Expedition to the Deep Slope 2007

This Old Tubeworm

[adapted from the 2002 Gulf of Mexico Expedition]

Focus

Growth rate and age of species in cold-seep communities

Grade Level

9-12 (Life Science)

Focus Question

What effect may conditions in cold-seep communities have upon growth rate and longevity among organisms typical of these communities?

Learning Objectives

Students will be able to explain the process of chemosynthesis.

Students will be able to explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.

Students will be able to construct a graphic interpretation of age-specific growth, given data on incremental growth rates of different-sized individuals of the same species.

Students will 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.

Materials

❒ Copies of "Lamellibrachia Growth Rate Data Sheet" and "Growth Data Worksheet," one of each sheet for each student group

Audio/Visual Materials

❒ None

Teaching Time

Two 45-minute class periods

Seating Arrangement

Pairs of two students

Maximum Number of Students

30

Key Words

Cold seeps
Methane hydrate ice
Chemosynthesis
Vestimentifera
Trophosome
Growth rate
Longevity

Background Information

Cold seeps are areas of the ocean floor where gases (such as methane and hydrogen sulfide) and oil seep out of sediments. These areas are commonly found along continental margins, and are home to many species of organisms that have not been found anywhere else on Earth. Unlike biological communities in shallow-water ocean habitats, cold-seep communities do not depend upon sunlight as their primary source of energy. Instead, these communities derive their energy from chemicals through a process called chemosynthesis (in contrast to photosynthesis in which sunlight is the basic energy source). Some chemosynthetic communities have been found near 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 and http://www.divediscover.whoi.edu/vents/index.html for more information and activities on hydrothermal vent communities.

Recently, increasing attention has been focused on cold seeps in the Gulf of Mexico, an area that produces more petroleum than any other region in the United States. Responsibility for managing exploration and development of mineral resources on the Nation's outer continental shelf is a central mission of the U.S. Department of the Interior's Minerals Management Service (MMS). In addition to managing the revenues from mineral resources, an integral part of this mission is to protect unique and sensitive environments where these resources are found. MMS scientists are particularly interested in finding deep-sea chemosynthetic communities in the Gulf of Mexico, because these are unique communities that often include species that are new to science and whose potential importance is presently unknown. In addition, the presence of these communities often indicates the presence of hydrocarbons at the surface of the seafloor.

The 2006 Expedition to the Deep Slope was focused on discovering and studying the sea floor communities found near seeping hydrocarbons on hard bottom in the deep Gulf of Mexico. The sites visited by the Expedition were in areas where energy companies will soon begin to drill for oil and gas. A key objective was to provide information on the ecology and biodiversity of these communities to regulatory agencies and energy companies. Dives by scientists aboard the research submersible ALVIN revealed that hydrocarbons seepage and chemosynthetic communities were present at all ten sites visited by the Expedition. The most abundant chemosynthetic organisms seen were mussels and vestimentiferan tubeworms. Expedition to the Deep Slope 2007 is focused on detailed sampling and mapping of four key sites visited in 2006, as well as exploring new sites identified from seismic survey data.

Vestimentiferan tubeworms are presently classified in the phylum Annelida, and are sometimes included among the Pogonophora (Vestimentifera were formerly classified within the phylum Pogonophora; recently Pogonophora and Vestimentifera have been included in the phylum Annelida). Pogonophora means "beard bearing," and refers to the fact that many species in this phylum have one or more tentacles at their anterior end. Tentacles of vestimentiferans are bright red because they contain hemoglobin (like our own red blood cells). Vestimentiferans can grow to more than 10 feet long, sometimes in clusters of millions of individuals, and are believed to live for more than 100 years. They do not have a mouth, stomach, or gut. Instead, they have a large organ called a trophosome that contains chemosynthetic bacteria. Hemoglobin in the tubeworm's blood absorbs hydrogen sulfide and oxygen from the water around the tentacles, and then transports these raw materials to bacteria living in the trophosome. The bacteria produce organic molecules that provide nutrition to the tubeworm. Similar relationships are found in clams and mussels that have chemosynthetic bacteria living in their gills. 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, sea stars, crabs, isopods, sea cucumbers, and fishes. Specific relationships between these organisms have not been well-studied.

In this lesson, students will investigate some aspects of growth and longevity in vestimentiferan tubeworms often associated with deep-sea chemosynthetic communities.

Learning Procedure

1. To prepare for this lesson, visit http://oceanexplorer.noaa.gov/explorations/07mexico/welcome.html for informa-

tion about Expedition to the Deep Slope 2007. You may want to visit http://www.bio.psu.edu/cold_seeps for a virtual tour of a cold-seep community, and http://www.bio.psu.edu/hotvents for a virtual tour of a hydrothermal vent community.

2. Briefly introduce Expedition to the Deep Slope 2007, and lead a discussion of deep-sea chemosynthetic communities. Contrast chemosynthesis with photosynthesis. Point out that there are a variety of chemical reactions that can provide energy for chemosynthesis.

3. Distribute a "Lamellibrachia Growth Rate Data Sheet" to each student group. Explain that these are results taken from studies on vestimentiferans at two cold-seep sites in the Gulf of Mexico. In these studies, the worms' outer tube was marked with a blue stain. After one or more years, stained individuals were collected, and new tube growth was measured as the length of the unstained segment of the tube between the stain mark and the end of the worm (visit http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/stainedtubeworms_600.html and http://oceanexplorer.noaa.gov/explorations/02mexico/background/tubeworms/media/2bluetubies.html for pictures of stained tubeoworms, and http://oceanexplorer.noaa.gov/explorations/02mexico/background/tubeworms/media/1tubies_sealink.html for an image of how a "bush" of tubeworms is collected). Have each group plot growth rate (y-axis) as a function of length of the worm (x-axis). Students should draw a curve that passes through or near as many data points as possible.

4. Discuss the plotted data. These graphs show that growth rate of the tubeworms becomes slower as the size of the animals increases. This is common among most species of animals.

5. Next we want to estimate the age of largest animals. The researchers did this by fitting a curvilinear regression line to the data, then integrating the growth equation over the interval [0, tube length]. An alternative, but less precise, approach can be used to estimate an approximate age. This approach involves breaking an animal's growth history into a series of intervals, determining how long it took to grow through each interval, then adding these individual growth times together to arrive at an approximate age (integration is based on a similar approach for a nearly infinite number of intervals). The curve drawn in step #2 represents the growth history of an "average" tubeworm, based on growth data from 35 individual tubeworms. This curve will be used to estimate the age of a tubeworm 200 cm long.

   Distribute one "Growth Data Worksheet" to each group. The first interval to be considered is 0 - 10 cm. Have students use their plots from step #2 to find the predicted growth rates (in cm per year) at size = 0 cm and size = 10 cm. Tell students to find the average of these two numbers, and assume that this average represents how fast the animal was growing between the sizes of 0 and 10 cm. Now, calculate how long (in years) it would take to grow 10 cm by dividing 10 cm by the average growth rate (cm/yr). Round answers to the nearest tenth of a year, and enter the result in the last column of the worksheet.

   Repeat this process for the remaining intervals (10 - 20 cm, 20 - 30 cm ....190 - 200 cm), finding the average growth rate for the interval, calculating how long it would take the animal to grow 10 cm, and entering the result in the last column of the worksheet.

   Add all of the entries in the last column of the worksheet to find the total time required to grow through all intervals from 0 through 200 cm. This sum is the estimated age of a tubeworm whose length is 200 cm.

6. Have each group present their results. Each group will probably be somewhat different due

to the need to estimate intermediate points on the graphs. The overall trend, however, should show that a 200 cm tubeworm from the sites studied would be over 200 years old. Discuss these results, asking students whether it is reasonable to suppose that tubeworms could be this old. *[Why not; after all, how much do we really know about average life expectancy among deep-sea organisms?].*

Ask what factors might contribute to this longevity. *[Such as a very stable environment; absence of many predators or competitors because of extreme conditions to which these animals are especially well-adapted]*.

Is it likely that other species could also be relatively old, compared to similar species in other communities?
[Again, why not, since the factors that might help tubeworms live for a long time could also help other species do the same]

Tell students that tubeworms at hydrothermal vents grow much more rapidly (some species grow 85 cm per year) than tubeworms in cold seep communities, but the longevity of vent tubeworms has been estimated to be less than 100 years. Ask for possible explanations for these differences. *[Vent communities exist in very transient conditions, and things may change dramatically at any time. Cold seep communities are based on slow leakage of hydrocarbon materials from beneath the sea floor, and may not experience much change over very long periods of time]*.

The Bridge Connection

www.vims.edu/bridge/vents.html

The "Me" Connection

Have students write a short essay contrasting life in two communities: The first community exists in a remote valley where weather patterns and local physical conditions combine to produce a very stable and livable climate that remains virtually unchanged from year to year. The other community exists in a region that frequently experiences significant volcanic activity, including eruptions of poisonous gases and superheated air. Students may assume that the first community offers unusually long life-spans to individuals living there, while the second community offers unusually rapid growth and maturation of individuals (couples typically have their first child at the age of 7), as well as the prospect of sudden and unpleasant death at any time.

Connections to Other Subjects

English/Language Arts, Earth Science

Assemssment

Have students prepare individual written interpretations of their results prior to oral presentations in Step #6.

Extensions

Visit http://oceanexplorer.noaa.gov/explorations/07mexico/welcome.html to keep up to date with the latest Expedition to the Deep Slope 2007 discoveries.

Multimedia Learning Objects

http://www.learningdemo.com/noaa/ Click on the links to Lessons 3, 5, 6, 11, and 12 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Chemosynthesis and Hydrothermal Vent Life, Deep-Sea Benthos, Energy from the Oceans, and Food, Water, and Medicine from the Sea.

Other Relevant Lessons from the Ocean Exploration Program

What's Down There? (8 pages; 278kb PDF) (from the Cayman Islands Twilight Zone 2007 Expedition) http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/whatsdown.pdf

Focus: Mapping Coral Reef Habitats
In this activity, students will be able to access data on selected coral reefs and manipulate these

data to characterize these reefs, and explain the need for baseline data in coral reef monitoring programs. Students also will be able to identify and explain five ways that coral reefs benefit human beings, and identify and explain three major threats to coral reefs.

The Benthic Drugstore (8 pages; 278kb PDF) (from the Cayman Islands Twilight Zone 2007 Expedition) http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/drugstore.pdf

Focus: Pharmacologically-active chemicals derived from marine invertebrates (Life Science/Chemistry)

In this activity, 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.

Watch the Screen! (8 pages; 278kb PDF) (from the Cayman Islands Twilight Zone 2007 Expedition) http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/watchscreen.pdf

Focus: Screening natural products for biological activity (Life Science/Chemistry)
In this activity, students will be able to explain and carry out a simple process for screening natural products for biological activity, and will be able to infer why organisms such as sessile marine invertebrates appear to be promising sources of new drugs.

Now Take a Deep Breath (8 pages; 278kb PDF) (from the Cayman Islands Twilight Zone 2007 Expedition) http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/breath.pdf

Focus: Physics and physiology of SCUBA diving (Physical Science/Life Science)

In this activity, students will be able to define Henry's Law, Boyle's Law, and Dalton's Law of Partial Pressures, and explain their relevance to SCUBA diving; discuss the causes of air embolism, decompression sickness, nitrogen narcosis, and oxygen toxicity in SCUBA divers; and explain the advantages of gas mixtures such as Nitrox and Trimix and closed-circuit rebreather systems.

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)

In this activity, 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 ^{13}C isotope values to draw inferences about energy-obtaining strategies used by organisms in cold-seep communities.

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)

In this activity, 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)

In this activity, 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

In this activity, 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, use energy, buoyancy, and gravity to enable them to move through the water.

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)

In this activity, students will understand the use of four methods commonly used by scientists to sample populations; will understand how to gather, record, and analyze data from a scientific investigation; will begin to think about what organisms need in order to survive; and 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)
In this activity, students will be able to explain the concept of gene-sequence analysis; and, given gene sequence data, 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)

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

Chemosynthesis for the Classroom (9 pages, 276k) (from the 2006 Expedition to the Deep Slope) http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/GOM%2006%20Chemo.pdf

Focus: Chemosynthetic bacteria and succession in chemosynthetic communities (Chemistry/Biology)

In this activity, students will observe the development of chemosynthetic bacterial communities and will recognize that organisms modify their environment in ways that create opportunities for other organisms to thrive. Students will also be able to explain the process of chemosynthesis and the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.

How Diverse is That? (12 pages, 296k) (from the 2006 Expedition to the Deep Slope) http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/GOM%2006%20Diverse.pdf

Focus: Quantifying biological diversity (Life Science)

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.

C.S.I. on the Deep Reef (Chemotrophic Species Investigations, That Is) (11 pages, 280k) (from the 2006 Expedition to the Deep Slope) http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/GOM%2006%20CSI.pdf

Focus: Chemotrophic organisms (Life Science/Chemistry)

In this activity, students will describe at least three chemotrophic symbioses known from deep-sea habitats and will identify and explain at least three indicators of chemotrophic nutrition.

This Life Stinks (9 pages, 280k) (from the 2006 Expedition to the Deep Slope) http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/GOM%2006%20Stinks.pdf

Focus: Methane-based chemosynthetic processes (Physical Science)

In this activity, students will be able to define the process of chemosynthesis, and contrast this process with photosynthesis. Students will also explain the process of methane-based chemosynthesis and explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.

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/explorations/07mexico/welcome.html – Follow Expedition to the Deep Slope 2007 daily as documentaries and discoveries are posted each day for your classroom use.

http://www.bio.psu.edu/People/Faculty/Fisher/fhome.htm – Web site for the senior biologist on Expedition to the Deep Slope 2007

http://www.rps.psu.edu/deep/ – Notes from another expedition exploring deep-sea communities

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.

Bergquist, D. C., F. M. Williams, and C. R. Fisher. 2000. Longevity record for deep-sea invertebrate. *Nature* 403:499-500. – Technical journal article upon which this activity is based.

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

- Chemical reactions

Content Standard C: Life Science

- Interdependence 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 sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Essential Principle 7.
The ocean is largely unexplored.

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

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

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

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

Send Us Your Feedback

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

Lamellibrachia Growth Rate Data Sheet

Length of Tubeworm (cm)	Growth Rate (cm per year)
5	4.75
10	4.25
10	4.75
10	3.75
20	4.25
20	3.60
20	3.00
30	3.20
30	2.80
40	2.75
40	3.00
50	2.00
50	2.75
50	2.40
60	2.00
70	2.25
70	1.25
80	1.50
90	1.75
90	0.75
100	1.25
110	1.00
120	0.75
130	0.75
130	1.00
130	0.50
150	0.50
150	0.75
150	0.25
170	0.50
170	0.10
180	0.70
180	0.10
200	0.05
200	0.45

Student Handout

Growth Data Worksheet

Growth Interval (cm)	Growth Rate at Beginning of Interval (cm/yr)	Growth Rate at End of Interval (cm/yr)	Average Growth Rate (cm/yr)	Time to Grow 10 cm (yr)
0 – 10				
10 – 20				
20 – 30				
30 – 40				
40 – 50				
50 – 60				
60 – 70				
70 – 80				
80 – 90				
90 – 100				
100 – 110				
110 – 120				