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2006 Exploring Ancient Coral Gardens

Feeding in the Flow

(adapted from The Charleston Bump 2003 Expedition)

Focus
Effect of water currents on food capture in corals

Grade Level
9-12 (Life Science)

Focus Question
How do water currents affect the food capture by particle feeders?

Learning Objectives
Students will be able to describe at least two ways in which current flow may affect food capture by particle-feeding organisms.

Students will be able to explain how interactions between current flow and the morphology of a particle-feeding organism may affect the organism's ability to capture food.

Students will be able to identify at least two environmental factors in addition to current flow that may affect the morphology of reef-building corals.

Materials
- ❒ Copies of "Data on Water Flow and Prey Capture by Three Corals," one for each student group

Audio/Visual Materials
- ❒ Chalk board, marker board, or overhead projector with transparencies for group discussions

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

Seating Arrangement
Groups of 4-6 students

Maximum Number of Students
30

Key Words
Davidson Seamount
Habitat
Deep-water coral
Hard coral
Soft coral
Zooxanthellae
Microhabitat
Polyp
Nematocysts

Background Information
Seamounts are undersea mountains formed by volcanic processes, either as isolated peaks or as chains that may be thousands of miles long with heights of 3,000 m (10,000 ft) or more. Compared to the surrounding ocean waters, seamounts have high biological productivity, and provide habitats for many species of plant, animal, and microbial organisms. Recently, increasing attention is being directed toward deep water coral species found on seamounts. In contrast to shallow-water coral reefs, deep-sea coral communities are virtually unknown to the general public and have received much less

scientific study. Yet, deep-water coral ecosystems may have a diversity of species comparable to that of corals reefs in shallow waters. Because many seamount species are endemic (that is, they are found nowhere else), these ecosystems may be a unique feature of seamounts, and are likely to be important for several reasons. First, because of their high biological productivity, these communities are directly associated with important commercial fisheries. Moreover, deep-sea corals have been identified as promising sources for new drugs to treat cancer and other diseases, as well as natural pesticides and nutritional substances. Recent discoveries suggesting that some corals may be hundreds of years old means that these organisms can provide important records of past climactic conditions in the deep ocean. Apart from these potential benefits, deep-sea corals are part of our world heritage—the environment we hand down from one generation to the next.

Despite their importance, there is growing concern about the impact of human activities on these ecosystems. Commercial fisheries, particularly fisheries that use trawling gear, cause severe damage to seamount habitats. Scientists at the First International Symposium on Deep Sea Corals (August, 2000), warned that more than half of the world's deep-sea coral reefs have been destroyed. Ironically, some scientists believe that destruction of deep-sea corals by bottom trawlers is responsible for the decline of major fisheries such as cod.

In addition to impacts from fisheries, deep-sea coral communities can also be damaged by oil and mineral exploration, ocean dumping, and unregulated collecting. Other impacts may result from efforts to mitigate increasing levels of atmospheric carbon dioxide. One proposed mitigation is to sequester large quantities of the gas in the deep ocean, either by injecting liquid carbon dioxide into deep ocean areas where it would form a stable layer on the sea floor or by dropping torpedo-shaped blocks of solid carbon dioxide through the water column to eventually penetrate deep into benthic sediments. While the actual impacts are not known, some scientists speculate that since coral skeletons are made of calcium carbonate, their growth would probably decrease if more carbon dioxide were dissolved in the ocean.

The Davidson Seamount, located about 75 miles southwest of Monterey, CA, was the first geological feature to be described as a "seamount" in 1933. The now-extinct volcanoes that formed this and other nearby seamounts were different from typical ocean volcanoes. While the typical undersea volcano is steep-sided, with a flat top and a crater, seamounts in the Davidson vicinity are formed of parallel ridges topped by a series of knobs. These observations suggest that the ridges were formed by many small eruptions that occurred 3 to 5 million years apart. Typical undersea volcanoes are formed by more violent eruptions that gush out lava more frequently over several hundred thousand years.

Although it was the first recognized seamount and is relatively near the U.S. coast, the Davidson Seamount is still 99.98% unexplored. In 2002, a NOAA-funded expedition to the Seamount found a wide variety of organisms, including extensive deep-water coral communities. Among many intriguing discoveries were observations of animals that had never been seen live before, as well as indications that some coral species may be several hundred years old (visit http://oceanexplorer.noaa.gov/explorations/02davidson/davidson.html and http://montereybay.noaa.gov/reports/2002/eco/ocean.html for more information about the 2002 Expedition).

The 2006 Exploring Ancient Coral Gardens Expedition is focussed on learning more about deep-sea corals at Davidson Seamount, with four general goals:

- to understand why deep-sea corals live where they do on the seamount;

- to determine the age and growth patterns of the bamboo coral;
- to improve the species list and taxonomy of corals from the seamount; and
- to share the exciting experience with the public through television and the Internet.

One of the key factors that determine where an organism lives is the availability of suitable food. Water movement is known to be an important environmental factor that affects the distribution of many coral species. In this activity, students will analyze data from previous research on water motion and feeding behavior of corals, and will infer how water currents and external morphology may affect the food capture of some particle-feeding organisms.

Learning Procedure

1. To prepare for this lesson, read the introductory essays for the 2006 Exploring Ancient Coral Gardens Expedition at http://oceanexplorer.noaa.gov/explorations/06davidson/welcome.html, and review the NOAA Learning Object on deep-sea corals at http://www.learningdemo.com/noaa/.

2. Lead a brief introductory discussion of the Davidson Seamount and the 2002 and 2006 Ocean Exploration expeditions to the area. You may want to show students some images from the 2002 Expedition Web site (http://oceanexplorer.noaa.gov/explorations/02davidson/davidson.html). Tell students that water motion has a significant influence on many biological communities. Say that deep water corals are one of the most conspicuous organisms seen in previous visits to the Davidson Seamount, and probably create microhabitats for other organisms by modifying water motion over the bottom.

3. Review the basic morphological features of corals. Be sure students understand that the corals we often see in pictures are colonies of individual animals called polyps. The polyps obtain food from the surrounding water with tentacles that contain stinging cells called nematocysts. Zooplankton and particulate materials are the primary food of most corals. Corals with large polyps can consume larger food items; even small fishes in some cases! Most shallow-water corals have symbiotic single-celled algae called zooxanthellae (pronounced zoh-zan-THEL-ee) living within their tissues. These symbionts are capable of photosynthesis, and supply some of the corals' nutritional requirements. Deep-water corals that live in virtual darkness do not have these symbionts. Be sure students understand that coral colonies may grow in a variety of shapes: branches, boulders, plates, fans, whips, etc. Visit http://sanctuaries.nos.noaa.gov for more background information and images of corals and coral reefs.

4. Tell students that both shallow- and deep-water corals are often exposed to strong water motion. Have students brainstorm how water motion may affect corals. Extremely strong currents or waves can break the colonies or dislodge them from the bottom (branched growth forms are particularly vulnerable to this). Very strong water motion can also flatten the soft tentacles, making feeding more difficult. On the positive side, currents can bring food to the polyps (an important benefit for animals that can't move around very much), and may also carrry away waste products, and keep sediment from settling on the surface of the corals.

5. Provide each student group with a copy of "Data on Water Flow and Prey Capture by Three Corals." You may want to have students use the internet or printed references to find out about the basic physical structure of the three species included on the data sheet. Alternatively, you can provide the following information:
   - *Madracis mirabilis* – small polyps (about 3-4 mm diameter); overall growth form is narrow

branches, roughly the size of a pencil

- *Montastrea cavernosa* – large polyps (about 11-14 mm diameter); overall growth form is boulders that range from fist-size to several meters in diameter
- *Porities porites* – small polyps (about 3-4 mm diameter); overall growth form is branched, with individual branches about finger-size

Note that these species are shallow-water corals, but their basic body form and feeding strategy is quite similar to corals found in deep water, so the results of these studies can provide a starting point for what might take place on the Davidson Seamount.

Tell students that researchers placed colonies of these three species in plankton-free underwater cages for 6-24 hours, then moved the colonies into underwater enclosures on reef areas that were exposed to different current strengths. The enclosures were screened to exclude zooplankton. Brine shrimp cysts ("eggs") were injected into the enclosures to study how well the corals could remove particulate material under different current strengths. The corals were allowed to feed on zooplankton for about 20 minutes, then were preserved so that the stomach contents of individual polyps could be examined.

6. Have student groups graph the experimental data to obtain information on how current flow correlates with food capture for each of the three coral species. Have each group prepare a short report summarizing their conclusions based on these graphs. Have each group present their conclusions and summarize the pooled results for the entire class. Students should recognize that increased current flow was correlated with increased particle (cyst) capture by *M. mirabilis* and *M. cavernosa*. Students may notice that *M. cavernosa* had fairly high capture rates, even at lower flow speeds. *P. porites* had low capture rates at all flow speeds, though the highest capture rates also occurred at flow rates of 9 -11 cm/sec and declined at the highest flow speeds.

7. Lead a discussion of these results. Increasing flow speeds would be expected to bring more food past the coral polyps in a given amount of time, and the fact that increasing capture rates were correlated with increasing flow suggests that the corals were able to take advantage of this. Ask students why *M. cavernosa* seemed to have fairly high capture rates at lower current speeds. One explanation is that the low, boulder-shaped growth form of this species can take advantage of particles that settle out of the water column by gravity, adding to the particles obtained through direct capture by the polyps' tentacles. Another factor might be the larger size of the *M. cavernosa* polyps.

   Ask why rates of particle capture by *P. porites* seemed to decline at flow speeds above 11 cm/sec. A possible explanation is that the polyps' tentacles were flattened or collapsed at the high flow speeds, reducing their effectiveness in capturing particles. Tell students that tentacles of *M. mirabilis* have been found to collapse at flow rates of 10 - 15 cm/sec, but colonies of this coral have still been able to capture particles from flows of 40-50 cm/sec. The explanation for this apparent contradiction lies in interactions between current flow and the coral's morphology: Branches of the coral colony modify water movement so that polyps on the downstream side of the colony are not flattened, and may even benefit from eddies that concentrate particles in the downstream area.

   Remind students that corals also feed on zooplankton, and ask whether they would expect current flow to have a similar effect on capture rates for these animals. A major difference between zooplankton and particles is that most zooplankton can swim, and often have behaviors that allow them to escape from predators. For some species of zooplankton, though, studies have shown that increased current flow is also correlated with increased capture by coral polyps.

Ask students to think of other environmental factors that might affect the growth form of corals. High rates of sedimentation, for example, would favor upright or branched growth forms that could shed sediment more easily than horizontal or boulder-shaped growth forms. Corals that contain zooxanthellae may benefit from growth forms (like flattened plates) that maximize exposure to light.

The BRIDGE Connection

www.vims.edu/bridge/ –Click on "Ocean Science" in the navigation menu to the left, then "Habitats," then "Coastal," then click on "Coral Reef" for resources on corals and coral reefs. Scroll over "Ocean Science Topics," then "Physics," for resources on ocean currents.

The "Me" Connection

Have students write a short essay on ways in which humans are adapted to specific physical conditions in their environment.

Connections to Other Subjects

English/Language Arts, Life Science, Earth Science

Assessment

Written reports prepared in Step 6 provide opportunities for assessment. You may also want to have students prepare individual or group analyses of the pooled data prior to discussion with the class as a whole.

Extensions

Log on to http://oceanexplorer.noaa.gov to keep up to date with the latest Davidson Seamount Expedition discoveries, and to find out what researchers are learning about deep-water hard-bottom communities.

Resources

NOAA Learning Objects

http://www.learningdemo.com/noaa/ – Click on the link to "Lesson 3 – Deep-Sea Corals" for an interactive multimedia presentation on deep-sea corals, as well as Learning Activities and additional information on global impacts and deep-sea coral communities.

Other Relevant Lesson Plans from the Ocean Exploration Program

Cool Corals (http://oceanexplorer.noaa.gov/explorations/03edge/background/edu/media/cool.pdf; (7 pages, 476k)

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.

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

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.

Round and Round (http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_round.pdf; (11 pages, 1Mb) (from the Mountains in the Sea 2003 Expedition)

Focus: Circulation cells in the vicinity of seamounts (Earth Science)

Students will be able to interpret data from a three-dimensional array of current monitors to infer an overall pattern of water circulation, hypothesize what effect an observed water circulation pattern might have on seamount fauna that reproduce by means of floating larvae, and describe the importance of measurements to verify theoretical predictions.

A Tough Neighborhood (http://oceanexplorer.noaa.gov/explorations/03bump/background/education/media/03cb_toughhood.pdf; (4 pages, 244k) (from The Charleston Bump 2003 Expedition)

Focus: Adaptations of benthic organisms to deep water, hard substrates, and strong currents (Life Science)

Students will be able to describe at least three attributes of the deep ocean physical environment that are radically different from ocean habitats near the sea surface and explain at least three morphological or physiological adaptations that allow organisms to survive in the physical environment of the deep ocean. Students will also be able to identify at least three organisms with adaptations to the deep ocean environment that are found (or may be found) on the Charleston Bump.

Keep It Complex! (http://oceanexplorer.noaa.gov/explorations/03bump/background/education/media/03cb_complex.pdf; (5 pages, 272k) (from The Charleston Bump 2003 Expedition)

Focus: Effects of habitat complexity on biological diversity (Life Science)

Students will be able to describe the significance of complexity in benthic habitats to organisms that live in these habitats and will describe at least three attributes of benthic habitats that can increase the physical complexity of these habitats. Students will also be able to give examples of organisms that increase the structural complexity of their communities and infer and explain relationships between species diversity and habitat complexity in benthic communities.

Eddies, Gyres, and Drowning Machines (http://oceanexplorer.noaa.gov/explorations/03bump/background/education/media/03cb_eddies.pdf; (5 pages, 256k) (from The Charleston Bump 2003 Expedition)

Focus: Effects of bottom topography on currents (Physical Science/Earth Science)

Students will be able to describe at least three types of effects that physical obstructions may have on water flowing past the obstructions, explain at least three ways in which current flow can be significant to benthic organisms, and explain how physical obstructions to current flow can create hazardous swimming conditions.

Top to Bottom (http://oceanexplorer.noaa.gov/explorations/05stepstones/background/education/ss_2005_topbottom.pdf; (7 pages, 348k) (from the North Atlantic Stepping Stones 2005 Expedition)

Focus (Earth Science/Life Science) - Impacts of climate change on biological communities of the deep ocean

Students will be able to describe thermohaline circulation, explain how climate change might affect thermohaline circulation, and identify the time scale over which such effects might take place. Students will also be able to explain how warmer temperatures might affect wind-driven surface currents and how these effects might impact biological communities of the deep ocean, and discuss at least three potential impacts on biological communities that might result from carbon dioxide sequestration in the deep ocean.

Designing Tools for Ocean Exploration (http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_designingtools.pdf; (13 pages, 1Mb) (from the Mountains in the Sea 2003 Expedition)

Focus: Ocean Exploration

Students will understand the complexity of ocean exploration; students will understand the technological applications and capabilities required for ocean exploration; students will understand the importance of teamwork in scientific research projects; students will develop abilities necessary to do scientific inquiry.

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

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.

Mystery of the Alaskan Seamounts (http://oceanexplorer.noaa.gov/explorations/02alaska/background/edu/media/mystery9_12.pdf; (9 pages, 132k) (from the Exploring Alaska's Seamounts 2002 Expedition)

Focus: Earth Science - Formation of seamounts in the Axial-Cobb-Eikelberg-Patton chain, Gulf of Alaska
Students will be able to describe the processes that form seamounts, learn how isotope ratios can be used to determine the age of volcanic rock, and interpret basalt rock age data from seamounts in the Gulf of Alaska to investigate a hypothesis for the origin of these seamounts.

Are You Related? (http://oceanexplorer.noaa.gov/explorations/05deepcorals/background/edu/media/05deepcorals_related.pdf; (11 pages, 465k) (from the Florida Coast Deep Corals 2005 Expedition)

Focus: Molecular genetics of deepwater corals (Life Science)

Students will define "microsatellite markers" and explain how they may be used to identify different populations and species, explain two definitions of "species," and describe processes that result in speciation. Students will also use microsatellite data to make inferences about populations of deep sea corals.

How Does Your (Coral) Garden Grow? (http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_growth.pdf; (6 pages, 456k) (from the Gulf of Mexico Deep Sea Habitats 2003 Expedition)

Focus: Growth rate estimates based on isotope ratios (Life Science/Chemistry)

Students will identify and briefly explain two methods for estimating the age of hard corals, learn 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.

Gellin (http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_gellin.pdf; (4 pages, 372k) (from the Gulf of Mexico Deep Sea Habitats 2003 Expedition)
Focus: DNA analysis

Students will explain and carry out a simple process for separating DNA from tissue samples, explain and carry out a simple process for separating complex mixtures, and explain the process of restriction enzyme analysis.

Breaking Away (Or Not . . .) (http://oceanexplorer.noaa.gov/explorations/02alaska/background/edu/media/breaking9_12.pdf; (5 pages, 96k) (from the Exploring Alaska's Seamounts 2002 Expedition)

Focus: Life Science - Reproductive/developmental strategies of some benthic seamount species

Students will be able to compare and contrast common reproductive strategies used by benthic invertebrates, describe the most common reproductive strategies among benthic invertebrates on a seamount and explain why these strategies are appropriate to seamount conditions. Students will also describe how certain reproductive strategies favor survival of species on seamounts and what changes on seamounts might favor other strategies, and discuss the implications of reproductive strategy to the conservation and protection of seamount communities.

Other Links and Resources

Sebens, K. P., J. Witting, and B. Helmuth. 1997. Effects of water flow and branch spacing on particle capture by the reef coral *Madracis mirabilis* (Duchassaing and Michelotti). Journal of Experimental Marine Biology and Ecology 211:1-28.

Helmuth, B., K. P. Sebens, and T. L. Daniela. Morphological variation in coral aggregations: branch spacing and mass flux to coral tissues. Journal of Experimental Marine Biology and Ecology 209:233-259.

Sebens, K.P. , S.P. Grace , B. Helmuth, E.J. Maney Jr ., and J.S. Miles. 1998. Water flow and prey capture by three scleractinian corals, *Madracis mirabilis*, *Montastrea cavernosa* and *Porites porites*, in a field enclosure. Marine Biology 131:347-360.

http://oceanexplorer.noaa.gov/explorations/02davidson/davidson.html – Daily logs, photos, video clips, and backgrounds essays on the 2002 Davidson Seamount Expedition

http://montereybay.noaa.gov/reports/2002/eco/ocean.html – Web page from the Monterey Bay National Marine Sanctuary describing the 2002 exploration of the Davidson Seamount

http://www.mbari.org/ghgases/ – Web page from the Monterey Bay Aquarium Research Institute describing MBARI's work on the Ocean Chemistry of Greenhouse Gases, including work on the potential effects of ocean sequestration of carbon dioxide

http://seamounts.sdsc.edu/#tabs=tab0 — Web site sponsored by the National Science Foundation

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

Morgan, L. E. 2005. What are deep-sea corals? Current 21(4):2-4; available online at http://www.mcbi.org/publications/pub_pdfs/Deep-Sea%20Coral%20issue%20of%20Current.pdf

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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/publications/pub_pdfs/Deep-Sea%20Coral%20issue%20of%20Current.pdf

Roberts, S. and M. Hirshfield. Deep Sea Corals: Out of sight but no longer out of mind. http://na.oceana.org/en/news-media/publications/reports/deep-sea-corals-out-of-sight-but-no-longer-out-of-mind — Background on deep-water coral reefs

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

http://oceanica.cofc.edu/activities.htm – Project Oceanica Web site, with a variety of resources on ocean exploration topics

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
- Motions and forces

Content Standard C: Life Science
- Interdependence of organisms
- Matter, energy, and organization in living systems
- Behavior of organisms

Content Standard F: Science in Personal and Social Perspectives
- Natural resources

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.
The Earth has one big ocean with many features.
- *Fundamental Concept b.* An ocean basin's size, shape and features (such as islands, trenches, mid-ocean ridges, rift valleys) vary due to the movement of Earth's lithospheric plates.
- *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 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 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.
- *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.

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 c.* The ocean is a source of inspiration, recreation, rejuvenation and discovery. It is also an important element in the heritage of many cultures.
- *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

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818
843.762.8737 (fax)
paula.keener-chavis@noaa.gov

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Problem links updated April 2011.

Student Handout

Data on Water Flow and Prey Capture by Three Corals

(adapted from Sebens, *et al.*, 1998)

Madracis mirabilis		*Montastrea cavernosa*		*Porites porites*	
Flow Speed (cm/sec)	Cyst Capture *	Flow Speed (cm/sec)	Cyst Capture *	Flow Speed (cm/sec)	Cyst Capture *
1.1	0.1	2.5	0.8	2.5	0.0
1.9	0.2	3.2	6.5	3.4	1.3
2.5	0.5	3.3	6.6	3.4	1.8
3.2	0.5	3.7	4.5	3.4	3.8
3.6	0.2	3.9	4.4	4.0	0.0
4.1	0.5	4.0	1.5	4.0	0.3
4.5	0.3	4.1	1.4	4.0	1.1
4.6	0.7	4.2	1.7	5.5	0.4
5.0	1.1	4.3	5.5	5.6	0.3
5.1	1.0	4.4	3.5	5.7	0.5
5.2	0.8	4.4	1.0	5.8	0.0
5.5	1.9	4.4	2.0	5.8	0.2
6.1	0.7	5.4	4.8	6.1	0.0
6.4	1.1	5.4	1.0	6.1	0.3
6.5	0.9	5.8	1.0	6.1	0.5
7.1	2.8	5.8	1.2	6.1	0.6
7.1	2.7	7.8	0.5	7.0	0.7
7.4	0.8	8.1	2.0	8.2	0.5
7.5	1.2	8.3	5.0	8.6	2.1
7.6	1.2	9.5	4.5	8.7	3.0
7.6	2.1	9.5	7.0	10.2	0.3
8.2	1.7	10.0	10.0	10.2	2.8
8.5	0.5			10.2	4.5
9.5	4.0			10.2	4.7
10.1	0.4			10.2	6.3
10.1	7.0			10.3	0.5
				11.5	0.8
				12.0	0.8
				12.5	0.5

* – Number of cysts captured per polyp during a 20-minute experiment