from carbon dioxide and water. This process requires energy; photosynthesizers obtain this energy from the sun, while chemosynthesizers obtain energy from chemical reactions. Review the concepts of food chains and food webs, including the concept of trophic levels (primary producer, primary consumer, secondary consumer, and tertiary consumer). Be sure students understand that food chains in most of the habitats are largely based upon photosynthetic production, either directly (primary consumers obtain energy from photosynthetic plants) or indirectly (primary consumers obtain energy from detritus). This situation is fundamentally different in deep-sea chemosynthetic communities, which may also provide an alternative basis for food chains in adjacent habitats.

3. Assign each student group one or more of the following deep ocean habitats to research:
   - Mesopelagic zone
   - Bathypelagic zone
   - Hadopelagic zone
   - Bathyal zone
   - Abyssal zone
   - Hadal zone
   - Deepwater coral reefs
   - Cold seeps

   In addition to written reference materials (encyclopedia, periodicals, and books on the deep-sea), the following Web sites contain useful information:
   http://www.bio.psu.edu/cold_seeps

http://people.whitman.edu/~yancey/deepsea.html
http://www.oceanlink.info/
http://www.pbs.org/wgbh/nova/abyss/life/bestiary.html
http://biodidac.bio.uottawa.ca/
http://www.fishbase.org/search.php

Each student group should identify six organisms typical of their assigned habitat, and determine the energy (food) source(s) of each of these organisms. It may not be possible to precisely determine specific foods in all cases, but students should be able to draw reasonable inferences from information about related organisms and anatomical features that may give clues about what the animals eat. Students should prepare a 5 x 7 index card for each organism with an illustration of the organism (photocopies from reference material, downloaded internet pictures, or their own sketches), notes on where the organism is found, approximate size of the organism, and its trophic level (whether it is a primary producer, primary consumer, secondary consumer, or tertiary consumer).

4. Have each student group orally present their research results to the entire class. On a corkboard, flip chart, or piece of poster board draw a general profile of ocean habitats (see *Student Handout: Generalized Ocean Habitats*), and arrange the cards to show representative organisms in each habitat. When all cards have been attached to the base material, draw lines to indicate trophic (feeding) relationships between these organisms.

5. Lead a discussion of the food web the students have created. What is the source of primary production in each habitat? What would the students infer about the relative abundance of each trophic level? In the simplest analysis, organisms at lower trophic levels (primary producers and primary consumers) must be more abundant than those on higher trophic levels. If this does not appear to be true, then there must be additional energy sources for the higher trophic levels (for example, some secondary or tertiary predators may feed in more than one habitat. Considering that the abyssal plain covers about half of the Earth's surface, and is largely unexplored, how might the students' ocean food web change with further exploration?

The Bridge Connection

www.vims.edu/bridge/ – Click on "Ocean Science Topics" in the navigation menu to the left, then "Biology," then "Plankton" for resources on ocean food webs. Click on "Ocean Science Topics," then "Habitats," then "Deep Sea" for resources on deep-sea communities.

The "Me" Connection

Have students write a short essay describing their personal position in a food web, and how they could adapt if their source of primary production were no longer available.

Connections to Other Subjects

English/Language Arts, Earth Science

Assessment

Results and presentation of the research component of this activity provide a basis for group evaluation. In addition, individual written interpretations of the pooled results may be required prior to Step 4 to provide a means of individual 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://oceanexplorer.noaa.gov/edu/learning/welcome.html Click on the links to Lessons 3, 5, 6, and 12 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Chemosynthesis and Hydrothermal Vent Life, Deep-Sea Benthos, and Food, Water, and Medicine from the Sea.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

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

http://oceanexplorer.noaa.gov/okeanos/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/okeanos/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.*

The Robot Ranger (14 pages, 1.1 MB)

http://oceanexplorer.noaa.gov/explorations/09lophelia/background/edu/media/09ranger.pdf

Focus - Robotic Analogues for Human Structures (Vision, Distance Estimation) (Life Science/Physical Science)

Students describe how humans are able to estimate the distance to visible objects, and describe a robotic system with a similar capability.

Big Enough? (15 pages, 964 KB)

http://oceanexplorer.noaa.gov/explorations/09lophelia/background/edu/media/09bigenough.pdf

Focus - Buoyancy (Physical Science)

Students define buoyancy, mass, volume, and density, and explain the relationships between these properties. Given the mass and volume of an object, students calculate the minimum buoyancy required to keep the object afloat in seawater. Students also explain why objects in seawater are more buoyant than the same objects in fresh water.

Cool Lights (7 pages, 220 KB)

http://oceanexplorer.noaa.gov/explorations/04deepscope/background/edu/media/coollights.pdf

Focus - Light-producing processes and organisms in deep-sea environments (Life Science/Physical Science)

Students compare and contrast chemiluminescence, bioluminescence, fluorescence, and phosphorescence. Given observations on materials that emit light under certain conditions, students infer whether the light-producing process is chemiluminescence, fluorescence, or phosphorescence. Students explain three ways in which the ability to produce light may be useful to deep-sea organisms and explain how scientists may be able to use light-producing processes in deep-sea organisms to obtain new observations of these organisms.

Now You See Me, Now You Don't (5 pages, 281 KB)

http://oceanexplorer.noaa.gov/explorations/05deepscope/background/edu/media/now_u_see_me.pdf

Focus - Light, color, and camouflage in the deep ocean (Life Science)

Students explain light in terms of electromagnetic waves, and explain the relationship between color and wavelength; compare and contrast color related to wavelength with color *perceived by biological vision systems; and explain how color and light may be important to deep-sea organisms, even under conditions of near-total darkness. Students also predict the perceived color of objects when illuminated by light of certain wavelengths.*

Microfriends (6 pages, 420 KB)
http://oceanexplorer.noaa.gov/okeanos/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

Paull, C.K., B. Hecker, C. Commeau, R.P. Feeman-Lynde, C. Nuemann, W.P. Corso, G. Golubic, J. Hook, E. Sikes, and J. Curray. 1984. Biological communities at Florida Escarpment resemble hydrothermal vent communities. Science 226:965-967 – Early report on cold seep communities.

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 B: Physical Science

- Transfer of energy

Content Standard C: Life Science

- Structure and function in living systems
- Populations and ecosystems
- Diversity and adaptations of organisms

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 3.
The ocean is a major influence on weather and climate.

Fundamental Concept f. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon and water.

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

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 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 g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustainthe 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: oceanexeducation@noaa.gov

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Acknowledgements

This lesson was developed by Mel Goodwin, PhD, Marine Biologist and Science Writer. Design/layout by Coastal Images Graphic Design, Mt. Pleasant, SC. If reproducing this lesson, please cite NOAA as the source, and provide the following URL: http://oceanexplorer.noaa.gov/

Student Handout:
Generalized Ocean Habitats