Lessons from the Deep:
Exploring the Gulf of Mexico's Deep-Sea Ecosystems
Education Materials Collection

Image captions/credits on Page 2.

lesson plan

The Benthic Drugstore

(adapted from the Cayman Islands Twilight Zone 2007 Expedition)

Focus

Pharmacologically-active chemicals derived from marine invertebrates

Grade Level

9-12 (Life Science)

Focus Question

What pharmacologically-active chemicals are obtained from marine invertebrates, and how do these chemicals act to fight disease in humans?

Learning Objectives

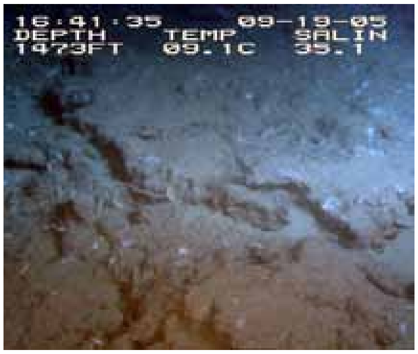
- Students will be able to identify at least three pharmacologically-active chemicals derived from marine invertebrates.
- Students will be able to describe the disease-fighting action of at least three pharmacologically-active chemicals derived from marine invertebrates.
- Students will be able to infer why sessile marine invertebrates appear to be promising sources of new drugs.
- Students will be able to explain ways in which deep-sea ecosystems may be directly beneficial to humans.

Materials

- None

Audio/Visual Materials

- Marker board, blackboard, or overhead projector with transparencies for group discussions



Areas of active, if subdued, hydrocarbon seeps are notably devoid of large sessile invertebrates. A fluffy gray biofilm coats the underlying rock, dotted with small white patches of the cold-seep-associated bacteria *Beggatoia*. Image courtesy Ken Sulak USGS 2004-2006 *Lophelia* program Chief Scientist.
http://fl.biology.usgs.gov/images/pictures/CHEMO_SEEP_BIOTOPE.jpg

This group of very old tubeworms (*Lamellibrachia luymesi* and *Seepiophila jonesi*) live on the same piece of carbonate rock as large colonies of the gorgonian *Callogorgia Americana*. Note the brittle stars and a galatheid crab crawling on the gorgonians. Image courtesy Derk Bergquist.
http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/signature_600.html

Images from Page 1 top to bottom:

A close-up mussel aggregation with *Chirodota heheva* sea cucumbers. Image courtesy of Expedition to the Deep Slope 2007.
http://oceanexplorer.noaa.gov/explorations/07mexico/logs/july3/media/cuke_600.html

A CTD rosette being recovered at the end of a cast. Note that the stoppers on the sample bottles are all closed. Image courtesy of INSPIRE: Chile Margin 2010.
http://oceanexplorer.noaa.gov/explorations/10chile/logs/summary/media/2summary.html

A methane hydrate mound on the seafloor; bubbles show that methane is continuously leaking out of features like this. If bottom waters warmed, this entire feature may be destabilized and leak methane at a higher rate.
http://oceanexplorer.noaa.gov/explorations/10chile/background/methane/media/methane4.html

Lophelia pertusa create habitat for a number of other species at a site in Green Canyon. Image courtesy of Chuck Fisher.
http://oceanexplorer.noaa.gov/explorations/08lophelia/logs/sept24/media/green_canyon_lophelia.html

Teaching Time

One or two 45-minute class periods, plus time for student research

Seating Arrangement

Groups of 4-6 students

Maximum Number of Students

30

Key Words

Natural products
Drugs from the sea
Gulf of Mexico
Deep-sea coral
Cold seep

Background Information

Deepwater ecosystems in the Gulf of Mexico are often associated with rocky substrates or "hardgrounds." Most of these hard bottom areas are found in locations called cold seeps where hydrocarbons are seeping through the seafloor. Microorganisms are the connection between hardgrounds and cold seeps. When microorganisms consume hydrocarbons under anaerobic conditions, they produce bicarbonate which reacts with calcium and magnesium ions in the water and precipitates as carbonate rock. Two types of ecosystems are typically associated with deepwater hardgrounds in the Gulf of Mexico: chemosynthetic communities and deep-sea coral communities. Hydrocarbon seeps may indicate the presence of undiscovered petroleum deposits, so the presence of these ecosystems may indicate potential sites for exploratory drilling and possible development of offshore oil wells. At the same time, these are unique ecosystems that may be important in other ways as well.

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.

Despite the many advances of modern medicine, disease is still the leading cause of death in the United States. Cardiovascular disease and cancer together account for more than 1.5 million deaths annually (40% and 25% of all deaths, respectively). In addition,

Organisms such as the slit shell mollusk, which is feeding on a lithistid sponge, produce chemicals to defend themselves against predation. Some such animals "stockpile" the compounds found in their diets. Image courtesy NOAA OE. http://oceanexplorer.noaa.gov/explorations/03bio/background/products/media/nat_prod3.html

Competition for resources is intense in habitats such as reefs. Many of the sessile invertebrates produce natural products to help them be more competitive. Image courtesy of J. Reed. http://oceanexplorer.noaa.gov/explorations/03bio/background/products/media/nat_prod1.html

Lophelia pertusa coral, with opened polyps, attached to an authigenic carbonate rock. Seep-dependent tubeworms are visible behind the coral. Image courtesy of *Lophelia* II 2009: Deepwater Coral Expedition: Reefs, Rigs and Wrecks. http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug25/media/lophelia_insitu_.html

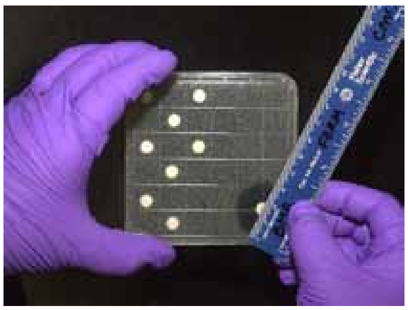
one in six Americans have some form of arthritis, and hospitalized patients are increasingly threatened by infections that are resistant to conventional antibiotics. The cost of these diseases is staggering: $285 billion per year for cardiovascular disease; $107 billion per year for cancer; $65 billion per year for arthritis. Death rates, costs of treatment and lost productivity, and emergence of drug-resistant diseases all point to the need for new and more effective treatments.

Most drugs in use today come from nature. Aspirin, for example, was first isolated from the willow tree. Morphine is extracted from the opium poppy. Penicillin was discovered from common bread mold. To date, almost all of the drugs derived from natural sources come from terrestrial organisms. But recently, systematic searches for new drugs have shown that marine invertebrates produce more antibiotic, anti-cancer, and anti-inflammatory substances than any group of terrestrial organisms. Particularly promising invertebrate groups include sponges, tunicates, ascidians, bryozoans, octocorals, and some molluscs, annelids, and echinoderms. Organisms from hydrothermal vent communities have proven to be useful in a variety of ways, including treatment of bone injuries and cardiovascular disease, copying DNA for scientific studies and crime scene investigations, and making sweeteners for food additives.

The potential for discovering important new drugs from deep-ocean organisms is high, because most of Earth's seafloor is still unexplored, and deep-sea explorations routinely find species that have never been seen before. In 2003, the Ocean Explorer Deep Sea Medicines Expedition visited the Gulf of Mexico to search for new resources with pharmaceutical potential. The expedition collected selected benthic invertebrates from deep-water bottom communities in the Gulf of Mexico (sponges, octocorals, molluscs, annelids, echinoderms, tunicates), and tested extracts of these organisms to identify those that may be useful in the treatment of cancer, cardiovascular disease, infections, inflammation, and disorders of the central nervous system. Because their potential importance is not yet known, it is critical to protect deepwater ecosystems from adverse impacts caused by human activities.

This activity is designed to familiarize students with some of the promising biologically-active chemicals that have been isolated from marine sources and with the organisms that produce these chemicals.

Tunicates that produce bioactive compounds are carefully studied in HBOI's biomedical aquaculture lab. Image courtesy NOAA OE.
http://oceanexplorer.noaa.gov/explorations/03bio/logs/sept15/media/tunicate_farm_lab.html



This bioassay plate detects antimicrobial activity. Small disks of blotter paper are dipped in marine-organism extracts and placed on an agar plate with various bacteria. The clear zone indicates that the extracts are inhibiting microbial growth. Image courtesy NOAA OE.
http://oceanexplorer.noaa.gov/explorations/03bio/background/microbiology/media/figure_04.html

Harbor Branch Oceanographic Institution has more than 16,000 cultures of microbes isolated from deep- and shallow-water marine organisms. Image courtesy NOAA OE.
http://oceanexplorer.noaa.gov/explorations/03bio/background/microbiology/media/figure_01.html

The deep-water sponge *Discodermia* is now in clinical trials for the treatment of cancer. Image courtesy NOAA OE.
http://oceanexplorer.noaa.gov/explorations/03bio/background/plan/media/discodermia.html

Learning Procedure

1.To prepare for this lesson:

(a) Review the following essays:

Chemosynthetic Communities in the Gulf of Mexico (http://oceanexplorer.noaa.gov/explorations/02mexico/background/communities/communities.html); and

The Ecology of Gulf of Mexico Deep-Sea Hardground Communities (http://oceanexplorer.noaa.gov/explorations/06mexico/background/hardgrounds/hardgrounds.html).

Medicines from the Deep-Sea: Discoveries to Date (http://oceanexplorer.noaa.gov/explorations/03bio/background/medicines/medicines.html); and

What is a Natural Product? (http://oceanexplorer.noaa.gov/explorations/03bio/background/products/products.html)

(b) You may also want to review the following visual resources and consider presenting some of these to your students:

- Image collections from Sulak, *et al.* (2008). Master Appendix D of this large report contains many images of deep-water coral communities. Download the pdf files "Master Appendix D - Megafaunal Invertebrates of Viosca Knoll, *Lophelia* Community Investigation," and "Key to Plates in Master Appendix D" from http://fl.biology.usgs.gov/coastaleco/OFR_2008-1148_MMS_2008-015/index.html

- Video showing some of the extraordinary biological diversity of the Gulf of Mexico (http://oceanexplorer.noaa.gov/explorations/03mex/logs/summary/media/ngom_biodiversity_cm3.html)

- Videos of deepwater corals and coral communities (http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/photolog/photolog.html)

- Virtual tour of a cold-seep community (http://www.bio.psu.edu/cold_seeps)

- Slideshow of highlights from Expedition to the Deep Slope 2006 (http://oceanexplorer.noaa.gov/explorations/06mexico/background/media/slideshow/slideshow.html)

- Slideshow of images from the Expedition to the Deep Slope 2007 (http://oceanexplorer.noaa.gov/explorations/07mexico/logs/summary/media/slideshow/html_slideshow.html)

2. Briefly introduce the concept of chemosynthetic communities, and describe the two types of deep-sea ecosystems found in the Gulf of Mexico. Discuss the potential of these ecosystems as sources of new drugs for the treatment of cardiovascular disease, cancer, inflammatory diseases, and infections, as well as other natural products. Ask students to list some reasons that these kinds of drugs might be found primarily among sessile invertebrates.

3. Tell students that their assignment is to prepare a written report on a substance that has been isolated from a marine benthic invertebrate and that has potential for treating human diseases. Reports should include:
   - information about the chemistry of the substance;
   - which organisms produce the substance;
   - basic life history information about these organisms (where they live, what they eat)
   - possible functions of the substance in these organisms; and
   - how the substance is beneficial to humans.

   Assign each student or student group one or more of the following biologically-active chemicals:
   - Ecteinascidin
   - Topsentin
   - Lasonolide
   - Discodermalide
   - Bryostatin
   - Pseudopterosins
   - ω-conotoxin MVIIA
   - HE 800
   - Tth DNA polymerase
   - Pullulanase

4. Have students orally summarize their reports, and lead a discussion of the results. Reports should include the following points:

The sponge *Forcepia* is the source of the lasonolides. The Deep-Sea Medicines 2003 Expedition collected specimens to continue work on the development of lasonolides as new treatments for cancer. Image courtesy NOAA OE.
http://oceanexplorer.noaa.gov/explorations/03bio/logs/sept10/media/lasonolide1.html

Ecteinascidin – Extracted from tunicates; being tested in humans for treatment of breast and ovarian cancers and other solid tumors; acts by blocking transcription of DNA

Topsentin – Extracted from the sponges *Topsentia genitrix*, *Hexadella* sp., and *Spongosorites* sp.; anti-inflammatory agent; mode of action not certain

Lasonolide – Extracted from the sponge *Forcepia* sp.; anti-tumor agent; acts by binding with DNA

Discodermalide – Extracted from deep-sea sponges belonging to the genus *Discodermia*; anti-tumor agent; acts by intefering with microtubule networks (you may want to review the function of microtubules here)

Bryostatin – Extracted from the bryozoan *Bugula neritina*; potential treatment for leukemia and melanoma; acts as a differentiating agent, forcing cancer cells to mature and thus halting uncontrolled cell division

Pseudopterosins – Extracted from the octocoral (sea whip) *Pseudopterogorgia elisabethae*; anti-inflammatory and analgesic agents that reduce swelling and skin irritation and accelerate wound healing; acts as an inhibitor of phospholipase A, which is a key enzyme in inflammatory reactions

ω-conotoxin MVIIA – Extracted from the cone snail, *Conus magnus*; potent pain-killer; acts by interfering with calcium ion flux, thereby reducing the release of neurotransmitters

HE 800 – Exopolysaccharide produced by *Vibrio diabolicus*; promising for the treatment of bone injuries and diseases

Tth DNA polymerase – Enzyme produced by *Thermus thermophylus* that can be used to make billions of copies of DNA for scientific studies and crime scene investigations

Pullulanase – Enzyme produced by *Thermococcus* sp. that can be used to make sweeteners for food additives

Students should recognize that many of these species are sessile. Tell students that to date, this has been true of most marine invertebrates that produce pharmacologically-active substances. Several reasons have been suggested to explain why sessile marine animals are particularly productive of potent chemicals. One possibility is that they use these chemicals to repel predators, since they are basically "sitting ducks." Since many of these species are filter feeders, and consequently are exposed to all sorts of parasites and pathogens in the water, they may use powerful chemicals to repel parasites or as antibiotics against disease-causing organisms. Competition for space may explain why some of these invertebrates produce anti-cancer agents: if two species are competing for the same piece of bottom space, it would be helpful to produce a substance that would attack rapidly dividing cells of the competing organism. Since cancer cells often divide more rapidly than normal cells, the same substance might have anti-cancer properties.

The Bridge Connection

www.vims.edu/bridge/ – Click on "Ocean Science Topics" in the navigation menu to the left, then "Habitats," then "Deep Sea" for resources on deep-sea communities. Click on "Human Activities" then "Technology" for resources on biotechnology.

The "Me" Connection

Have students write a short essay about how deep-sea organisms might benefit them personally in ways other than as sources of potentially important drugs.

Connections to Other Subjects

English/Language Arts, Chemistry

Assessment

Written and oral group reports provide opportunities for assessment.

Extensions

1. See the "Resources" section of *Lessons from the Deep: Exploring the Gulf of Mexico's Deep-Sea Ecosystem Education Materials Collection Educators' Guide* for additional information, activities, and media resources about deepwater ecosystems in the Gulf of Mexico.

2. Visit http://www.woodrow.org/teachers/bi/1993/ for more activities related to biotechnology from the 1993 Woodrow Wilson Biology Institute.

3. Visit http://oceanexplorer.noaa.gov/explorations/03bio/welcome.html to find out more about the Deep Sea Medicines 2003 Expedition.

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html 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 NOAA's Ocean Exploration Program

Monsters of the Deep (6 pages, 464 KB)

http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/monsters.pdf

Focus - Predator-prey relationships between cold-seep communities and the surrounding deep-sea environment (Life Science)

Students describe major features of cold seep communities, list at least five organisms typical of these communities, and infer probable trophic relationships among organisms typical of cold-seep communities and the surrounding deep-sea environment. Students also describe the process of chemosynthesis in general terms, contrast chemosynthesis and photosynthesis, and describe at least five deep-sea predator organisms.

One Tough Worm (8 pages, 476 KB)

http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/worm.pdf

Focus - Physiological adaptations to toxic and hypoxic environments (Life Science)

Students explain the process of chemosynthesis, explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps, and describe three physiological adaptations that enhance an organism's ability to extract oxygen from its environment. Students also describe the problems posed by hydrogen sulfide for aerobic organisms, and explain three strategies for dealing with these problems.

Cell Mates (6 pages, 444k)

http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/meds_cellmates.pdf

Focus: Bacterial endosymbionts and organelles of eukaryotic cells (Life Science)

In this activity, students will be able to compare and contrast prokaryotic and eukaryotic cells, explain the endosymbiont theory for the origin of eukaryotic cell organelles, and explain evidence that suggests an endosymbiotic origin for at least two common eukaryotic cell organelles.

The Electric Sieve (5 pages, 400k)

http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/meds_elecsieve.pdf

Focus: Separation of complex mixtures (Chemistry)

In this activity, students will be able to explain and carry out a simple process for separating complex mixtures, and will be able to infer why organisms such as sessile marine invertebrates appear to be promising sources of new drugs.

Watch the Screen! (5 pages, 428k)

http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/meds_watchscreen.pdf

Focus: Screening natural products for biological activity (Life Science)

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.

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/ – Ocean Explorer Web site

Mayer, A. M. S. and K. R. Gustafson. 2003. Marine pharmacology in 2000: Antitumor and cytotoxic compounds. Int. J. Cancer 105:291-299. Available online at http://marinepharmacology.midwestern.edu/docs/MP2000_Anticancer_Mayer_Gustafson.pdf

Tim Batchelder, T. 2001. Natural products from the sea: Ethnopharmacology, nutrition and conservation. Townsend Letter for Doctors and Patients, Feb, 2001. Available online at http://www.findarticles.com/p/articles/mi_m0ISW/is_2001_Feb/ai_70777319/pg_1.

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

http://www.woodrow.org/teachers/bi/1993/ – Background and activities from the 1993 Woodrow Wilson Biology Institute on biotechnology

Sulak, K. J., M. T. Randall, K. E. Luke, A. D. Norem, and J. M. Miller (Eds.). 2008. Characterization of Northern Gulf of Mexico Deepwater Hard Bottom Communities with Emphasis on *Lophelia* Coral - *Lophelia* Reef Megafaunal Community Structure, Biotopes, Genetics, Microbial Ecology, and Geology. USGS Open-File Report 2008-1148; http://fl.biology.usgs.gov/coastaleco/OFR_2008-1148_MMS_2008-015/index.html

Fisher, C., H. Roberts, E. Cordes, and B. Bernard. 2007. Cold seeps and associated communities of the Gulf of Mexico. Oceanography 20:118-129; available online at http://www.tos.org/oceanography/issues/issue_archive/20_4.html

http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/maincontent.htm – Web site for the National Methane Hydrate Research and Development Program

http://marine.usgs.gov/fact-sheets/gas-hydrates/title.html – Gas (Methane) Hydrates—A New Frontier; Web page from the U.S. Geological Survey's Marine and Coastal Geology Program

Van Dover, C.L., P. Aharon, J.M. Bernhard, E. Caylord, M. Doerriesa, W. Flickinger, W. Gilhooly, S.K. Goffredi, K.E. Knick, S.A. Macko, S. Rapoport, E.C. Raulfs, C. Ruppel, J.L. Salerno, R.D. Seitz, B.K. Sen Gupta, T. Shank, M. Turnipseed, R. Vrijenhoek. 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.mbari.org/staff/vrijen/PDFS/VanDover_2003DSR.pdf)

MacDonald, I. and S. Joye. 1997. Lair of the "Ice Worm." Quarterdeck 5(3); http://www-ocean.tamu.edu/Quarterdeck/QD5.3/macdonald.html; article on cold-seep communities and ice worms

Siegel, L. J. 2001. Café Methane. http://nai.arc.nasa.gov/news_stories/news_detail.cfm?ID=86; article on cold-seep communities and ice worms from NASA's Astrobiology Institute

Kirschvink, J. L. and T. D. Raub. 2003. A methane fuse for the Cambrian explosion: carbon cycles and true polar wander. Comptes Rendus Geoscience 335:65-78. Journal article on the possible role of methane release in rapid diversification of animal groups. Also available on-line at http://www.gps.caltech.edu/users/jkirschvink/pdfs/KirschvinkRaubComptesRendus.pdf

Simpson, S. 2000. Methane fever. *Scientific American* (Feb. 2000) pp 24-27. Article about the role of methane release in the Paleocene extinction event

http://www.piersystem.com/go/site/2931/ – Main Unified Command Deepwater Horizon response site

http://response.restoration.noaa.gov/deepwaterhorizon – NOAA Web site on Deepwater Horizon Oil Spill Response

http://docs.lib.noaa.gov/noaa_documents/NESDIS/NODC/LISD/Central_Library/current_references/current_references_2010_2.pdf – Resources on Oil Spills, Response, and Restoration: a Selected Bibliography; document from NOAA Central Library to aid those seeking information concerning the Deepwater Horizon oil spill disaster in the Gulf of Mexico and information on previous spills and associated remedial actions; includes media products (Web, video, printed and online documents) selected from resources available via the online NOAA Library and Information Network Catalog (NOAALINC)

http://www.gulfallianceeducation.org/ – Extensive list of publications and other resources from the Gulf of Mexico Alliance; click "Gulf States Information & Contacts for BP Oil Spill" to download the Word document

http://rucool.marine.rutgers.edu/deepwater/ – Deepwater Horizon Oil Spill Portal from the Integrated Ocean Observing System at Rutgers University

http://www.darrp.noaa.gov/southeast/deepwater_horizon/index.html – Information about damage assessments being conducted by NOAA's Damage Assessment Remediation and Restoration Program

http://response.restoration.noaa.gov/ – Click "Students and Teachers" in the column on the left for information, fact sheets, and activities about oil emergencies, habitats, and other ocean issues

http://www.noaa.gov/sciencemissions/bpoilspill.html – Web page with links to NOAA Science Missions & Data relevant to the Deepwater Horizon/BP Oil Spill

http://ecowatch.ncddc.noaa.gov/jag/data.html – Data Links page on the Deepwater Horizon Oil Spill Joint Analysis Group Web site

http://ecowatch.ncddc.noaa.gov/jag/reports.html – Reports page on the Deepwater Horizon Oil Spill Joint Analysis Group Web site

http://www.education.noaa.gov/Ocean_and_Coasts/Oil_Spill.html - "Gulf Oil Spill" Web page from NOAA Office of Education with links to multimedia resources, lessons & activities, data, and background information

http://www.geoplatform.gov/gulfresponse/ - Web page for GeoPlatform.gov/gulfresponse—an online map-based tool developed by NOAA with the EPA, U.S. Coast Guard, and the Department of Interior to provide a "one-stop shop" for spill response information; includes oil spill trajectory, fishery area closures, wildlife data, locations of oiled shoreline and positions of deployed research ships

National Science Education Standards

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard C: Life Science

- The cell
- Interdependence of organisms
- Behavior of organisms

Content Standard E: Science and Technology

- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Personal and community health
- Natural resources
- Science and technology in local, national, and global challenges

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 e-mail your comments to: oceanexeducation@noaa.gov

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Acknowledgements

This lesson was developed by Mel Goodwin, PhD, Marine Biologist and Science Writer. Design/layout by Coastal Images Graphic Design, Mount Pleasant, SC. If reproducing this lesson, please cite NOAA as the source, and provide the following URL: http://oceanexplorer.noaa.gov/