Lophelia II 2010:
Cold Seeps and Deep Reefs

Let's Hit the Slopes!

Image captions/credits on Page 2.

lesson plan

Focus
Benthic communities on continental slopes in the Gulf of Mexico

Grade Level
7-8 (Life Science)

Focus Question
What are some of the benthic communities found on continental slopes in the Gulf of Mexico?

Learning Objectives
- Students will describe benthic communities found at selected sites on continental slopes in the Gulf of Mexico.
- Students will explain the possible ecological role of at least three species that are characteristic of these communities.
- Students will be able to calculate an index of similarity between two biological communities given species occurrence data.

Materials
- ❑ Copies of *Deep-Sea Biotopes Inquiry Guide,* one copy for each student group

Audio-Visual Materials
- ❑ (Optional) Video projection or other equipment to show images (see Learning Procedure Steps 1a, 1d, and 1e)

Teaching Time
One or two 45-minute class periods

Seating Arrangement
Groups of 2-4 students

Maximum Number of Students
32

Key Words
Gulf of Mexico
Cold seep
Lophelia

Deepwater coral
Coefficient of community

Background Information

NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

For the past four years, NOAA's Office of Ocean Exploration and Research (OER) has sponsored expeditions to locate and explore deep-sea chemosynthetic communities in the Gulf of Mexico. On April 20, 2010, a gas explosion occurred on the mobile offshore drilling unit Deepwater Horizon about 40 miles southeast of the Louisiana coast. The explosion killed 11 workers, injured 17 others, ignited an intense fire that burned until the Deepwater Horizon sunk 36 hours later, and resulted in a massive release of crude oil that is now considered the greatest environmental disaster in U.S. history. The total volume of oil released into the Gulf of Mexico is estimated to have been 205 million gallons (4.9 million barrels), dwarfing the 11-million gallon *Exxon Valdez* spill of 1989. Efforts to prevent the released oil from making landfall included the use of dispersants, some of which were injected at the wellhead to reduce the amount of oil that reached the surface. Extensive media attention has been directed toward the ecological impacts of released oil on beaches, marshes, birds, turtles, and marine mammals. Many scientists, however, are also concerned about how oil and dispersants may affect the unusual and biologically-rich communities of the Gulf of Mexico seafloor.

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. 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 Deepwater Horizon blowout highlights the vulnerability of deep-sea ecosystems to impacts from human activity. Increasingly, the biological communities associated with deepwater corals, cold seeps, and hydrothermal vents are the focus of efforts to protect these resources that may have enormous value to human well-being. One of the ways that scientists will assess possible impacts from the blowout is to compare photographic surveys that were done before the blowout in

Images from Page 1 top to bottom:
Lophelia pertusa on the seafloor. Note extended polyp on the right. Image courtesy of Ian MacDonald, NOAA.
http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/sept1/media/lophelia_insitu_close.html

Video monitors inside Jason control van allow scientists and Jason crew to see all seafloor operations. Tim Shank (right) records observations using the "Virtual Van" software. Image courtesy Troy Kitch, NOAA.
http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug31/media/controlvan.html

Preserved specimens collected during *Lophelia* II 2009. Image courtesy Troy Kitch, NOAA.
http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug23/media/species_jar.html

Viosca Knoll Wreck: The stempost of the wreck is covered in *Lophelia*, stalk barnacles, *Acesta* clams and anemones. A little *Eumunida picta* is also evident in the lower corner. Image courtesy Stephanie Lessa, NOAA.
http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/sept6/media/7_biostem.html

some areas, with follow-up surveys of the same areas after the blowout. In this lesson, students will compare species occurrence data from five biotope types found on Viosca Knoll in the Gulf of Mexico, about 60 km from the Deepwater Horizon wellhead.

Learning Procedure

1. To prepare for this lesson:
   a) Review introductory essays for the *Lophelia* II 2010: Cold Seeps and Deep Reefs Expedition at http://oceanexplorer.noaa.gov/explorations/10lophelia/welcome.html. You may also want to consider showing students some images of deep-sea ecosystems from http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/photolog/photolog.html. You can find a virtual tour of a cold-seep community at http://www.bio.psu.edu/cold_seeps.
   b) Review procedures and questions on the *Deep-Sea Biotopes Inquiry Guide*, and make a copy of the *Inquiry Guide* for each student group.
   c) Review the essay on The Ecology of Gulf of Mexico Deep-Sea Hardground Communities (http://oceanexplorer.noaa.gov/explorations/06mexico/background/hardgrounds/hardgrounds.html), and decide whether to provide this to students as a reading assignment.
   d) Download an image of a photomosaic from http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/hires/madrepora_mosaic_hires.jpg.
   e) Download PDF files containing images from the Viosca Knoll survey upon which this lesson is based (Sulak *et al.*, 2008; http://fl.biology.usgs.gov/coastaleco/OFR_2008-1148_MMS_2008-015/index.html; scroll to the bottom of the Web page to link to specific sections of the report). Master Appendix D contains images of many of the organisms found in the survey, and Master Appendix E contains images of the biotopes that the survey identified.

2. Briefly introduce the *Lophelia* II 2010: Cold Seeps and Deep Reefs Expedition, and describe, in general terms, cold-seep and deepwater coral communities. If desired, show images from the Web page referenced in Step 1a. Lead a brief discussion about the Deepwater Horizon blowout. Tell students that many scientists are concerned about possible impacts from the blowout on deep-sea ecosystems, and ask why these systems might be important enough to justify such concern.

3. Tell students that one way scientists may be able to find out whether deep-sea ecosystems have been affected is to compare photographic surveys that were done before the blowout with follow-up surveys. Show students the photomosaic image downloaded in Step 1d, and explain that this image is made up of about 70 separate photographs that cover a total area of about 25 square meters (that is, the area is a square measuring roughly five meters on each side).

Show students images of two or three of the biotopes illustrated in Master Appendix E (Sulak *et al.*, 2008). Explain that while photographs of different biotopes may appear obviously different, it is important to be able to quantify these differences; particularly when trying to assess the impacts of unusual events. Point out that large photomosaics may include many different species, and it may be difficult to decide how different one mosaic is from another. A simple way to reduce this difficulty is to calculate a number called the coefficient of community (also known as the Jaccard coefficient), which compares the number of species that two mosaics have in common with the total number of different species in the two mosaics combined:

$$C = a / (b + c - a)$$

where C is the coefficient of community, a is the number of species in common to both mosaics, b is the total number of species found in one of the mosaics, and c is the total number of species found in the other mosaic (note that we must subtract a in the denominator because otherwise the species found in both mosaics would be counted twice).

This coefficient will range from 0 to 1, and the closer it is to 1 the more similar the communities are. Be sure students understand that this technique can be used to compare "before-and-after" photomosaics to assess whether unusual events have had an impact on biological communities.

4. Provide each student group with a copy of the *Deep-Sea Biotopes Inquiry Guide*, and assign each group one of the sites to describe in detail (you may choose to have these descriptions prepared in written form, presented orally, or both). Be sure students understand that they are to calculate to coefficient of community for each pair of sites, so they will calculate a total of 10 coefficients.

5. Lead a discussion of students' results. The following points should be included:
   - Coefficients of community for each of the site combinations are:

Site 1 & Site 2	0.5
Site 1 & Site 3	0
Site 1 & Site 4	0.25
Site 1 & Site 5	0.2
Site 2 & Site 3	0
Site 2 & Site 4	0.125
Site 2 & Site 5	0.333
Site 3 & Site 4	0.083
Site 3 & Site 5	0.1
Site 4 & Site 5	0.125

- Based on the calculated Coefficients of Community, Sites 1 and 2 are most similar, and these sites are least similar to Site 3. These results suggest that these are probably different biotopes, since the highest Coefficient of Community was only 0.5.

- Dominant phyla at each site are:
  Sites 1 and 2 — Porifera and Cnidaria
  Site 3 — Echinodermata, Annelida, and Bacterial Phyla
  Site 4 — Cnidaria, Echinodermata, and Arthropoda
  Site 5 — Cnidaria and Bacterial Phyla

  Students should realize that with the possible exception of Sites 1 and 2, each site has a distinctly different composition than the others, confirming that these are probably different biotopes.

- The three most abundant species at Sites 1, 2, and 4 are all carnivores. This is contrary to conventional ideas about food webs in which the most abundant organisms are primary producers. Ask students how this result might be explained. Students should realize that the primary producers might be microscopic organisms not visible in photomosaics. It is also possible that animals at these sites are dependent upon primary production that takes place elsewhere and is carried into the sites by currents.

- Species present at Site 3 include *Vestimentifera* worms and *Beggiatoa* bacterial mats, both of which are organisms that obtain their nutrition from chemosynthesis, and are among the primary producers in food webs at this site. The sea urchin *Echinus*, also present at Site 3, is often described as an algal grazer. Since there are no algae present at this site, it is reasonable to hypothesize that this species of *Echinus* may be grazing on the *Beggiatoa* mats. These bacterial mats are also abundant at Site 5, along with carnivorous cnidarians. It is not clear that the organisms at Site 5 are part of the same food web, but even if they are, other organisms are probably more directly involved with the nutrition of the cnidarians.

- Students should realize that the coefficient of community comparing two surveys at the same site should be very high if the site has remained unchanged between the surveys, because the same species should be present during both surveys. Lower values of the coefficient of community comparing surveys of the same site before and after an event such as the Deepwater Horizon blowout mean that the number of species or the kinds of species has changed. This would suggest that the site had been affected by this event or some other disturbance that occurred during the interval between the surveys.

The BRIDGE Connection

www.vims.edu/bridge/ - Type "Gulf of Mexico" in the "Search" box on the left for resources and links about the Gulf.

The "Me" Connection

Have students write a brief essay describing how they might be personally affected if deep-sea ecosystems in the Gulf of Mexico were disrupted by a catastrophic event.

Connections to Other Subjects

Life Science, Social Studies, English/Language Arts

Assessment

Students' answers to inquiry guide questions and class discussions provide opportunities for assessment.

Extensions

See http://www.education.noaa.gov/Ocean_and_Coasts/Oil_Spill.html for links to multimedia resources, lessons and activities, data, and background information from NOAA's Office of Education.

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 Medicine from the Sea.

Other Relevant Lesson Plans from NOAA's Office of Ocean Exploration and Research

Forests of the Deep Ocean

(from the *Lophelia* II 2008 Expedition)

http://oceanexplorer.noaa.gov/explorations/08lophelia/background/edu/media/forests.pdf

Focus: Morphology and ecological function in habitat-forming deep-sea corals (Life Science)

Students will describe at least three ways in which habitat-forming deep-sea corals benefit other species in deep-sea ecosystems, explain at least three ways in which the physical form of habitat-forming deep-sea corals contributes to their ecological function, and explain how habitat-forming deep-sea corals and their associated ecosystems may be important to humans. Students will also be able to describe and discuss conservation issues related to habitat-forming deep-sea corals.

Monsters of the Deep
(from the Expedition to the Deep Slope 2007)
http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/monsters.pdf

Focus: Predator-prey relationships between cold-seep communities and the surrounding deep-sea environment (Life Science)

Students will describe major features of cold-seep communities, and list at least five organisms typical of these communities; and will be able to infer probable trophic relationships among organisms typical of cold-seep communities and the surrounding deep-sea environment. Students will also be able to describe the process of chemosynthesis in general terms, contrast chemosynthesis and photosynthesis, and describe at least five deep-sea predator organisms.

One Tough Worm
(from the Expedition to the Deep Slope 2007)
http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/worm.pdf

Focus: Physiological adaptations to toxic and hypoxic environments (Life Science)

Students will explain the process of chemosynthesis, explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps, and describe three physiological adaptations that enhance an organism's ability to extract oxygen from its environment. Students will also be able to describe the problems posed by hydrogen sulfide for aerobic organisms, and explain three strategies for dealing with these problems.

Life is Weird
(from the 2006 Expedition to the Deep Slope)
http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/gom_06_weird.pdf

Focus: Biological organisms in cold-seep communities (Life Science)

Students will describe major features of cold-seep communities, and list at least five organisms typical of these communities. Students will also be able to infer probable trophic relationships among organisms typical of cold-seep communities and the surrounding deep-sea environment, and describe the process of chemosynthesis in general terms, and contrast chemosynthesis and photosynthesis.

Other 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/explorations/10lophelia/welcome.html – Web site for the *Lophelia* II 2010: Cold Seeps and Deep Reefs Expedition

http://oceanexplorer.noaa.gov/edu/guide/gomdse_edguide.pdf – *Gulf of Mexico Deep-Sea Ecosystems Education Materials Collection Educators' Guide*

Schroeder, W. 2003. NOAA Office of Ocean Exploration: Quick Look Report project number OE_2003_011: The occurrence and ecology of deep-water corals and associated communities; http://docs.lib.noaa.gov/OEDV/GOM_Deep_habitats_2003/docs/Schroeder/QLReport_Lophelia.doc

http://oceanexplorer.noaa.gov/edu/development/online_development.html – Online professional development opportunities, including *Lessons from the Deep: Exploring the Gulf of Mexico's Deep-Sea Ecosystems*

http://celebrating200years.noaa.gov/edufun/book/welcome.html#book - A free printable book for home and school use introduced in 2004 to celebrate the 200th anniversary of NOAA; nearly 200 pages of lessons focusing on the exploration, understanding, and protection of Earth as a whole system

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 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

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

Kellogg, C. A., 2009, Gulf of Mexico deep-sea coral ecosystem studies, 2008–2011: U.S. Geological Survey Fact Sheet 2009–3094, 4 pp. available at http://pubs.usgs.gov/fs/2009/3094/

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
- Understandings about scientific inquiry

Content Standard C: Life Science
- Populations and ecosystems
- Diversity and adaptations of organisms

Content Standard E: Science and Technology
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives
- Populations, resources, and environments
- Risks and benefits
- Science and technology in society

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.
The Earth has one big ocean with many features.

Fundamental Concept g. The ocean is connected to major lakes, watersheds and waterways because all major watersheds on Earth drain to the ocean. Rivers and streams transport nutrients, salts, sediments and pollutants from watersheds to estuaries and to the ocean.

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

Essential Principle 2.
The ocean and life in the ocean shape the features of the Earth.
Fundamental Concept a. Many earth materials and geochemical cycles originate in the ocean. Many of the sedimentary rocks now exposed on land were formed in the ocean. Ocean life laid down the vast volume of siliceous and carbonate rocks.

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 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 a. The ocean affects every human life. It supplies freshwater (most rain comes from the ocean) and nearly all Earth's oxygen. It moderates the Earth's climate, influences our weather, and affects human health.
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 c. Over the last 40 years, use of ocean resources has increased significantly, therefore the future sustainability of ocean resources depends on our understanding of those resources and their potential and limitations.

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 send your comments to:
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Deep-Sea Biotopes Inquiry Guide

1. Table 1 lists organisms that were identified in photomosaics showing bottom areas on Viosca Knoll in the Gulf of Mexico. Your assignment is to compare each of these mosaics with the others to determine how similar they are. The same type of comparisons can be used with "before-and-after" photomosaics to assess whether unusual events have had an impact on biological communities.

   To make this comparison, calculate the coefficient of community:

   $$C = a / (b + c - a)$$

   where C is the coefficient of community, a is the number of species in common to both mosaics, b is the total number of species found in one of the mosaics, and c is the total number of species found in the other mosaic. This coefficient will range from 0 to 1, and the closer it is to 1 the more similar the communities are.

   Record the results of your calculations in the Data Table. Which of the five sites are most similar? Which are least similar?

Data Table

Site Comparison	Coefficient of Community
Site 1 & Site 2	
Site 1 & Site 3	
Site 1 & Site 4	
Site 1 & Site 5	
Site 2 & Site 3	
Site 2 & Site 4	
Site 2 & Site 5	
Site 3 & Site 4	
Site 3 & Site 5	
Site 4 & Site 5	

2. Examine the column in Table 1 that corresponds to the site assigned to your group by your teacher. Prepare a description of this site that includes:
   - The name of the most common species;
   - The probable role of the three most abundant species in the food web at this site; and
   - Major animal phyla represented on this site.

3. Suppose these sites were re-surveyed following the Deepwater Horizon blowout. How could Coefficient of Community calculations comparing pre- and post-blowout survey results at each site help determine whether the blowout had affected any of these sites?

Table 1
Relative Abundance of Organisms Identified from Sites on Viosca Knoll
(higher numbers are more abundant)

Species	Site 1	Site 2	Site 3	Site 4	Site 5
Brown *Lophelia*	1			9	
White *Lophelia*	6	2		10	5
Bamboo Coral	9	9			5
Pink Black Coral		1			5
Red Black Coral	3	8		6	
White Black Coral	7	7			
Black Cerianthid					9
Pink Cerianthid					5
Unknown Anemone		4			6
Venus Fly Trap Anemone	5	5			
White Anemone	10			7	7
Demo Sponge	1				
Glass Sponge	4	3			
Squat Lobster				1	
Unknown Crabs/Lobsters				2	
Echinus			6	3	
Brisingid				6	
Crinoid				4	
Vestimentifera			8		
Beggiatoa Bacterial Mat			7		8
Hydroid	2				
Unknown Alcyonarian				8	

from Sulak, *et al*. 2008