



Section 5: Underwater Robots

Lesson 10: What *Little Herc* Saw



A video engineer adjusts the images from the HD camera on the remotely operated vehicle, *Little Hercules*. Image courtesy of the NOAA *Okeanos Explorer* Program.

<http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/hires/apr17-3-hires.jpg>

Focus

Use of robotics for ocean exploration

Grade Level

7-8 (Physical Science/Technology)

Focus Question

How are remotely operated vehicles used aboard *Okeanos Explorer* to help explore Earth's deep ocean?

Learning Objectives

- Students will explain how robotic vehicle technology is used to extend the exploration capacity of scientific investigations aboard the *Okeanos Explorer*.
- Students will discuss how information from underwater robots about the variety of biological and geological conditions in marine ecosystems is relevant to the concept of biodiversity.
- Students will analyze and interpret video data from the *Okeanos Explorer*'s underwater robot to make inferences about environmental interactions of organisms in deep-sea ecosystems.

Materials

- Copies of *Some Things Little Herc Saw*; one for each student group
- Digital or print copies of still imagery (see Learning Procedure Step 1e)

Audio Visual Materials

- (Optional) Video projector or other equipment to display downloaded images (see Learning Procedure, Step 1e)

Teaching Time

One or two 45-minute class periods

Seating Arrangement

Groups of two to four students

Maximum Number of Students

30



Key Words and Concepts

Ocean Exploration
Okeanos Explorer
Robot
Imagery
Video

Background

The site characterization component of the *Okeanos Explorer* exploration strategy depends heavily upon remotely operated vehicles (ROVs; for more information about the *Okeanos Explorer* exploration strategy, please see *Lesson 1: To Explore Strange New Worlds*). For additional information about ROVs used aboard the *Okeanos Explorer*, please see the *Introduction to Underwater Robots* on page 123.

This lesson introduces students to remotely operated vehicles and video imagery as they are used for ocean exploration aboard the *Okeanos Explorer*. The techniques presented in this lesson may be used to complete *Okeanos Explorer* ROV Imagery Supplemental Datasheets for selected *Okeanos Explorer* cruises (e.g., http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/background/edu/media/ex1202_sdrov1.pdf).

Learning Procedure

1. To prepare for this lesson:

a) Review:

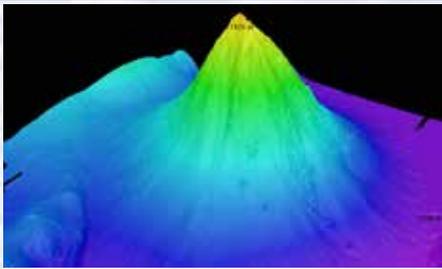
- Introductory essays for the INDEX-SATAL 2010 Expedition (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html>); including *Little Hercules* ROV (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/rov/rov.html>);
- Daily log entries for
July 7 (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july07/july07.html>);
July 24 (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july24/july24.html>); and
August 6 (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/aug06/aug06.html>).

You may want to assign one or more of these essays as background reading prior to beginning the rest of the lesson.

- (b) Review background information about the *Okeanos Explorer* exploration strategy and technologies.
- (c) Review procedures for analyzing ROV imagery beginning with Step 4. Depending upon available time, you may decide to have individual student groups analyze fewer images, then pool their results.
- (d) Make copies of *Some Things Little Herc Saw*; one copy for each student group.
- (e) Download the following image and video files from the INDEX-SATAL 2010 Expedition by going to: http://oceanexplorer.noaa.gov/okeanos/edu/resources/media/movies/0711_site_k_transit_video.html:

20100711_01h56m25s04_ROVHD_TRANSIT.jpg
20100711_01h56m44s04_ROVHD_TRANSIT.jpg
20100711_01h57m05s04_ROVHD_TRANSIT.jpg
20100711_01h57m25s04_ROVHD_TRANSIT.jpg
20100711_01h57m49s04_ROVHD_TRANSIT.jpg
20100711_01h58m11s04_ROVHD_TRANSIT.jpg
20100711_01h58m30s04_ROVHD_TRANSIT.jpg





Okeanos Explorer's EM302 multibeam sonar mapping system produced this detailed image of the Kawio Barat seamount, which rises around 3800 meters from the seafloor. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june26fig1_hires.jpg



A CTD is attached to a metal frame called a rosette, or carousel, along with numerous water sampling bottles and when deployed, provides information about the composition of the water column. Image courtesy NOAA.

<http://oceanexplorer.noaa.gov/technology/tools/sondectd/sondectd.html>



Okeanos Explorer crew launch the vehicle during test dives off Hawaii. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/launch_hires.jpg



ROV Team Lead, Commanding Officer, and Science Team Lead discuss operations at the Mid-Cayman Rise with participants located at both the Silver Spring ECC, and URI's Inner Space Center. Image courtesy of NOAA *Okeanos Explorer* Program, MCR Expedition 2011.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/logs/hires/daily_updates_aug9_1_hires.jpg

20100711_01h58m39s04_ROVHD_TRANSIT.jpg

20100711_01h56m16s04_ROVHD_TRANSIT-300kb.mov

You may want to print the still images, but if possible it is preferable to have students work with these on classroom computers or their own computers. If students will not be using classroom computers, ensure that they will have access to the still image (.jpg) files.

- (f) (Optional) You may also want to download images referenced in Steps 2 and 3, and/or additional examples of imagery from underwater robots (http://oceanexplorer.noaa.gov/okeanos/media/slideshow/flash_slideshow.html and http://oceanexplorer.noaa.gov/okeanos/media/slideshow/video_playlist.html).

- Briefly introduce the NOAA Ship *Okeanos Explorer* and the INDEX-SATAL 2010 Expedition, and discuss why this kind of exploration is important (for background information, please see the lesson, *Earth's Ocean is 95% Unexplored: So What?*; http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_wbat.pdf). Highlight the overall exploration strategy used by *Okeanos Explorer*, including the following points:

- The overall strategy is based on finding anomalies;
- This strategy involves
 - Underway reconnaissance;
 - Water column exploration; and
 - Site characterization;
- This strategy relies on four key technologies:
 - Telepresence technologies that allow people to observe and interact with events at a remote location;
 - Multibeam sonar mapping system;
 - CTD and other electronic sensors to measure chemical and physical seawater properties; and
 - A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery and samples in depths as great as 4,000 meters.

You may want to show some or all of the images in the adjacent sidebar to accompany this review.

- Briefly describe the capabilities of typical ROVs (you may want to show some images from <http://oceanexplorer.noaa.gov/technology/subs/subs.html>). Conclude with the *Little Hercules* ROV, and explain that the primary purpose of this underwater robot is to gather high quality video imagery as part of site characterization activities. At this point you may want to show the video clip compilation referenced in Step 1f. Lead a discussion of how ocean explorers might use this imagery. Students should realize that in many cases this imagery provides the only indication of living organisms in sites being characterized. In addition, this imagery can provide data about geological formations and other environmental conditions that cannot be obtained with other data gathering instruments. Students should also realize that video imagery also has limitations, including:

- coverage is limited to a relatively small area;
- mobile organisms may avoid the moving ROV and/or lights used for video imaging; and
- many organisms cannot be accurately identified from photographs alone.

Show one of the still images downloaded in Step 1e, call students' attention to the



red dots near the center of the image and ask for ideas about why these dots are present. Students should realize (possibly with your help) that these dots provide a scale that makes it possible to estimate the size of objects in the image. Explain that *Little Hercules'* video system has two lasers whose beams are parallel and are 10 cm apart. This places two bright dots on each image that establish the scale of the image.

4. Show students the video clip **20100711_01h56m16s04_ROVHD_TRANSIT-300kb.mov**. Say that this video was made by the ROV *Little Hercules* on July 11, 2010, during a dive to a volcanic cone-shaped seamount that turned out to be one of the most diverse sites visited by the INDEX-SATAL 2010 Expedition.

Tell students that their assignment is to analyze eight still frames from this video, and estimate the number of different organisms in each frame, and the abundance of each organism. Provide each student group with one or more frames (either printed or on a computer), and a copy of *Some Things Little Herc Saw*. You may want to review the general biology of some of the organisms depicted on the handout, or assign each student group to provide this background for one or more organisms.

Provide each student group with one or more of the images downloaded in Step 1e. It is easiest to examine these images on a computer since zoom functions are available, but printed copies may be used if adequate computer resources are not available.

Instruct students to identify organisms as completely as possible. Students may protest that they have never seen most of the things in the video clip; and this is exactly the point! Deep-ocean explorers often encounter organisms that no one has seen before. All they can do is obtain good descriptions (which is why images are so valuable) and consult with experts who are familiar with organisms that appear similar. Having the ability to make these consultations at sea is one of the great benefits of telepresence. Tell students that during ROV dives, an Internet-based intercom system allows all participants, regardless of location, to easily communicate with all other participants. This real-time voice communication is supplemented by a real-time text-based tool called “the Eventlog,” which allows each participant to write their personal observations to a common log. Log entries made by individuals can immediately be seen by all other users in real-time. The Eventlog software automatically records the date, time of entry, and author of each text observation.

Figure 1 shows the Eventlog entries during the time that the video clip was made. Table 1 lists some of the abbreviations that are used in Eventlog entries to name various organisms.

5. Have each student group present the results of their analyses. There is considerable variety of organisms in the video clip, and among the eight still frames. Briefly discuss the concept of biodiversity. This concept is usually understood to include variety at several levels:
 - **variety of ecosystems:** high biodiversity suggests many different ecosystems in a given area;

So many images, so little time!

During the INDEX-SATAL 2010 Expedition, the *Okeanos Explorer's* ROV team saved about 3,400 high-resolution still images. To make the images useful for later analyses (including the analyses done in this lesson), each image must be accompanied by certain information, including the geographic location and depth.

Each video file has a unique name that includes the date and time of the first frame as well as the camera source and a brief description. Individual frames from video files are selected by the ROV video team and saved as high-resolution JPEG images. The image filenames match the original video filename, but the date and time portions of the filenames are corrected to correspond with the actual time that the individual video frame was recorded.

Knowing the time that a specific frame was recorded makes it possible to retrieve information from other data files, including geographic location and depth. This information is included with each JPEG image, similar to the way that date and time are included with images from most digital cameras. For more details, see Pinner (2010).

Table 1. Some Eventlog abbreviations for various groups of animals

| | |
|-----|-----------------------------|
| ACN | Actinaria |
| APH | Amphipod |
| ART | Arthropod |
| ASR | Asteroid |
| BAR | Barnacle |
| BIO | Biology (Unspecified) |
| BIV | Bivalve |
| BRY | Bryozoan |
| CHI | Chiton |
| CHN | Chondrichthyes |
| CNI | Cnidarian |
| COR | Coral |
| CRA | Crab |
| CRI | Crinoid |
| ECN | Echiuran |
| EGG | Egg case |
| FEC | Fecal matter |
| FSH | Fish |
| GAS | Gastropod |
| GRO | Gromiid |
| HOL | Holothurian |
| HYD | Hydroid |
| ISO | Isopod |
| JFH | Jellyfish |
| LOB | Lobster |
| MAT | Bacterial Mat |
| MOL | Mollusk |
| NUD | Nudibranch |
| OCT | Octopus |
| OPH | Ophiuroid |
| PAG | Pagurid (hermit) |
| PEN | Pennatulacean |
| POL | Polychaete |
| SCA | Scale worm |
| SHI | Shrimp |
| SPO | Sponge |
| SQA | Squat lobster |
| SQD | Squid |
| STY | Stylasterid |
| TUN | Tunicate |
| URC | Urchin |
| USO | Unidentified sessile object |
| WOD | Wood |
| WOR | Worm |
| XEN | Xenophyophoran |
| ZOA | Zoanthid |

Figure 1. Excerpt from Eventlog for July 11, 2010

| | | | |
|------------|----------|-----------------|------------------------------------------------------------------------------------|
| 2010-07-11 | 01:56:29 | jonathanrose | FSH |
| 2010-07-11 | 01:56:57 | okeanosexplorer | we'll try to get a few for him |
| 2010-07-11 | 01:57:10 | okeanosexplorer | depth is 48m, heading is 57 |
| 2010-07-11 | 01:57:16 | okeanosexplorer | 458m |
| 2010-07-11 | 01:57:18 | cherissedupreez | SQA |
| 2010-07-11 | 01:57:40 | davebutterfield | the light-colored material around the base of the rocks is primarily coral debris. |
| 2010-07-11 | 01:58:14 | okeanosexplorer | large stalked CRI |
| 2010-07-11 | 01:58:23 | okeanosexplorer | SQA |
| 2010-07-11 | 01:58:25 | okeanosexplorer | SHI |
| 2010-07-11 | 01:58:30 | okeanosexplorer | STY's |
| 2010-07-11 | 01:58:35 | okeanosexplorer | with OPH's |
| 2010-07-11 | 01:58:49 | okeanosexplorer | very neat SPO's |
| 2010-07-11 | 01:58:58 | jonathanrose | FSH |
| 2010-07-11 | 01:59:00 | okeanosexplorer | purple COR |
| 2010-07-11 | 01:59:13 | dustinschomagel | ROV Depth 452 Hdg 62 deg |
| 2010-07-11 | 01:59:34 | okeanosexplorer | URC |

- **variety of species:** high biodiversity suggests many different species in a given area;
- **variety of interactions between species;** and
- **variety within species (genetic diversity):** high biodiversity suggests a relatively high level of genetic variety among individuals of the same species.

The concept of biodiversity generally combines two measurements:

- the number of species in a given area; and
- 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.

Discuss these measurements as they apply to students' analyses of the eight still frames. There are many different species represented among the eight frames, but only a few are abundant in all of the frames. Many are only represented by one or two individuals in all eight frames. This is typical of biological communities that have relatively high biodiversity. If we did similar analyses of frames from video clips made in other locations, we could compare numbers of species and number of individuals within each species to get an idea about the relative diversity between the various locations.

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 discussions 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 now provides a powerful cancer treatment; or the *Forcepsia* sponges from deep-ocean habitats that have similar anti-cancer properties (for more information, see <http://oceanexplorer.noaa.gov/explorations/03bio/welcome.html>).

6. **Some Math Connections** – When scientists discuss biodiversity and populations of organisms, they often like to estimate the abundance of various species. One way to do this with video data is to navigate an underwater robot along a series of transects (a transect is a path along which data are collected) while recording video from a forward-looking camera. When the transects are completed, the video recording is reviewed and imaged organisms are identified and counted. The total counts for each species are divided by the total area of the transect to obtain an estimate of the density of each species. For example, if 50 corals belonging to a single species were counted in a video transect that covered 100 square meters, the density of that species would be
- $$50 \text{ corals} / 100 \text{ square meters} = 0.5 \text{ coral/square meter.}$$

Ask students how we might estimate the area covered during the video clip. Students should realize that we need to know the width of the area covered by each frame, and the total length of the transect. The width of the frames can be estimated using the laser dots (which are 10 cm apart). The spacing of these dots is similar on each of the eight still frames, and the width of the area covered is about 3.6 m.

To find the length of the transect, we first need to know whether the ROV was headed in a straight line (more or less) during the time of the video clip. Checking the heading recorded for each of the eight frames, we find that the ROV's heading varied between 48.5 and 80.0 degrees. This is not exactly a straight line, but is okay for an approximation. Since we know the geographic location of each frame, we can find the distance between the location of the first frame (2° 50.84217' N, 125° 3.47277' E) and the location of the last frame (2° 50.84815' N, 125° 3.48355' E) using an online calculator (such as <http://www.movable-type.co.uk/scripts/latlong.html>) which gives a distance between the locations of the first and last frame equal to 0.02282 km.

So, our estimate of the area covered during the video clip is

$$3.6 \text{ m} \cdot 22.8 \text{ m} = 82.1 \text{ m}^2$$

To calculate the density of the various types of organisms seen in the video clip, we would need to analyze the entire clip, counting each individual of each organism, then dividing the totals by the area of the video transect.

7. Discussion of underwater robots and image technology may also include the following components of technological literacy (ITEA, 2007):
- **Core concepts of technology:** Underwater robots are composed of closely inter-related systems designed to meet specific requirements and constraints, which often involve trade-offs.
 - **Relationships between technologies and other fields of study:** Underwater robotics technology is closely linked to advancements in science and mathematics, and specific information requirements in these fields drive further innovation and invention.



- **Effects of technology on the environment:** Underwater robotics technology provides new ways to monitor various aspects of the environment to provide information for decision-making.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over “Ocean Science Topics” in the menu on the left side of the page, then “Human Activities,” then “Technology” for links to resources about submersibles, ROVs, and other technologies used in underwater exploration.

The “Me” Connection

Have students write a brief essay about how the ability to use robotic imagery to compare biological communities could be personally beneficial.

Connections to Other Subjects

English Language Arts, Life Science, Mathematics, Physics

Assessment

Students’ analyses of video images and class discussions provide opportunities for assessment.

Extensions

1. Visit the *Okeanos Explorer* Web page (<http://oceanexplorer.noaa.gov/okeanos/welcome.html>) for reports, images, and other products from *Okeanos Explorer* cruises.
2. For additional techniques for analyzing video images, see the *Through Robot Eyes* lesson.
3. Visit <http://www.marinetech.org/rov-competition-2/> for a video from the Marine Technology Society’s most recent student ROV competition, and links to other sites about underwater robots.
4. For ideas about building your own underwater robots, see Bohm and Jensen (1998), Bohm (1997), and the Sea Perch Program (see Other Resources).
5. For additional work with ROV video imagery, see *Okeanos Explorer* ROV Imagery Supplemental Datasheets for selected *Okeanos Explorer* cruises (e.g., http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/background/edu/media/ex1202_sdrov1.pdf).

Multimedia Discovery Missions

<http://oceanexplorer.noaa.gov/edu/learning/welcome.html> – Click on the links to Lessons 1, 5, and 6 for interactive multimedia presentations and Learning Activities on Plate Tectonics, Chemosynthesis and Hydrothermal Vent Life, and Deep-Sea Benthos.

Other Relevant Lesson Plans from NOAA’s Ocean Exploration Program

I, Robot, Can Do That!

(from the Lost City 2005 Expedition)

http://oceanexplorer.noaa.gov/explorations/05lostcity/background/edu/media/lostcity05_i_robot.pdf

Focus: Underwater robotic vehicles for scientific exploration (Physical Science/ Life Science)

Students will describe and contrast at least three types of underwater robots used for scientific explorations; discuss the advantages and disadvantages of



using underwater robots in scientific explorations; and identify robotic vehicles best suited to carry out certain tasks.

Let's Hit the Slopes!

(from the *Lophelia* II 2010: Cold Seeps and Deep Reefs Expedition)

http://oceanexplorer.noaa.gov/explorations/10lophelia/background/edu/media/lopb10_hitslopes78.pdf

Focus: Benthic communities on continental slopes in the Gulf of Mexico (Grades 7-8; Life Science)

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

Next Generation Science Standards

Lesson plans developed for Volume 2 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: http://oceanexplorer.noaa.gov/okeanos/edu/collection/hdwe_ngss.pdf

Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings.

Please send your comments to:
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<http://oceanexplorer.noaa.gov>



Some Things *Little Herc* Saw



Anglerfish. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



An anemone (Phylum Cnidaria) on the branches of a bamboo coral. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Unidentified Cnidarian. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Sea anemone (Phylum Cnidaria); white stylasterid coral in background. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Brittle star (Phylum Echinodermata; Class Ophiuroidea) on reddish bubblegum coral (Phylum Cnidaria); yellow sea lily (Phylum Echinodermata; Class Crinoidea) at base of coral; another soft coral (Phylum Cnidaria) to the right. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Cnidarian; brittle star (Phylum Echinodermata; Class Ophiuroidea) on white stylasterid coral to the right. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Yellow sea lily (Phylum Echinodermata; Class Crinoidea); bubblegum coral (Phylum Cnidaria) in background. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Cup coral (Phylum Cnidaria). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Gray-brown encrusting sponge (Phylum Porifera) on rock; white soft corals (Cnidaria) to the left. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Flatfish. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Gastropod snail. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Sea cucumber (Genus *Holothuria*). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Hermit crab (Phylum Arthropoda). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Bamboo coral (Phylum Cnidaria; Family Isididae). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Octopus (Phylum Mollusca; Class Cephalopoda). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



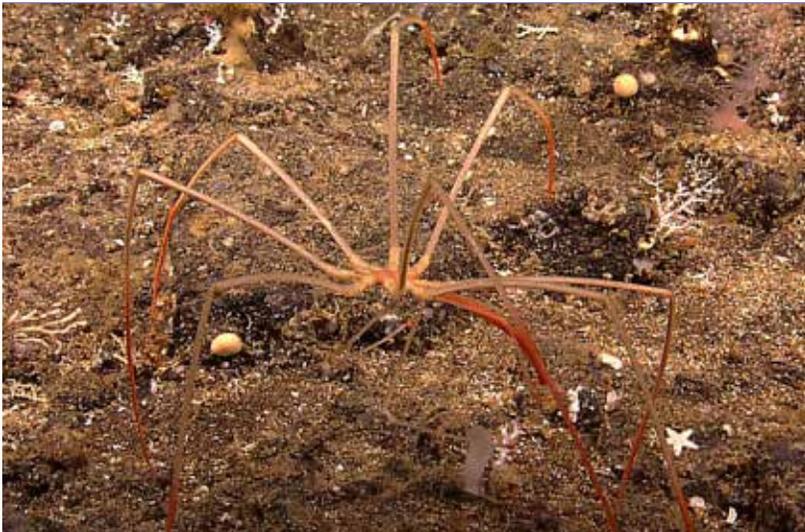
Purple soft coral (Phylum Cnidaria) with brittle star (Phylum Echinodermata; Class Ophiuroidea). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Brittle star (Phylum Echinodermata; Class Ophiuroidea). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Purple sponge (Phylum Porifera). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Sea spider (Class Pycnogonida). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Soft coral (Phylum Cnidaria). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Soft coral (Phylum Cnidaria) and sponges (Phyla Porifera); squat lobsters (Phylum Arthropoda) in right foreground. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Stalked sea lily (Phylum Echinodermata; Class Crinoidea), left; sea urchin (Phylum Echinodermata; Class Echinodea). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Yellow encrusting sponge (Phylum Porifera). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

