2006 Gulf of Mexico Expedition

How Diverse is That?

(adapted from the 2003 Windows to the Deep Expedition)

Focus
Quantifying biological diversity

Grade Level
9-12 (Life Science)

Focus Question
What do ecologists mean when they say a biological community is "diverse?"

Learning Objectives
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 in two communities, students will be able to calculate an appropriate numeric indicator that describes the biological diversity of these communities.

Materials
- ❒ Copies of "Species Distribution in Seep and Non-Seep Areas at Two Sites on the California Slope," one copy for each student group
- ❒ (Optional) Pieces of colored paper and a coffee-can size container (if you choose to do activities from The Moonsnail Project's mini-lecture on biodiversity)

Audio/Visual Materials
- ❒ Overhead projector, transparencies, and markers, or marker board, or chalk board

Teaching Time
One or two 45-minute class periods plus time for group research

Seating Arrangement
Groups of 4-6 students

Maximum Number of Students
30

Key Words
Cold seeps
Methane hydrate
Clathrate
Diversity
Diversity index
Species richness
Species evenness

Background Information
On August 28, 2005, Hurricane Katrina swept across the Gulf of Mexico, gathering strength to become a Category 3 storm that proved to be the most costly—and one of the most deadly—hurricanes in U.S. history. Four days later, the Department of the Interior's Minerals Management Service (MMS) reported that oil production in the Gulf of Mexico had been reduced by over 90 percent, and that natural gas production had been reduced by more than 78 percent. In the weeks that followed, fuel shortages and soaring prices underscored the importance of the Gulf of Mexico to petroleum supplies in the United States.

In fact, 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 focussed 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 provide energy to terrestrial and shallow-water communities through processes in which sunlight is the basic energy source).

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. Hydrogen sulfide is abundant in the water erupting from hydrothermal vents, and is used by chemosynthetic bacteria that are the base of the vent community food chain. These bacteria obtain energy by oxidizing hydrogen sulfide to sulfur:

$$CO_2 + 4H_2S + O_2 > CH_2O + 4S + 3H_2O$$

(carbon dioxide plus sulfur dioxide plus oxygen yields organic matter, sulfur, and water). Visit http://www.pmel.noaa.gov/vents/home.html 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 areas where hydrocarbon gases (often methane and hydrogen sulfide) and oil seep out of sediments. These areas, known as cold seeps, are commonly found along continental margins, and (like hydrothermal vents) are home to many species of organisms that have not been found anywhere else on Earth. Typical features of communities that have been studied so far include mounds of methane hydrate (an ice-like substance composed of methane molecules held in a crystalline cage of water molecules) that are home to polychaete worms. 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.

Where hydrogen sulfide is present, large tubeworms (phylum Annelida) known as vestimentiferans are often found, sometimes growing in clusters of millions of individuals. These unusual animals do not have a mouth, stomach, or gut. Instead, they have a large organ called a trophosome that contains chemosynthetic bacteria. Vestimentiferans have a structure called a plume that consists of filaments (sometimes referred to as "tentacles") that extend into the water. The tentacles are bright red due to the presence of hemoglobin which can absorb hydrogen sulfide and oxygen which are transported to the bacteria in the trophosome. The bacteria produce organic molecules that provide nutrition to the tube worm. A similar symbiotic relationship is found in clams and mussels that have chemosynthetic bacteria living in their gills.

Bacteria are also found living independently from other organisms in large bacterial mats. A variety of other organisms are also found in cold seep communities, and probably use tubeworms, mussels, and bacterial mats as sources of food. These include snails, eels, starfish, crabs, lobsters, isopods, sea cucumbers, and fishes. Specific relationships between these organisms have not been well-studied.

Deepwater chemosynthetic communities 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. 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. MMS has the dual responsibility of managing these resources as well as protecting the environment from adverse impacts that might result from development activities. In 1988, MMS issued regulations specifically targeted toward protecting deepwater chemosynthetic communities. An essential part of the protection strategy requires identification of seafloor areas that could support chemosynthetic communities. These areas must be avoided by drilling, anchoring, pipeline installation, and other activities that involve disturbing the seafloor. Developing better ways to locate deepwater biological communities, evaluating their sensitivity to impacts from human activities, and understanding more about the ecological relationships of organisms that inhabit these communities are key objectives of the 2006 Gulf of Mexico Expedition.

One of the ways scientists describe and compare biological communities is based on the abundance of species and individuals within a specific area. Two measurements are frequently used:

- 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.moonsnailproject.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 -1.

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 www.cees.iupui.edu/Education/Workshops/Project_Seam/Exercises/bird_biodiversity_exerciese.htm.

This lesson is based on an investigation to compare the fauna of sediments in methane seep and non-seep environments off the California coast to determine whether the community structure and nutritional sources of seep infauna were distinct from those in non-seep, margin sediments (Levin, et al., 2000).

	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.

The table below illustrates the calculation:

Learning Procedure

1. To prepare for this lesson, review
   - Introductory essays for the 2006 Gulf of Mexico Expedition at http://oceanexplorer.noaa.gov/explorations/06mexico/

2. Lead a brief discussion of deep-sea chemosynthetic communities. Contrast chemosynthesis with photosynthesis: in 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. Contrast hydrothermal vent communities with cold-seep communities. Visit http://www.bio.psu.edu/cold_seeps for a virtual tour of a cold seep community.

   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. Briefly describe MMS regulations that require petroleum development companies to locate potentially sensitive biological communities and avoid these during exploration and development activities. Tell students that a key objective of the 2006 Gulf of Mexico Expedition is to identify different types of deep-sea communities and identify those that are particularly vulnerable to impacts from human activities.

   Discuss the concept of biodiversity. Show students the sample data given in "Background" and ask them which of the two communities they intuitively feel is most diverse. This should lead to the concepts of species richness and evenness. Say that the Shannon-Weaver information function is a commonly used index of diversity that incorporates both concepts of species richness and evenness. Work through the sample calculation, and be sure students understand the steps involved.

3. Tell students that expeditions to deep-sea communities often discover new and unusual communities of living organisms, and that calculations of diversity indices provide a way to compare various communities. Distribute copies of "Species Distribution in Seep and Non-Seep Areas at Two Sites on the California Slope" to each student group. Tell students that they are to calculate the Shannon-Weaver diversity index for each of the four communities included in the sample, and to use this index to compare the biodiversity of seep and non-seep communities at the two sites (A and B). You may want to divide the assignment among the student groups (each group calculating the diversity index for one or two communities). You may also want to suggest that students use a spreadsheet program to speed the calculation process. One approach is to set up columns in the spreadsheet to make the calculations described in the sample diversity index calculation in "Background," then enter the species data for the appropriate communities.

4. Have student groups summarize their results on an overhead transparency, marker board, etc. This summary should resemble the the table at the bottom of this page.

   Have each student write an individual analysis of these results. Lead a group discussion of these results. Students should realize that the diversity of seep and non-seep communities dif-

	Site A		Site B	
	Non-Seep Area	Seep Area	Non-Seep Area	Seep Area
Diversity Index H	1.56	0.57	1.46	1.43

fered considerably at Site A, with the seep site having the lower diversity index. Point out that even though the total number of individuals at the seep site was greater than at the non-seep site, the seep site was heavily dominated by one species (*Mediomastus* spp.); consequently, the diversity index was lower. In contrast, there was little difference in diversity between the seep and non-seep communities at Site B. Ask students to speculate on the possible reasons for these results. The investigators who gathered these data concluded that the seep areas sampled were relatively small and possibly transient, and that the fauna in these communities were not highly adapted to or dependent upon the methane-seep environment. Conditions may have been more severe at the seep area in Site A, excluding some species that were found in the surrounding non-seep environment.

Lead a discussion on the significance of biodiversity. The fact that diversity often decreases in stressed environments suggests that high diversity may be "good." On the other hand, it is important to realize that diversity can also be increased by changed or variable conditions (such as those at the boundary of two different types of habitat) or following a major change in a mature ecosystem (such as a forest fire). Encourage pro and con discussion of these questions, but be sure to challenge students to defend their positions. At some point in this discussion, ask students whether "unknown" is the same as "unimportant." You may want to cite examples in which obscure species proved to be directly important to humans (such as the Madagascar periwinkle that provides a powerful cancer treatment).

The Bridge Connection

www.vims.edu/bridge/ – Enter "cold seep" in the "Search" box, then click "Search" to display entries on the Bridge Web site for cold seep communities; enter "diversity" in the "Search" box, then click "Search" to display entries on the Bridge Web site for biodiversity.

The "Me" Connection

Have students write a short essay contrasting and comparing the importance of diversity in ocean communities to their own communities.

Connections to Other Subjects

English/Language Arts, Earth Science, Mathematics

Assessment

Written and oral group reports provide opportunities for assessment.

Extensions

1. Visit http://oceanexplorer.noaa.gov/explorations/06mexico/ for daily logs and updates about discoveries being made by the 2006 Gulf of Mexico Expedition.

2. Couple this lesson with "What's the Big Deal?" [http://oceanexplorer.noaa.gov/explorations/03windows/background/education/media/03win_bigdeal.pdf] and/or "Life is Weird" explorations/06mexico/background/edu/edu.html to give students opportunities to explore the significance of methane hydrates and chemosynthetic biological communities in greater detail.

Resources

NOAA Learning Objects

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 the Ocean Exploration Program

Biochemistry Detectives (8 pages, 480k)) (from the 2002 Gulf of Mexico Expedition) [http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_biochem.pdf]

Focus: Biochemical clues to energy-obtaining strategies (Chemistry)

Students will be able to explain the process of chemosynthesis, explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps, and describe three energy-obtaining strategies used by organisms in cold-seep communities. Students will also be able to interpret analyses of enzyme activity and $\delta^{13}C$ isotope values to draw inferences about energy-obtaining strategies used by organisms in cold-seep communities.

This Old Tubeworm (10 pages, 484k)) (from the 2002 Gulf of Mexico Expedition) [http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_oldtube.pdf]

Focus: Growth rate and age of species in cold-seep communities

Students will be able to explain the process of chemosynthesis, explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps, and construct a graphic interpretation of age-specific growth, given data on incremental growth rates of different-sized individuals of the same species. Students will also be able to estimate the age of an individual of a specific size, given information on age-specific growth in individuals of the same species.

Hot Food (4 pages, 372k) (from the 2003 Gulf of Mexico Deep Sea Habitats Expedition) [http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_hotfood.pdf]

Focus: Energy content of hydrocarbon substrates in chemosynthesis (Chemistry)

Students will compare and contrast photosynthesis and chemosynthesis as processes that provide energy to biological communities, and given information on the molecular structure of two or more substances, will make inferences about the relative amount of energy that could be provided by the substances. Students will also be able to make inferences about the potential of light hydrocarbons as an energy source for deep-water coral reef communities.

Cool Corals (7 pages, 476k) (from the 2003 Life on the Edge Expedition) [http://oceanexplorer.noaa.gov/explorations/03edge/background/edu/media/cool.pdf]

Focus: Biology and ecology of *Lophelia* corals (Life Science)

Students will describe the basic morphology of *Lophelia* corals and explain the significance of these organisms, interpret preliminary observations on the behavior of *Lophelia* polyps, and infer possible explanations for these observations. Students will also discuss why biological communities associated with *Lophelia* corals are the focus of major worldwide conservation efforts.

Submersible Designer (4 pages, 452k) (from the 2002 Galapagos Rift Expedition) [http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr9-12_l4.pdf]
Focus: Deep Sea Submersibles

Students will understand that the physical features of water can be restrictive to movement; students will understand the importance of design in underwater vehicles by designing their own submersible; Students will understand how submersibles such as ALVIN and ABE, use energy, buoyancy, and gravity to enable them to move through the water.

The Benthic Drugstore (4 pages, 360k) (from the 2003 Deep Sea Medicines Expedition) [http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/Meds_Drugstore.pdf]

Focus: Pharmacologically active chemicals derived from marine invertebrates (life science)

Students will be able to identify at least three pharmacologically active chemicals derived from marine invertebrates, describe the disease-fighting action of at least three pharmacologically active chemicals derived from marine invertebrates, and infer why sessile marine invertebrates appear to be promising sources of new drugs.

What's the Difference? (15 pages, 1Mb) (from the 2003 Mountains in the Sea Expedition) [http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_difference.pdf]

Focus: Identification of biological communities from survey data (Life Science)

Students will be able to calculate a simple similarity coefficient based upon data from biological surveys of different areas, describe similarities between groups of organisms using a dendrogram, and infer conditions that may influence biological communities given information about the groupings of organisms that are found in these communities.

Living in Extreme Environments (12 pages, 1Mb) (from the 2003 Mountains in the Sea Expedition)
[http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_extremeenv.pdf]

Focus: Biological Sampling Methods (Biological Science)

Students will understand the use of four methods commonly used by scientists to sample populations; students will understand how to gather, record, and analyze data from a scientific investigation; students will begin to think about what organisms need in order to survive; students will understand the concept of interdependence of organisms.

Cut-off Genes (12 pages, 648k) (from the 2004 Mountains in the Sea Expedition)
[http://oceanexplorer.noaa.gov/explorations/04mountains/background/edu/media/MTS04.genes.pdf]

Focus: Gene sequencing and phylogenetic expressions (Life Science)

Students will be able to explain the concept of gene-sequence analysis; and, given gene sequence data, students will be able to draw inferences about phylogenetic similarities of different organisms.

What was for Dinner? (5 pages, 400k) (from the 2003 Life on the Edge Expedition)
[http://oceanexplorer.noaa.gov/explorations/03edge/background/edu/media/dinner.pdf]

Focus: Use of isotopes to help define trophic relationships (Life Science)

Students will describe at least three energy-obtaining strategies used by organisms in deep-reef communities and interpret analyses of $\delta^{15}N$, $\delta^{13}C$, and $\delta^{34}S$ isotope values.

Other Resources and Links

http://www.gomr.mms.gov/index_common.html – Minerals Management Service Web site

http://www.gomr.mms.gov/homepg/lagniapp/chemcomp.pdf – "Chemosynthetic Communities in the Gulf of Mexico" teaching guide to accompany a poster with the same title, introducing the topic of chemosynthetic communities and other ecological concepts to middle and high school students.

http://www.gomr.mms.gov/homepg/lagniapp/lagniapp.html – Kids Page on the Minerals Management Service Web site, with posters, teaching guides and other resources on various marine science topics http://www.coast-nopp.org/ – Resource Guide from the Consortium for Oceanographic Activities for Students and Teachers, containing modules, guides, and lesson plans related to oceanography and coastal processes

http://cosee-central-gom.org/ – Web site for The Center for Ocean Sciences Education Excellence: Central Gulf of Mexico (COSEE-CGOM)

http://www.energybulletin.net/4901.html – Article "Out of Gas: Sediments in Northern Gulf of Mexico Not Right for Methane Gas Hydrate Formation, Study Shows" published by Georgia Research Tech News, 21 Mar 2005

http://www.ridge2000.org/eo/index.html – Links to other deep ocean exploration Web sites

http://www-ocean.tamu.edu/education/oceanworld-old/resources/general_links.htm – Links to other ocean-related Web sites

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://dbhs.wvusd.k12.ca.us/webdocs/ChemTeamIndex.html – Web site for help with basic chemical concepts including oxidation-reduction reactions

http://www.geol.ucsb.edu/faculty/valentine/Valentine%202002.pdf – Review of methane-based chemosynthetic processes

Van Dover, C. L., et al. 2003. Blake Ridge methane seeps: characterization of a soft-sediment, chemosynthetically based ecosystem. Deep-Sea Research Part I 50:281–300. (available as a PDF file at http://www.geomar.de/projekte/sfb_574/abstracts/vanDover_et_al_2003.pdf)

http://www.accessexcellence.org/BF/bf01/arp/bf01p1.html – verbatim transcript of a slide show on coping with toxic sulfide environments

Levin, L. A., et al. 2000. Do methane seeps support distinct macrofauna assemblages? Observations on community structure and nutrition from the northern California slope and shelf. Marine Ecology Progress Series 208:21-39. Available online at http://www.int-res.com/articles/meps/208/m208p021.pdf

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

- Interactions of energy and matter

Content Standard C: Life Science

- Interdependence of organisms

Content Standard D: Earth and Space Science

- Geochemical cycles

Content Standard F: Science in Personal and Social Perspectives

- 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 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 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, clima-

tologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

Send Us Your Feedback

We value your feedback on our lesson plans. Please send your comments to:
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Student Handout

Species Distribution in Seep and Non-Seep Areas at Two Sites on the California Slope
(Condensed from Levin, *et al.*, 2000)

Species	Site A		Site B	
	Non-Seep Area Total Individuals	Seep Area Total Individuals	Non-Seep Area Total Individuals	Seep Area Total Individuals
Cnidaria				
Obelia sp.	0	2	0	0
Anemone	0	0	6	0
Scolanthus sp.	0	1	0	0
Edwardsid sp.	3	0	0	0
Platyhelminthes				
Turbellaria	0	0	1	0
Polycladida	0	1	0	0
Nemertea				
Unidentified nemertean	1	4	1	1
Cerebratulus sp.	1	0	1	0
Lineus bilineatus	0	1	0	0
Annelida				
Amaeana occidentalis	6	200	8	0
Ampharete arctica	1	0	1	0
Apoprionospio pygmaea	0	0	7	4
Aricidea catherinae	1	4	2	0
Chaetozone cf. *hartmanae*	300	0	0	0
Chaetozone columbiana	0	120	0	0
Eteone cf. *spilotus*	3	0	1	0
Glycera cf. *convoluta*	0	0	3	0
Glycinde sp.	1	2	0	0
Heteromastus filobranchus	150	180	0	0
Levinsenia oculata	0	1	0	0
Magelona sp.	0	1	0	0
Mediomastus spp.	0	10200	0	1
Myriochele sp.	1	0	0	0
Orbinia johnsoni	0	0	1	0
Pholoe glabra	2	5	0	0
Prionospio (Minuspio) lighti	3	140	3	0
Proceraea sp.	0	1	0	0
Scoletoma tetraura	200	190	220	1
Spiochaetopterus costarum	0	1	0	0
Sternaspis fossor	6	7	0	0