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2007 Cayman Island Twilight Zone

Let's Go to the Video Tape!
(adapted from the 2003 Gulf of Mexico Deep Sea Habitats Expedition)

Focus
Characteristics of biological communities on deep-water reef habitats

Grade Level
7-8 (Life Science)

Focus Question
How do species diversity and number of biological organisms vary among deep-water reef habitats?

Learning Objectives
Students will be able to recognize and identify some of the fauna groups found in deep-sea coral reef communities.

Students will be able to infer possible reasons for observed distribution of groups of animals in deep-sea coral reef communities.

Students will be able to discuss the meaning of "biological diversity," and will be able to compare and contrast the concepts of "variety" and "relative abundance" as they relate to biological diversity.

Given abundance and distribution data of species, students will be able to calculate an appropriate numeric indicator that describes the biological diversity of a community.

Materials
❒ Copies of "Results of a Video Survey on a Deep-water *Lophelia* Reef," one copy for each student group

Audio/Visual Materials
None

Teaching Time
One 45-minute class period

Seating Arrangement
Groups of 2-4 students

Maximum Number of Students
30

Key Words
Lophelia pertusa
Deep-water coral
Habitat
Biological diversity
Diversity index
Species richness
Species evenness

Background Information
Coral reefs provide habitats for some of the most diverse biological communities on Earth. Most people have seen photographs and video images of shallow-water coral reefs, and many have visited these reefs in person. Historically, scientists have believed that reef-building corals were confined to relatively shallow depths because many of these corals have microscopic algae called zooxanthellae (pronounced "zoh-zan-THEL-ee") living inside their soft tissues. These algae are often important for the corals' nutrition and growth, but require sunlight for photosynthesis. The maximum depth for reef-building corals was assumed to be

about 150 m, since light levels below this depth are not adequate to support photosynthesis. Recently, though, ocean explorers have discovered extensive mounds of living coral in depths from 400 m to 700 m – depths at which there is virtually no light at all! These deep-water corals do not contain zooxanthellae, and do not build the same types of reef that are produced by shallow-water corals. But branches of deep-water coral species such as Lophelia pertusa grow on mounds of dead coral branches that can be several meters deep and hundreds of meters long. Recent studies indicate that the diversity of species in deep-water coral ecosystems may be comparable to that of coral reefs in shallow waters, and that there are just as many species of deep-water corals (slightly more, in fact) as there are species of shallow-water corals.

Because of the high species diversity found on shallow- and deep-water reefs, these ecosystems are proving to be very promising sources of powerful new antibiotic, anti-cancer and anti-inflammatory drugs. In addition, these reefs provide habitat for important food resources, and shallow reefs are an important part of coastal recreation and tourism industries and protect shorelines from erosion and storm damage. Despite the direct importance of coral reefs to many aspects of human well-being, shallow- and deep-water reefs are both threatened by human activities. Shallow-water reefs are damaged by sewage, chemical pollution, careless tourists, boat anchors, and abnormally high temperatures that result in thermal stress. Commercial fisheries, particularly fisheries that use trawling gear, cause severe damage to both shallow and deep-water habitats. Deep-sea coral communities can also be damaged by oil and mineral exploration, ocean dumping, and unregulated collecting.

Around the world, shallow water coral reefs have been intensively studied by scientists using self-contained underwater breathing (SCUBA) equipment, while deep coral systems are being investigated with submersibles and remotely operated underwater vehicles (ROVs). Recent explorations have found a third type of coral ecosystem between depths of 50 m and 150 m: light-limited deep reefs living in what coral ecologists call the "twilight zone" (these areas are also referred to as "deep fore reefs" because they represent the most seaward portion of the reef). These reefs have been studied much less than shallow and deep-water reefs because they are beyond the safe range of conventional SCUBA equipment, yet are too shallow and close to shore to justify the use of expensive submersibles and ROVs. The few studies of twilight zone reefs suggest that these ecosystems not only include species unique to this depth range, but may also provide important refuges and nursery habitats for corals and fishes that inhabit shallower reefs. This is particularly important in areas where shallow reefs are severely stressed, since twilight zone coral ecosystems may provide a natural option for recovery.

Scientific exploration of twilight zone coral reef ecosystems is urgently needed to provide information for their protection, as well as to identify potentially important sources of drugs and other biological products from organisms that are endemic to these systems. Helping to meet this need is the primary focus of the 2007 Ocean Explorer Cayman Island Twilight Zone Expedition. Scientists on the expedition plan to make extensive use of video recordings to document fauna associated with deep coral fore reefs. In this lesson, students will analyze data from a study of a *Lophelia* reef, and make inferences about factors that may affect the distribution of organisms on and around deep coral reefs.

Learning Procedure

1. To prepare for this lesson, review the introductory essays for the 2007 Cayman Island Twilight Zone Expedition at http://oceanexplorer.noaa.gov/explorations/07twilightzone/welcome.html.

If you are not already familiar with coral reefs, you may also want to review the coral reef tutorials at nos.noaa.gov/education/kits/corals/, and http://oceanexplorer.noaa.gov/explorations/islands01/background/islands/sup10_lophelia.html for more background on *Lophelia* reefs.

2. Briefly review background information on the Cayman Island Twilight Zone Expedition, and the overall characteristics of coral reefs in shallow water, deep water, and intermediate depths (the "twilight zone"). Be sure students understand that shallow- and deepwater reefs both have a high diversity of species and large number of individual organisms, and that deep fore reef areas probably do as well, but are virtually unexplored. Compare and contrast deep-water reef corals (e.g., *Lophelia pertusa*) with reef-building corals in shallow water.
3. Review the concept of biological diversity. Two measurements are frequently used by scientists to describe the abundance of species and individuals within an area (or environment):
   - **Species Diversity (S)** - the number of species in the environment; and
   - **Species Evenness (or equitability)** - a measure of how evenly individuals are distributed among these species. Evenness is greatest when species are equally abundant.

The simplest measure of species diversity is the number of species present in an environment. This is called "species richness." But there is more to diversity than just the number of species in an environment. A community that has more or less equal numbers of individuals within the species present is usually thought of as more diverse than a community that is dominated by one species. For example, samples from two separate communities might each contain the same seven species, with distribution of individuals as follows:

Species	**Number of Individuals**	
	Community 1	Community 2
Species a	44	8
Species b	2	8
Species c	2	8
Species d	2	8
Species e	2	8
Species f	2	8
Species g	2	8
Total	**56**	**56**

Our notion of what "diversity" means leads us to consider Community 2 as more diverse than Community 1, even though they both have the same number of species and total individuals. [NOTE: You can demonstrate this more tangibly with an activity from The Moonsnail Project's mini-lecture on diversity at http://www.moonsnail.org/Mini_Diversity.htm; this site also has a related activity demonstrating the effect of sample size on diversity estimates].

Because of the importance of both species evenness and species richness to our idea of diversity, some measures of diversity include a way of including both concepts. One commonly used measure of species diversity that includes proportions of individuals is the Shannon-Weaver information function which is:

$$H = -\Sigma\, p_i \ln p_i$$

Where:
H is the diversity index
ln is the natural logarithm
i is an index number for each species present in a sample
p_i is the number of individuals within a species (ni) divided by the total number of individuals (N) present in the entire sample

To calculate the diversity index H, you multiply the proportion (p_i) of each species in the sample times the natural log of that same value (ln p_i), then sum (Σ) the values for each species, and finally multiply by minus 1. You can find tables of natural logs on the Web (e.g., http://www.geocities.com/CapeCanaveral/Hall/1216numtab/nlogs.htm), and it is also among the functions included on most electronic calculators.

The table below illustrates the calculation.

	Number of Individuals	Proportion (p_i)	$\ln(p_i)$	$p_i \ln(p_i)$
Species a	3	3÷47 = 0.064	-2.749	0.064 • -2.749 = -.176
Species b	5	5÷47 = 0.106	-2.244	0.106 • -2.244 = -.238
Species c	10	10÷47 = 0.213	-1.546	0.213 • -1.546 = -.329
Species d	6	6÷47 = 0.128	-2.056	0.128 • -2.056 = -.263
Species e	12	12÷47 = 0.255	-1.366	0.255 • -1.366 = -.348
Species f	7	7÷47 = 0.149	-1.904	0.149 • -1.904 = -.284
Species g	4	4÷47 = 0.085	-2.465	0.085 • -2.465 = -.123
Total	47			-1.761 (= $\Sigma p_i \ln p_i$)
H				-1 • $\Sigma p_i \ln p_i$ = 1.761

So, the diversity index H = 1.761.

Species diversity is often used as a measure of environmental health. A stressed environment typically has a lower number of species with one or two species (those adapted to the stress) having many more individuals than the other species. Species diversity tends to increase at the edges of environments (ecotones) where conditions are more variable. For more background on species diversity, visit the Moonsnail Project's mini-lecture on diversity (referenced above), and the Arbor Project's Web page on bird biodiversity at http://www.cees.iupui.edu/Outreach/SEAM/Biodiversity_Exercise.htm.

3. Provide students or student groups with copies of "Results of a Video Survey on a Deep-water *Lophelia* Reef." Tell students that they are to compare the communities of macrofauna on the five habitats, and make inferences about possible causes for patterns they observe. Say that they should consider total number of species and the biological diversity (calculated as explained above) in each habitat. You may want to assign one or two habitats to each group to reduce the time required to do the diversity calculations. Students should consider "unidentified" organisms as representing one species, and omit unquantified species from diversity calculations. Each group should prepare a brief written report in which they summarize their results and make inferences about factors that may affect the distribution organisms in these habitats.

4. Lead a discussion of students' results and inferences. Students should observe that diversity was highest in the dead *Lophelia* habitat, and lowest on the silt/clay bottom. Possible explanations for this are that dead *Lophelia* would provide a great deal of spatial variety and consequently many different types of shelter that could accommodate a wide range of organisms. Living *Lophelia* habitats might have a similar spatial variety, but the living corals might have defense mechanisms to reduce competition for space with other species. The silt/clay bottom would obviously have much less spatial variety, few solid points of attachment for sessile species, and could present fouling problems for filter feeders.
The *Lophelia* rubble habitat had the lowest num-

ber of species, but the highest average density of individuals. This suggests that this habitat may be unsuitable for many of the species found in other habitats. Since species that can live in the rubble environment face less competition from other species, more individuals of rubble-tolerant species could exist in this habitat.

None of the species observed in the mixed stone habitat was confined to this habitat alone, but also occurred in *Lophelia* and/or the silt/clay habitats. Studies of other *Lophelia* reefs have shown that biological communities on these reefs are not unique to *Lophelia* habitats, but usually occur elsewhere as well.

Invite students to comment on the video survey methodology. Students should realize that this technique gives only a partial picture of the communities being studied. Two obvious examples are microbial organisms and organisms dwelling with the sediments. Both are invisible to the video camera, but almost certainly present. Both groups are very important components of many deep-sea bottom communities and are probably present in large numbers. Inclusion of these species could significantly change the overall impression of the biological communities associated with these habitats.

The BRIDGE Connection

http://www.vims.edu/bridge/reef.html

The "Me" Connection

Have students write a short essay describing the major groups of organisms in their own biological community, and how they are connected to other communities.

Connections to Other Subjects

English/Language Arts

Assessment

Written reports prepared in Step 4 provide an opportunity for assessment.

Extensions

1. Visit oceanexplorer.noaa.gov to keep up to date with the latest 2007 Cayman Island Twilight Zone Expedition discoveries, and to find out what researchers are learning about deep-water coral communities.

2. Assign one or more of the biological groups found in these habitats to each student group, and have the groups prepare short presentations on their assigned group including a description of the animal(s), habitat, food source(s) and feeding habits and an illustration.

Multimedia Learning Objects

http://www.learningdemo.com/noaa/ – Click on the links to Lessons 3 and 12 for interactive multimedia presentations and Learning Activities on deep-sea corals and biotechnology.

Other Relevant Lesson Plans from the Ocean Exploration Program

Big Fleas Have Little Fleas [http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_fleas.pdf] (7 pages, 1Mb) (from the 2003 Mountains in the Sea Expedition)

Focus: Physical structure in benthic habitats (Life Science)

In this activity, students will recognize that natural structures and systems often display recurrent complexity over many scales of measurement, infer the importance of structural complexity to species diversity and abundance in benthic habitats, and discuss ways that octocorals may modify seamount habitats to make these habitats more suitable for other species.

Climate, Corals, and Change [http://oceanexplorer.noaa.gov/explorations/06davidson/background/edu/climate.pdf] (14 pages, 441k) (from the 2006 Exploring Ancient Coral Gardens Expedition)

Focus (Physical Science - Paleoclimatology)

In this activity, students will be able to explain the concept of "paleoclimatological proxies" and describe at least two examples, describe how oxygen isotope ratios are related to water temperature, and interpret data on oxygen isotope ratios to make inferences about the growth rate of deep-sea corals. Students will also be able to define "forcing factor" and will be able to describe at least three forcing factors for climate change and discuss at least three potential consequences of a warmer world climate.

Design a Reef! [http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_aquarium.pdf] (5 pages, 408k) (from the Gulf of Mexico Deep Sea Habitats 2003 Expedition)

Focus: Niches in coral reef ecosystems (Life Science)

In this activity, students will compare and contrast coral communities in shallow water and deep water, describe the major functions that organisms must perform in a coral ecosystem, and explain how these functions might be provided in a miniature coral ecosystem. Students will also be able to explain the importance of three physical factors in coral reef ecosystems and infer the fundamental source of energy in a deep-water coral community.

Biodiversity of Deep Sea Corals [http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_deepseacoral.pdf] (3 pages, 1Mb) (from the Mountains in the Sea 2003 Expedition)

Focus: Deep-sea corals

In this activity, students will research life found on tropical coral reefs to develop an understanding of the biodiversity of the ecosystem; students will research life found in deep-sea coral beds to develop an understanding of the biodiversity of the ecosystem; students will compare the diversity and adaptations of tropical corals to deep-sea corals.

Deep Sea Coral Biodiversity [http://oceanexplorer.noaa.gov/explorations/deepeast01/background/education/media/deepseacorals.pdf] (3 pages, 152k) (from the 2001 Deep East Expedition)

Focus: George's Bank

In this activity, students will research life found on tropical coral reefs to develop an understanding of the biodiversity of the ecosystem; students will research life found in deep-sea coral beds to develop an understanding of the biodiversity of the ecosystem; and students will compare the diversity and adaptations of tropical corals to deep-sea corals.

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 – Web site for NOAA's Ocean Exploration program

http://oceanexplorer.noaa.gov/gallery/livingocean/livingocean_coral.html – Ocean Explorer image gallery

http://www-biol.paisley.ac.uk/courses/Tatner/biomedia/units/cnid1.htm – Phylum Cnidaria on Biomedia of the Glasgow University Zoological Museum on the Biological Sciences, University of Paisley, Scotland Web site; includes explanations of the major classes, a glossary of terms and diagrams and photos

http://www.calacademy.org/research/izg/calwildfall2000.pdf – Article from California Wild: "Stinging Seas - Tread Softly In Tropical Waters" by Gary C. Williams; an introduction to the venomous nature of tropical cnidarians, why and how they do it

http://www.cees.iupui.edu/Education/Workshops/Project_Seam/Exercises/bird_biodiversity_exerciese.htm – Biodiversity exercises from the Center for Earth and Environmental Science, Indiana University – Purdue University, Indianapolis

http://www.mcbi.org/publications/pub_pdfs/Deep-Sea%20Coral%20issue%20of%20Current.pdf – A special issue of Current: the Journal of Marine Education on deep-sea corals.

http://www.mesa.edu.au/friends/seashores/index.html – "Life on Australian Seashores" by Keith Davey on the Marine Education Society of Australasia Web site, with an easy introduction to Cnidaria, including their method of reproduction

http://www.moonsnailproject.org/Mini_Diversity.htm – The Moonsnail Project's mini-lecture on diversity

http://www.oceanicresearch.org/ – The Oceanic Research Group Web site; lots of photos, but note that they are very explicit about their copyrights; check out "Cnidarians: Simple but Deadly Animals!" by Jonathan Bird, which provides an easy introduction designed for classroom use

http://www.ucmp.berkeley.edu/cnidaria/cnidaria.html – Introduction to Cnidaria from the University of California Museum of Paleontology

http://www.wwf.org.uk/filelibrary/pdf/darwin_mounds.pdf – Report on the Darwin Mounds, a recently discovered group of hard-bottom habitats in the United Kingdom's 200 nm offshore zone

Maxwell, S. 2005. An Aquatic Pharmacy: The Biomedical Potential of the Deep Sea. Current 21(4):31-32; available online at http://www.mcbi.org/what/what_pdfs/Current_Magazine/Pharmacy.pdf

Frame, C. and H. Gillelan. 2005. Threats to deep-sea corals and their conservation in U.S. waters. Current 21(4):46-47; available online at http://www.mcbi.org/what/what_pdfs/Current_Magazine/Threats_Conservation.pdf

Morgan, L. E. 2005. What are deep-sea corals? Current 21(4):2-4; available online at http://www.mcbi.org/what/what_pdfs/Current_Magazine/What_are_DSC.pdf

Mortensen, P. B., M. Hovland, T. Brattegard, and R. Farestveit. 1995. Deep water bioherms of the scleractinian coral *Lophelia pertusa* (L) on the Norwegian shelf: Structure and associated megafauna. Sarsia 80:145-158. – The technical journal article upon which this activity is based

Pickrell, J. 2004. Trawlers Destroying Deep-Sea Reefs, Scientists Say. National Geographic News. http://news.nationalgeographic.com/news/2004/02/0219_040219_seacorals.html

Reed, J. K. and S. W. Ross. 2005. Deep-water reefs off the southeastern U.S.: Recent discoveries and research. Current 21(4):33-37; available online at http://www.mcbi.org/what/what_pdfs/Current_Magazine/Southeastern_US.pdf

Roberts, S. and M. Hirshfield. Deep Sea Corals: Out of sight but no longer out of mind. http://www.oceana.org/fileadmin/oceana/uploads/reports/oceana_coral_report_final.pdf — Background on deep-water coral reefs

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

- Interdependence of organisms

Content Standard F: Science in Personal & Social Perspectives
- Natural resources
- Environmental quality

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 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 e. The ocean is three-dimensional, offering vast living space and diverse habitats from the surface through the water column to the seafloor. Most of the living space on Earth is in the ocean.

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 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.

For More Information

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http://oceanexplorer.noaa.gov

Student Handout

Results of a Video Survey on a Deep-water *Lophelia* Reef

(adapted from Mortensen, et al., 1995)

Organism	Density of Individuals (No. of Individuals/10m^2)				
	Silt/Clay Bottom	Mixed Stone	*Lophelia* Rubble	Dead *Lophelia*	Living *Lophelia*
Porifera					
Crustose sponges	*	*	*	*	*
Other sponges	*	*	*	*	*
Phakellia ventilabrum	0.17	1.98	0.44	0.67	0.03
Isops phlegraei	0.10	2.19	0.13	1.41	0.81
Axinella infundibuliformis	0.03	0.29	0.31	0.17	
Geodia sp.				0.07	
Cnidaria					
Cerianthus lloydii	*	0.01			
Paragorgia arborea		0.04	0.03	0.28	0.43
Paramuricea placomus		0.02		0.05	0.19
Trachymuricea kuekenthali				0.10	0.07
Primnoa resedaeformis		0.01		0.29	0.69
Actinostola callosa				0.02	0.07
Bolocera tuediae	0.02	0.02	0.03	0.10	0.09
Unidentified anthozoa					0.03
Unidentified stylasterid		0.01		0.02	
Unidentified hydroid		*			0.01
Polychaeta					
Unidentified sabellid				0.02	0.03
Crustacea					
Unidentified brachyuran					*
Lithodes maja		0.01		*	
Munida sarsi	0.34	0.29	4.03	0.33	0.31
Echiuridae					
Unidentified Echiuridae	0.02	0.02	0.090	0.03	0.31
Mollusca					
Neptunea despecta	*				
Acesta excavata		0.04		0.14	0.52
Bryozoa					
Unidentified bryozoan		0.03			

Student Handout *(continued)*

Organism	Density of Individuals (No. of Individuals/10m²)				
	Silt/Clay Bottom	Mixed Stone	*Lophelia* Rubble	Dead *Lophelia*	Living *Lophelia*
Echinodermata					
Unidentified asteroid	0.03				0.01
Cidaris cidaris	0.02	0.02		0.12	0.04
Hathrometra sarsii			0.06	0.03	0.19
Henricia sanguinolenta	0.14	0.07	0.03	0.12	0.11
Unidentified ophiuroid		0.02	0.03		
Parastichopus tremulus	0.08	0.02			
Teleostei					
Pollachiusvirens	1.10	1.39	3.25	3.03	1.15
Brosme brosme	0.02	0.02		0.02	0.03
Sebastes sp.	0.07	0.33	0.78	0.90	2.61
Chimaera monstrosa	0.03	*			
Gadus morhua					0.01
Unidentified teleost	0.09	0.02			*

* – present but not quantified