NOAA ocean explorer www.oceanexplorer.noaa.gov

The NOAA Ship *Okeanos Explorer*

NOAA Ship *Okeanos Explorer:* America's Ship for Ocean Exploration. Image credit: NOAA. For more information, see the following Web site: *http://oceanexplorer.noaa.gov/okeanos/welcome.html*

Stressed Out!

An essential component of the NOAA Office of Ocean Exploration and Research mission is to enhance understanding of science, technology, engineering, and mathematics used in exploring the ocean, and build interest in careers that support ocean-related work. To help fulfill this mission, the Okeanos Explorer *Education Materials Collection is being developed to encourage educators and students to become personally involved with the voyages and discoveries of the* Okeanos Explorer*—America's first Federal ship dedicated to Ocean Exploration. Leader's Guides for Classroom Explorers focus on three themes: "Why Do We Explore?" (reasons for ocean exploration), "How Do We Explore?" (exploration methods), and "What Do We Expect to Find?" (recent discoveries that give us clues about what we may find in Earth's largely unknown ocean). Each Leader's Guide provides background information, links to resources, and an overview of recommended lesson plans on the Ocean Explorer Web site (*http://oceanexplorer.noaa.gov*). An Initial Inquiry Lesson for each of the three themes leads student inquiries that provide an overview of key topics. A series of lessons for each theme guides student investigations that explore these topics in greater depth. In the future additional guides will be added to the Education Materials Collection to support the involvement of citizen scientists.*

This lesson guides student inquiry into the key topic of Ocean Health within the "Why Do We Explore?" theme.

Focus

Threats to ocean health

Grade Level

7-8 (Life Science)

Focus Question

What stresses threaten the health of ocean ecosystems, and what may be done to reduce these stresses?

Learning Objectives

- Students will be able to identify stresses that threaten the health of ocean ecosystems.
- Students will be able to explain natural and human-caused processes that contribute to these stresses.
- Students will be able to discuss actions that may be taken to reduce these stresses.

Materials

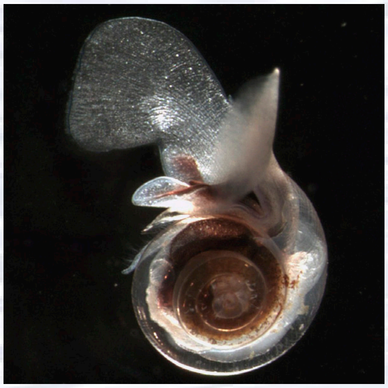
- (Optional) Materials for Scientific Posters: see Learning Procedure Note and Step 5)
- (Optional) Materials for Constructing a Tabletop Shrimp Support Module (TSSM): see Learning Procedure Note and Step 6)
- Copies of *Tabletop Shrimp Support System Construction Guide* (Appendix C), one copy for each student group
- Materials for constructing TSSM modules:

  Materials for one TSSM:
  - 1 - 1 quart glass canning jar
  - 3 - plastic containers, 1 quart capacity or larger
  - 12 (approximately) - River pebbles, about grape-size; enough to cover the bottom of the glass jar in a single layer
  - 3-4 - small shells
  - 1 - Amano shrimp, Caridina multidentata (from an aquarium store)
  - 4 - aquatic snails, each less than 1 cm overall length
  - 8-inch stem of ornwort (*Ceratophyllum demersum*; from an aquarium store)
  - Duckweed, approximately 2 inches x 2 inches (from an aquarium store or local pond)
  - 2-8 - Amphipods (from a local pond)

  Materials that may be shared by several groups:
  - Fishnet or kitchen strainer
  - Dechlorinating solution (for treating tap water; from an aquarium store)
  - Solution of freshwater minerals (e.g., “chichlid salts;” from an aquarium store)
  - Calcium carbonate powder (from an aquarium store)
  - Tablespoon measure
  - Pond sludge
  - Plastic bucket, 1 gallon or larger capacity

Audiovisual Materials

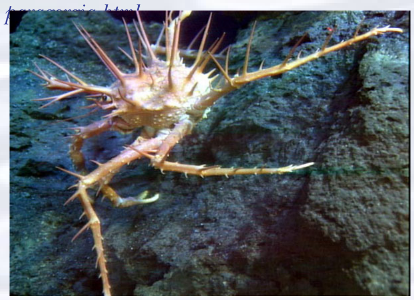
- None



Limacina helicina, a free-swimming planktonic snail. These snails, known as pteropods, form a calcium carbonate shell and are an important food source in many marine food webs. As levels of dissolved CO_2 in sea water rise, skeletal growth rates of pteropods and other calcium-secreting organisms will be reduced due to the effects of dissolved CO_2 on ocean acidity. Image credit: Russ Hopcroft, UAF/NOAA.
http://www.noaanews.noaa.gov/stories2006/images/pteropod-limacina-helicina.jpg

According to the Intergovernmental Panel on Climate Change (the leading provider of scientific advice to global policy makers), surface ocean pH is very likely to decrease by as much as 0.5 pH units by 2100, and is very likely to impair shell or exoskeleton formation in marine organisms such as corals, crabs, squids, marine snails, clams and oysters.

Large *Paragorgia* colonies on basalt substrate. From the Mountains in the Sea 2004. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/04mountains/logs/summary/media/paragorgia.html



Unusual spiny crab spotted on NW Rota 1 volcano. Crabs are opportunistic predators at vent sites. The body of this crab is ~2 in. (~5 cm) across. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/04fire/logs/march30/media/spinycrab.html

Teaching Time

Two or three 45-minute class periods plus time for student research; additional time will be required for optional activities (see Learning Procedure Note)

Seating Arrangement

Six groups of students

Maximum Number of Students

30

Key Words and Concepts

Ocean health
Overfishing
Habitat destruction
Invasive species
Climate change
Pollution
Ocean acidification

Background Information

NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

> **"The great mass extinctions of the fossil record were a major creative force that provided entirely new kinds of opportunities for the subsequent explosive evolution and diversification of surviving clades. Today, the synergistic effects of human impacts are laying the groundwork for a comparably great Anthropocene mass extinction in the oceans with unknown ecological and evolutionary consequences. Synergistic effects of habitat destruction, overfishing, introduced species, warming, acidification, toxins, and massive runoff of nutrients are transforming once complex ecosystems like coral reefs and kelp forests into monotonous level bottoms, transforming clear and productive coastal seas into anoxic dead zones, and transforming complex food webs topped by big animals into simplified, microbially dominated ecosystems with boom and bust cycles of toxic dinoflagellate blooms, jellyfish, and disease. Rates of change are increasingly fast and nonlinear with sudden phase shifts to novel alternative community states. We can only guess at the kinds of organisms that will benefit from this mayhem that**

> **is radically altering the selective seascape far beyond the consequences of fishing or warming alone. The prospects are especially bleak for animals and plants compared with metabolically flexible microbes and algae. Halting and ultimately reversing these trends will require rapid and fundamental changes in fisheries, agricultural practice, and the emissions of greenhouse gases on a global scale."**
>
> ***– Dr. Jeremy Jackson, Scripps Institution of Oceanography, 2008***

The health of Earth's ocean is simultaneously threatened by over-exploitation, destruction of habitats, invasive species, rising temperatures, and pollution. Most, if not all, of these threats are the result of human activity. Appendix A provides an overview of these issues, which are discussed in greater detail in Allsopp, Page, Johnston, and Santillo (2007) and Jackson (2008). Most of these threats involve entire ocean ecosystems, which are highly complex and are not well-understood. Since Earth's ocean occupies more than 70% of our planet and the entire ocean is being affected, these issues inevitably will affect the human species as well.

At NW Eifuku volcano, mussels are so dense in some places that they obscure the bottom. The mussels are ~18 cm (7 in) long. The white galatheid crabs are ~6 cm (2.5 in) long. Image credit: NOAA. *http://oceanexplorer.noaa.gov/explorations/04fire/logs/april11/media/mussel_mound.html*

Despite their severity, many of the issues described in Appendix A are not widely accepted as pervasive and pressing problems requiring immediate attention. Part of the problem is a phenomenon called "shifting baselines," a term first used by fishery biologist Daniel Pauly. A baseline is a reference point that allows us to recognize and measure change. It's how certain things are at some point in time. Depending upon the reference point (baseline), a given change can be interpreted in radically different ways. For example, the number of salmon in the Columbia River in 2007 was about twice what it was in the 1930s, but only about 20% of what is was in the 1800s. Things look pretty good for the salmon if 1930 is the baseline; but not nearly as good compared to the 1800s. The idea is that some changes happen very gradually, so that we come to regard a changed condition as "normal." When this happens, the baseline has shifted. Shifting baselines are a serious problem, because they can lead us to accept a degraded ecosystem as normal—or even as an improvement (Olson, 2002).

Perceptions of coral reefs offer another example of shifting baselines. Many of Earth's coral reefs appear to be in serious trouble due to causes that include over-harvesting, pollution, disease, and climate change (Bellwood et al., 2004). In the Caribbean, surveys of 302 sites between 1998 and 2000 show widespread recent mortality among shallow- (<5 m depth) and deep-water (> 5 m depth) corals. Remote reefs showed as much degradation as reefs close to human coastal development, suggesting that the decline has probably resulted from multiple sources of long-term as well as short-term stress (Kramer, 2003). Despite these kinds of data and growing concern among marine scientists, visitors continue to be thrilled by the "abundance and diversity of life on coral reefs." So, people who have never seen a coral reef before may still find it to be spectacular, even though many species have disappeared and the corals are severely stressed.

This activity guides a student inquiry into stresses that threaten the health of ocean ecosystems, and actions that may be taken to reduce these stresses.

Learning Procedure

NOTE: This lesson includes two optional activities; one involving scientific communication (Step 5) and another involving experiment-based hypothesis testing (Step 6). These activities will add significantly to time requirements, but they are both fundamental elements of modern science and can be related to many other curriculum elements, which may justify allocating the extra time needed for their completion.

1. To prepare for this lesson:
   - If you have not previously done so, review introductory information on the NOAA Ship *Okeanos Explorer* at http://oceanexplorer.noaa.gov/okeanos/welcome.html. You may also want to consider having students complete some or all of the Initial Inquiry Lesson, *To Boldly Go…* (http://oceanexplorer.noaa.gov/okeanos/edu/leadersguide/media/09toboldlygo.pdf).
   - Review information in Appendix A, *Ocean Health Overview*.
   - If you plan to use the optional scientific communication activity (Step 5), review Appendix B: Scientific Posters.
   - If you plan to use the optional experiment-based hypothesis testing activity (Step 6), review procedures in the *Tabletop Shrimp Support Modules Construction Guide*, and decide whether you will assemble the necessary materials or have students do this as part of their assignment. You may also want to review the original article, available online at http://cachefly.oreilly.com/make/wp_aquanaut.pdf.

   You may also want to check out Dr. Jeremy Jackson's *Brave New Ocean* presentation at http://www.esi.utexas.edu/outreach/ols/lectures/Jackson/ (has links to a Webcast of the presentation) and/or http://www.esi.utexas.edu/outreach/ols/clicks.php?id=41a (PowerPoint® version of the presentation).

2. If you have not previously done so, briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons that ocean exploration is important, which should include understanding ocean health issues.

3. Tell students that their assignment is to research six major topics relevant to ocean health. Assign one of the following topics to each student group:
   Overfishing
   Habitat Destruction
   Invasive Species
   Toxins, Nutrients, Marine Debris
   Climate Change
   Ocean Acidification

   Instruct each group to prepare a report that includes:
   - Description of the problem;
   - Causes of the problem;
   - What needs to be done to correct the problem; and
   - What individuals can do to be part of the solution.

   There are several options for the format of the report, including an oral presentation, written report, PowerPoint™ or video presentation, or scientific poster (see Step 5). You may want to assign one or more of these formats or leave the choice to individual student groups, depending upon available time and resources.

4. Have each group present and discuss results of their research. Since the assigned topics include problems that exist on a global scale, it may be difficult for students to identify solutions and meaningful individual action. If this problem arises, you may want to ask, "How do you eat an elephant?" The answer is, "One bite at a time." The key point is that these problems didn't happen all at once, so we probably shouldn't expect to fix them all at once. It may be helpful to consider specific individual decisions or actions that collectively contribute to the problem, and then how these decisions or actions could be modified to achieve a different outcome. Sharing the results of this discussion is important! Social networks used by students are an obvious possibility, as are a variety of school-to-school network projects. Please share your ideas with us, and let us know if you need our help (see Send Us Your Feedback, below).

5. (Optional) Have student groups prepare scientific posters about ocean health issues. See Appendix B for information about scientific posters. Arrange for students to present their posters to one or more audiences, such as other classes, parent groups, teachers, or community groups. Prior to beginning this activity, explain to students that communication is a fundamental part of modern science, and is essential for scientists to be able to learn and build on the results of others. In the case of ocean health issues, communication to non-scientific audiences is particularly important, because most people are unaware of these problems, and because most solutions involve public policy decisions that can be stimulated by large numbers of people expressing concern, or (even better) demanding that specific action be taken.

6. (Optional) The activity provided in Appendix C is based on the Tabletop Shrimp Support Module (TSSM) described in an article titled *Ecosystems Engineering* by Martin John Brown, which appeared in Volume 10 of *Make* magazine. You can download a pdf of Brown's original article from http://cachefly.oreilly.com/make/wp_aquanaut.pdf. In a followup comment about the article, Brown says:

   > **"Most of the questions I've gotten have to do with switching ingredients or adding extra animals. The short answer is, DON'T. Making a bottle ecosystem is not the same as just throwing some stuff from the local pond in a jar, and it is nothing like running a regular fish tank. There is a reason for everything in the article."**

   The concept of this activity is to investigate the reasons for some of the individual components in the TSSM through experimental manipulation. The objectives of this activity are to give students experience in formulating and testing hypotheses, as well as identifying critical functions in aquatic ecosystems.

   Prior to beginning this activity, you will need to decide whether students will be required to obtain their own materials for constructing their TSSMs, or whether you will provide some or all of them. You will also need to decide whether students will work individually or in pairs. Larger groups are not recommended, because this will limit the number of replicate and control systems available, and these are essential to a well-designed experimental procedure.

Begin the activity with a class discussion that reviews TSSMs and the functions of individual components. Explain to students that you want to conduct a class experiment that tests hypotheses about one or more of these functions. Since the TSSM as described in the *Tabletop Shrimp Support Module Construction Guide* and in the original article by Brown is supposed to be a balanced system, hypotheses about the functions of components will be tested through experimental manipulations that alter this balance. Guide a class discussion to define one or more hypotheses and experimental manipulations that can test each hypothesis. Be sure to include controls, replicates, and to avoid manipulating more than one variable at a time. A class of 30 students working in pairs would provide 15 TSSM systems, that could be allocated to 5 replicate controls and two sets of 5 replicate experimental systems to test two levels of a particular manipulation (e.g., half as much calcium carbonate and no calcium carbonate). Also, plan to allow systems to equilibrate for at least one week after they are assembled before beginning experimental manipulations, and randomly assign the systems to experimental and control groups. One technique for doing this is to give each system a number beginning with "01." Then select a page from a telephone book and read the last two digits of the telephone numbers beginning at the top of the page. When the last two digits match the number of one of the systems, that system is assigned as a control. The next match is assigned to the first experimental group. The third match is assigned to the second experimental group. The fourth match is assigned as a control, and so on, consecutively assigning systems to control and experimental groups in rotation until all systems have been assigned.

Hypotheses and predictions should be based on students' knowledge of processes that occur in the TSSM system, such as photosynthesis and respiration. For example, students should realize that respiration produces carbon dioxide, and dissolved carbon dioxide will lower the pH of surrounding water (see *"To Boldly Go…"* Appendix 1 for a demonstration of this). So, predictions about the function of calcium carbonate and/or shells might involve fluctuations in pH that could be measured in experimental and control systems.
Here are a few other ideas:

- Keep experimental systems in the dark for 24 hours, then check pH & compare to pH of systems after 12 hours darkness & 12 hours light.

- Omit calcium carbonate and shells from some systems and repeat above, comparing results with systems that have calcium carbonate and shells.
- Double the amount of plant material.
- If you have an electronic dissolved oxygen meter, measure oxygen as well as pH in the above comparison.

Once data are collected, students should perform simple statistical analyses to evaluate the significance of any differences observed, and state whether the experimental results support or reject the hypothesis. After a particular hypothesis has been tested, you may have students restore all of the TSSMs to the “balanced” design, allow the systems to equilibrate, and test another hypothesis. Again, systems should be randomly assigned to experimental and control groups.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over “Ocean Science Topics,” “Human Activities,” then “Environmental Issue” for links to resources about pollution, conservation, bycatch, sustainability, and policy.

The “Me” Connection

Have students write a brief essay describing how they could have a personal impact on an issue affecting ocean health.

Connections to Other Subjects

English/Language Arts, Social Sciences, Physical Science, Mathematics

Assessment

Students’ reports and class discussions provide opportunities for assessment.

Extensions

1. Follow events aboard the *Okeanos Explorer* at http://oceanexplorer.noaa.gov/okeanos/welcome.html.

Multimedia Discovery Missions

http://www.oceanexplorer.noaa.gov/edu/learning/welcome.html
Click on the links to Lessons 12, 13 and 15 for interactive multimedia presentations and Learning Activities on Food, Water, and Medicine from the Sea; Ocean Pollution; and Seamounts.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

(Unless otherwise noted, the following Lesson Plans are targeted toward Grades 7-8)

Treasures in Jeopardy
http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/treasures.pdf
(8 pages; 278kb PDF) (from the 2007 Cayman Island Twilight Zone Expedition)

Focus: Conservation of deep-sea coral communities (Life Science)

In this activity, students will compare and contrast deep-sea coral communities with their shallow-water counterparts and explain at least three benefits associated with deep-sea coral communities. Students will also describe human activities that threaten deep-sea coral communities and describe actions that should be taken to protect resources of deep-sea coral communities.

Boom and Bust
http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_boombust.pdf
(6 pages, 1Mb) (from the 2003 Mountains in the Sea Expedition)

Focus: Fishery management

In this activity, students will be able to describe stages in a commercial fishery that eventually becomes severely depleted, interpret basic data to predict when a fishery stock is beginning to show signs of overexploitation, and describe the potential consequences of overexploitation on fish populations, marine habitats, and fishing businesses. Students will also be able to described and discuss potential management policies that could avoid or remediate overexploitation in commercial fisheries.

Other 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 – Web site for NOAA's Ocean Exploration Program

http://celebrating200years.noaa.gov/edufun/book/welcome.html#book – A free printable book for home and school use introduced in 2004 to celebrate the 200th anniversary of NOAA; nearly 200 pages of lessons focusing on the exploration, understanding, and protection of Earth as a whole system

Allsopp, M., R. Page , P. Johnston , and D. Santillo. 2007. Oceans in Peril. Worldwatch Report 174. Worldwatch Institute, Washington, DC. 56 pp. Available as a hard copy or e-book for $9.95 from http://www.worldwatch.org/node/5353

Jackson, J. B. C. 2008. Ecological extinction and evolution in the brave new ocean. Proceedings of the National Academy of Sciences, August 12, 2008 Vol. 105 No. Supplement 1 11458-11465. Abstract available online at http://www.pnas.org/content/105/suppl.1/11458.

Historical Overfishing and the Recent Collapse of Coastal Ecosystems by Jeremy Jackson et al., Science, 293, 629 (2001) – http://www.palomar.edu/oceanography/www_resources/jacksonetal.pdf

http://cachefly.oreilly.com/make/wp_aquanaut.pdf – Ecosystem Engineering by Martin John Brown; article on which the hands-on activity in this lesson is based

http://www.esi.utexas.edu/outreach/ols/lectures/Jackson/ – Hot Science - Cool Talks Outreach Lecture Series Web page from the University of Texas at Austin for *Brave New Ocean*, a presentation by Dr. Jeremy Jackson, March 3, 2006, with links to webcasts and PowerPoint® versions of the presentation; you can hear Jeremy Jackson's presentation (without the slides) at http://www.youtube.com/watch?v=2fRPiNcikOU

http://www.esi.utexas.edu/outreach/ols/clicks.php?id=41a – Jeremy Jackson's PowerPoint® presentation, *Brave New Ocean*

Devine, J. A., K. D. Baker, and R. L. Haedrich. 2006. Fisheries: Deep-sea fishes qualify as endangered. Nature 439:29; abstract available online at http://www.nature.com/nature/journal/v439/n7072/abs/439029a.html

Hood, M., W. Broadgate, E. Urban, and O. Gaffney, eds. 2009. Ocean Acidification. A Summary for Policymakers from the

Second Symposium on the Ocean in a High-CO_2 World; available online at http://ioc3.unesco.org/oanet/OAdocs/SPM-lorezv2.pdf.

http://www.terrain.org/articles/21/burns.htm – Article on ocean acidification

http://www.oceana.org/climate/impacts/acid-oceans/ – *Oceana* article on ocean acidification

Bellwood, D.R., T.P. Hughes, C. Folke, and M. Nyström. 2004. Confronting the coral reef crisis. Nature 429:827-833 (http://www.eco.science.ru.nl/Organisme%20&%20Milieu/PGO/PGO3/Bellwood.pdf)

Kramer, P. 2003. Synthesis of coral reef health indicators for the Western Atlantic: Results of the AGRRA program (1997-2000). In Lang, J.C. (ed.) 2003. Status of coral reefs in the Western Atlantic: results of initial surveys, Atlantic and Gulf Rapid Reef Assessment (AGRRA) program. Atoll Research Bulletin 496. 639 pp. Washington, DC. (http://www.botany.hawaii.edu/faculty/duffy/arb/496/Synthesis.pdf)

Olson, R. 2002. Slow-motion disaster below the waves. Los Angeles Times, November 17, 2002, pp. M.2 (http://www.actionbioscience.org/environment/olson.html)

National Science Education Standards

Content Standard A: Science As Inquiry

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

Content Standard B: Physical Science

- Chemical reactions

Content Standard C: Life Science

- Biological evolution
- Interdependence of organisms
- Matter, energy, and organization in living systems
- Behavior of organisms

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Personal and community health
- Population growth
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

Content Standard G: History and Nature of Science

- Science as a human endeavor

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.

The Earth has one big ocean with many features.

Fundamental Concept a. The ocean is the dominant physical feature on our planet Earth— covering approximately 70% of the planet's surface. There is one ocean with many ocean basins, such as the North Pacific, South Pacific, North Atlantic, South Atlantic, Indian and Arctic.

Fundamental Concept h. Although the ocean is large, it is finite and resources are limited.

Essential Principle 4.

The ocean makes Earth habitable.

Fundamental Concept a. Most of the oxygen in the atmosphere originally came from the activities of photosynthetic organisms in the ocean.

Essential Principle 5.

The ocean supports a great diversity of life and ecosystems.

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 a. The ocean affects every human life. It supplies freshwater (most rain comes from the ocean) and nearly all Earth's oxygen. It moderates the Earth's climate, influences our weather, and affects human health.

Fundamental Concept b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.

Fundamental Concept e. Humans affect the ocean in a variety of ways. Laws, regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise pollution) and physical modifications (such as changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.

Fundamental Concept g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Essential Principle 7.
The ocean is largely unexplored.

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

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

Fundamental Concept c. Over the last 40 years, use of ocean resources has increased significantly, therefore the future sustainability of ocean resources depends on our understanding of those resources and their potential and limitations.

Fundamental Concept 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, including how you use it in your formal/informal education setting.
Please send your comments to: oceanexeducation@noaa.gov

For More Information

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Appendix A: Ocean Health Overview

Unless otherwise cited, the following information is from Allsopp, Page, Johnston, and Santillo (2007).

Overfishing

Global demand for seafood has grown steadily over the past century, resulting in increasingly sophisticated fishing industries that use powerful boats, freezer trawlers, acoustic fish finders, and other advanced technologies. In 2005, capture fisheries around the world harvested about 95 million tons of fish. In the same year, at least 76 percent of the populations that support those fisheries were considered fully exploited, overexploited, or depleted. In most cases, overfishing has been the primary cause for the declines, though in some cases environmental conditions have also contributed. Between 1950 and 2000, nearly one-fourth of all fisheries collapsed. Small fisheries, small fish stocks, and bottom-dwelling species were the most vulnerable. One of the best-known collapses took place in the Atlantic cod fishery, which collapsed in 1991.

Although fishery collapses may be reversible, it takes time. Although the Atlantic cod fishery was closed in 1992, there is little sign of recovery of offshore cod populations. A study of 90 collapsed fish stocks has shown that many bottom-dwelling fish showed little if any recovery, even after 15 years. Benthic fish stocks are particularly vulnerable to overfishing by deep-sea bottom trawling. For example, along the continental slope in the Atlantic waters of Canada, populations of roundnose grenadier were reduced by 99.6% between 1978 and 2003. Bottom trawling also causes severe impacts on deep-sea bottom habitats that are discussed below.

Many of these declines have taken place in fisheries that target large predators. In the north Atlantic over the past 50 years, the abundance of predatory fishes has declined by approximately two thirds (Devine, Baker and Haedrich, 2006). In the case of large, predatory, open-ocean fish, such as tuna, swordfish, and marlin, abundance has declined by approximately 90% since 1952.

In addition to the obvious impact of having fewer fishes, intensive fishing has other impacts as well:

- Selectively targeting larger, faster-growing fishes may change the genetic diversity within populations of these species and reduce their survival capabilities.
- As populations of large predators are depleted, fishing is moving farther down the ocean food webs, placing increasing pressure on populations of smaller, shorter-lived fishes and resulting in simplified food webs. These webs are less able to compensate for changes caused by climate shifts or other environmental alterations.

Appendix A: Ocean Health Overview – 2

- Overfishing herbivorous species can result in excessive growth of algae and other marine plants. This is a significant problem in coral reef ecosystems where removal of herbivorous fishes is resulting in corals being displaced by algae.
- Depletion of traditional fisheries is causing modern fishing vessels to move onto the high seas where there is little or no fisheries regulation or management.
- In addition to harvesting fishes that are valuable as food, industrial fishing is also targeting other species for conversion into fishmeal or fish oil. Since many of the latter species are low in ocean food webs, overfishing of these stocks can have serious impacts on many other species.
- Substantial numbers of seabirds, marine mammals, and sea turtles become entangled or hooked accidentally by fishing gear, causing further disruption to ocean food webs.
- Overcapacity in the world's fishing fleets (i.e., too many boats, not enough fish) is causing an increase in illegal, unregulated, and unreported (IUU) fishing, which may account for as much as 20 percent of the global fishery harvest. IUU fishing includes bottom trawling and other methods that cause severe damage to marine ecosystems, and are a serious threat to marine diversity, the livelihood of local fishing communities, the food security of coastal countries, and the entire concept of achieving sustainable fisheries.

Habitat Destruction

Nearshore marine habitats are susceptible to damage or destruction by coastal development, especially in developing countries. Aquaculture for tropical shrimp and fish has led to the destruction of thousands of hectares of mangroves and coastal wetlands. Perhaps the greatest damage for the ocean as a whole comes from bottom trawling, a fishing method that uses a heavy net, weighted by anchors, which is dragged behind a boat along the sea floor. The result is that almost everything is removed from the ocean floor (only rocks remain), and the bottom is converted to mud that forms a plume behind the trawlers. Bottom trawling is analogous to clearcutting in old growth forests. Besides the impact on fish populations, bottom trawling causes severe habitat destruction, particularly in deep ocean coral reefs and seamounts that provide habitats for many species. Photographs of seafloor habitats off the coasts of Norway and the United Kingdom show trawl scars up to four kilometers long, some of which have destroyed reefs that were 4,500 years old. Off the Atlantic coast of Florida, an estimated 90–99 percent of reefs formed by the deep-water coral *Oculina* have been destroyed.

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Invasive Species

Invasive species are non-native species that have been introduced to a region, have established thriving reproductive populations, and are expanding their range. Invasive species often have no natural predators in their new environment, and can successfully compete with and possibly replace native species. Invasive species are usually introduced accidentally or deliberately by humans. A particularly dangerous example is the Mediterranean Clone of Caulerpa (*Caulerpa taxifolia*), a marine alga containing a toxin that is lethal to some species and may interfere with the eggs of some marine mammals. *C. taxifolia* was accidentally introduced into the Mediterranean by a marine aquarium, and is now forming dense mats that displace invertebrates, fish, and native algae from the sea floor. Until recently, *C. taxifolia* was a popular species in aquarium stores. The European Green Crab (*Carcinus maenas*) is another invasive species, introduced to the U.S. over 150 years ago in the ballast and heavily fouled outer hulls of wooden ships coming from Europe. These crabs feed on a variety of organisms, including clams, oysters, mussels, marine worms and small crustaceans, and are a serious potential competitor for native fish and bird species. At the turn of the century, European green crabs almost destroyed the soft clam industry of Maine and surrounding waterways, and is at least partially responsible for the decline of scallop populations on Martha's Vineyard. In California, the green crab has caused the loss of as much as 50 percent of Manila clam stocks and declines in other crab populations. Lionfish (*Pterois volitans*) are native to the Indo-Pacific from Australia north to southern Japan and south to Micronesia, but have recently been seen along the Atlantic coast of the United States and in the Caribbean; probably introduced in ballast water or from marine aquaria. Lionfish feed on smaller fishes, shrimp, and small crabs. Venomous spines in the dorsal and pectoral fins are used to immobilize prey species, as well as to discourage potential predators. The ecological impact of invasive lionfish in the Atlantic and Caribbean is not yet known, but they may compete with many native species, including economically important species of snapper and grouper. Populations of prey species could be seriously affected as well.

Toxins, Nutrients, Marine Debris

For thousands of years, Earth's ocean has provided a convenient means for disposing of unwanted products of human activity. The ocean's impressive size, coupled with the fact that it is largely out of sight, makes it easy to assume that this practice is of no particular consequence. But there is growing evidence that thousands of different chemicals, radioactive substances, nutrients, oil, and marine debris are having a significant impact.

Recent concerns about chemical contamination have focused on the impact of synthetic chemicals known as persistent organic pollutants (POPs), which are

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toxic, long-lived, often accumulate in the tissues of fish and other animals, and may travel long distances from their point of origin. POPs include chemicals that have significant benefits to humans, such as brominated flame retardants (BFRs), that are added to plastics, resins, textiles, paints, electronics, and other products to increase their fire resistance. Global use of BFRs doubled between 1990 and 2000, and they are known to contaminate marine organisms all over the world including those in the deep oceans and remote Arctic regions. Toxic effects have not been extensively studied, but there is evidence that they can disrupt endocrine systems, nervous systems, and immune functions.

Artificial radionucleides are another class of substances that have no natural counterparts, are extremely long-lived, and are known to cause cancers and mutations. Nuclear weapons testing between 1954 and 1962 has been the largest single source of artificial radionuclides to the ocean due to fallout, but contamination continues from nuclear power facilities and nuclear reprocessing plants.

Nutrient pollution, mainly nitrogen and phosphorous compounds, enters coastal waters via agricultural fertilizer run-off, sewage discharges, and atmospheric pollution from burning fossil fuels. Excess nutrients in coastal waters can cause massive blooms of phytoplankton and other marine plants. When these plants die, they sink to the bottom and are decomposed by microorganisms that consume oxygen. This is called eutrophication. In some cases, this decomposition process consumes almost all of the dissolved oxygen in the surrounding water. The result is the formation of vast, oxygen-depleted areas known as “dead zones.” Around the world, the number of dead zones has risen every decade since the 1970s. One of the largest dead zones occurs in the northern Gulf of Mexico, and has been linked to massive increases in the use of fertilizers in the Mississippi River watershed which began in the 1950s.

Actually, dead zones aren’t really dead; they often contain abundant populations of bacteria, jellyfish, and other species that can tolerate low-oxygen conditions. This replacement of populations of healthy aerobic populations with anoxia-tolerant bacteria and jellyfish has been called “the rise of slime” (Jackson, 2008). It has also been pointed out (Jackson, 2008) that dead zone ecosystems resemble ocean communities before the Cambrian explosion.

Oil spills are a well-known form of contamination as a result of the publicity that typically surrounds major spills. Less well known are much smaller spills that occur every day from ships, offshore drilling operations, and routine vessel maintenance. The amount of damage caused by an oil spill depends upon the size of the spill, type of oil involved, location of the spill, and weather conditions. Major spills have severe impacts on coastal wildlife, but long term continued exposure to low levels of oil can also have a significant effect on survival and reproduction of seabirds and marine mammals.

Marine debris is a pervasive problem affecting all of Earth's ocean, and injures and kills many different marine animals through drowning, suffocation, strangulation, starvation (through reduced feeding efficiency), injuries, and internal damage. Large quantities of marine debris are found in shipping lanes, near fishing areas, and in oceanic convergence zones. 80% of marine debris is from land-based sources; the rest comes from marine activities. Major sources include tourist-related litter, debris in sewage, derelict fishing gear, and wastes from ships and boats. Plastic bags are the major type of marine debris found on the seabed, especially in coastal areas. Derelict fishing gear can continue to trap and catch fish even when they are no longer tended by fishermen. This "ghost fishing," can capture large quantities of marine organisms. Marine debris can also act as rafts, possibly carrying marine animals and plants long distances to areas where they become invasive species.

Climate Change

An overview of climate change issues is provided in Appendix A of the lesson, *Where Have All the Glaciers Gone?* Major impacts on ocean health are related to increased temperature, sea level rise, and ocean acidification (which is discussed in a separate section below).

Global sea surface temperature is approximately one degree C higher now than 140 years ago. One degree may not sound like much, but the key point is the rate at which this increase has taken place. Over the past 25 years the rate of increase in sea surface temperature in all European seas has been about 10 times faster than the average rate of increase during the past century. Earth's ocean could warm by an additional 1 – 2 degrees C by the end of this century.

Many marine organisms live at temperatures close to their thermal tolerances, so even a slight warming could have serious effects on their physiological functioning and ability to survive. Coral reefs are a frequently-cited example. Shallow-water reef-building corals live primarily in tropical latitudes (less than 30 degrees north or south of the equator) where water temperatures are close to the maximum temperature that corals can tolerate. Abnormally high temperatures result in thermal stress, and many corals respond by expelling symbiotic algae (zooxanthellae) that live within the coral's soft tissues. Since the zooxanthellae are responsible for most of the corals' color, corals that have expelled their algal symbionts appear to be bleached. Zooxanthellae are important to corals' nutrition and growth, and expelling these symbionts can have significant impacts on the corals' health. In some cases, corals are able to

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survive a bleaching event and eventually recover. But if other types of stress are present and the stress is sustained, the corals may die.

Prior to the 1980s, coral bleaching events were isolated and appeared to be the result of short-term events such as major storms, severe tidal exposures, sedimentation, pollution, or thermal shock. Over the past 20 years, though, these events have become more widespread, and many laboratory studies have shown a direct relationship between bleaching and water temperature stress. In general, coral bleaching events often occur in areas where the sea surface temperature rises 1 degree C or more above the normal maximum temperature.

It is possible that corals' physiology might change to allow them to become acclimated to higher temperatures, or that populations might adapt if individual corals' ability to tolerate higher temperatures provided a survival advantage that allowed these corals to become more numerous. There is no indication, however, that either of these possibilities is actually happening. It is important to remember that the impacts of rising ocean temperatures are not confined to corals; corals happen to be very conspicuous and have been the subject of scientific research for many years, so changes are likely to be noticed. Similar impacts are almost certainly taking place in many other species that are less-studied or are presently unknown to science.

Even when individual species are able to tolerate increased temperatures, they may still be affected by changes within their food webs. For example, warmer waters in northwestern Europe have caused clams (*Macoma balthica*) to spawn earlier in the year, but blooms of phytoplankton on which the clams feed do not happen until later in the spring. Clam larvae also face increased predation from shrimp whose abundance has increased in early spring due to warmer temperatures.

Sea-level rise is caused by the expansion of sea water as it warms, as well as melting of ice on land (melting sea ice doesn't increase sea level, as you can demonstrate with ice cubes in a glass of water). Global sea level rose an average of 1.8 mm per year between 1961 and 2003, and is expected to continue rising for at least several decades. The amount of additional rise will depend largely on how much melting occurs at the polar ice caps. Even if greenhouse gas concentrations were stabilized immediately, sea level will continue to rise from thermal expansion, and ice sheets will continue to melt. Increased sea level will have significant impacts on low-lying coastal areas and on species whose habitats are in these areas.

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Increased influx of fresh water from melting ice sheets coupled with warmer ocean temperatures may also cause changes in ocean currents, which are driven by temperature and salinity differences between large masses of seawater. Potential changes to the deep-ocean thermohaline circulation ("The Great Ocean Conveyor Belt") are described in the Leader's Guide, *Why Do We Explore?*

Some of the most rapid warming is taking place in Earth's polar regions. Continued loss of sea ice is expected to have negative impacts on species that depend upon the sea ice habitat, such as fishes, birds, seals, whales, and polar bears. These are discussed in *The Good, The Bad and The Arctic*, a lesson plan from the Ocean Explorer 2005 Hidden Ocean Expedition (http://oceanexplorer.noaa.gov/explorations/05arctic/background/edu/media/arctic05_goodandbad.pdf).

Ocean Acidification

Ocean acidification is "the other carbon dioxide problem," additional to the problem of carbon dioxide as a greenhouse gas. Each year, the ocean absorbs approximately 25% of the CO_2 added to the atmosphere by human activities. When CO_2 dissolves in seawater, carbonic acid is formed, which raises acidity. Ocean acidity has increased by 30% since the beginning of the Industrial Revolution, causing seawater to become corrosive to the shells and skeletons of many marine organisms as well as affecting the reproduction and physiology of others. The present increase in ocean acidification is happening 100 times faster than any other acidification event in at least 20 million years.

Ocean acidification is a result of increased CO_2 emissions, and is not directly related to climate change. There are many uncertainties about the causes, extent, and impacts of global climate change; but these do not apply to ocean acidification which can be observed happening right now and is highly predictable into the future. Measures to reduce global temperatures or the concentration of other greenhouse gases will have no effect on ocean acidification. Only a reduction in atmospheric CO_2 concentrations will affect the acidification problem.

Research is just beginning on the impacts of ocean acidification on marine organisms and ecosystems (more than 60% of the research papers on this subject have been published since 2004). Impacts have been observed in many species, however, and range from interference with calcification processes to reduced resistance to other environmental stresses such as increasing temperatures and pollution.

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Where Do We Go From Here?

Ocean Health issues revolve around two points:

Earth's ocean is about systems; everything is connected.

Human activities have global impacts on Earth's ocean.

It's very easy to be overwhelmed by the magnitude of ocean health problems, and just assume we can do nothing. The reality is that these problems did not arise through a single, deliberate action. They are the result of numerous individual actions that took place without any consideration for their collective impacts on Earth's ecosystems. And another reality is that effective solutions to these problems will not occur in a single, global action, but rather will involve numerous individual actions that by themselves seem insignificant, but collectively can have global impacts. Individually, we are all insignificant on a global scale. Collectively, we have global impacts. The root cause of ocean health problems is the cumulative impact of individual actions; and the solution to these problems is also through the cumulative impact of individual actions.

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Appendix B: Scientific Posters

Scientific posters are an increasingly popular way to communicate results of scientific research and technical projects. There are a number of reasons for this, including limited time at conferences for traditional "public speaking"-style presentations, better options for interacting one-on-one with people who are really interested in your work, opportunities for viewers to understand the details of your work (even if you aren't present), and having a more relaxed format for those who dislike speaking in public. In addition, posters are more durable that one-time presentations; once they are created they can be used in many different settings, over and over again. For more discussion of pros and cons, as well as examples of good and bad posters, visit

http://www.swarthmore.edu/NatSci/cpurrin1/posteradvice.htm
http://www.ncsu.edu/project/posters/NewSite/
http://www.the-aps.org/careers/careers1/GradProf/gposter.htm

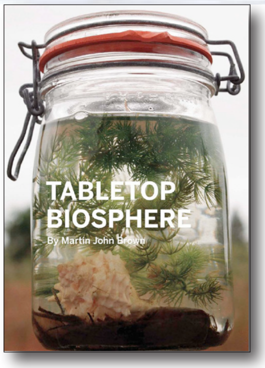
Scientific posters usually contain the same elements as traditional written reports: title, introduction, materials and methods, results, conclusions, literature cited (key citations only!), acknowledgments, and contact points for further information. Good posters do NOT usually have an abstract, though an abstract is often required as part of the submission process and may be included in a printed program.

Another similarity to traditional reports is that the best posters almost always go through several drafts. You should always expect that the first draft of your poster will change significantly before it emerges in final form. Be sure to allow enough time for others to review your first draft and for you to make needed changes.

An important difference (and advantage) that posters have compared to written reports is that posters can be much more flexible in terms of layout and where these elements appear, as long as there is still a clear and logical flow to guide viewers through your presentation. Here are a few more tips for good scientific posters (see the Web sites listed above for many other ideas):

- Posters should be readable from 6 feet away;
- Leave plenty of white space (35% is not too much) – densely packed posters can easily repel potential viewers;
- The top and right columns of your poster are prime areas for vital material, while the bottom edge will receive much less attention;
- Serif fonts (e.g., Times) are easier to read than sans serif fonts (e.g., Helvetica), so use sans serif fonts for titles and headings, and serif fonts for body text (usually no more than two font families on a single poster)
- Text boxes are easiest to read when they are about 40 characters wide

Appendix C: Tabletop Shrimp Support Module Construction Guide



From *Make*, Volume 10

NOTE: These procedures are adapted from *Ecosystems Engineering*, an article by Martin John Brown that appeared in Volume 10 of *Make* magazine. The article can be downloaded from http://cachefly.oreilly.com/make/wp_aquanaut.pdf.

Materials (for one module)

- 1 - 1 quart glass canning jar
- 3 - plastic containers, 1 quart capacity or larger
- 12 (approximately) - River pebbles, about grape-size; enough to cover the bottom of the glass jar in a single layer
- 3-4 - small shells
- 1 - Amano shrimp, *Caridina multidentata* (from an aquarium store)
- 4 - aquatic snails, each less than 1 cm overall length
- 8-inch stem of hornwort (*Ceratophyllum demersum*; from an aquarium store)
- Duckweed, approximately 2 inches x 2 inches (from an aquarium store or local pond)
- 2-8 - Amphipods (from a local pond)
- Pond sludge (from a local pond)
- Plastic bucket, 1 gallon or larger capacity

These materials may be shared by several groups:

- Fishnet or kitchen strainer
- Dechlorinating solution (for treating tap water; from an aquarium store)
- Solution of freshwater minerals (e.g., “cichlid salts;” from an aquarium store)
- Calcium carbonate powder (from an aquarium store)
- Tablespoon measure

Procedure

1. Your teacher may provide some or all of the materials for your Tabletop Shrimp Support Module (TSSM), or you may be on your own. If you are responsible for rounding up the materials, you can obtain Amano shrimp, snails, hornwort, duckweed from an aquarium store. You can also obtain the dechlorinating and mineral solutions from an aquarium store, but you may want to partner with other groups since you don’t need very much of either solution for one TSSM.

   You can get pond sludge from (you guessed it!) a local pond. Try to find one that has a shallow end where you can easily reach the bottom. Make your collection late in the afternoon, because this is when dissolved oxygen should be highest, and acidity lowest. The best places for collecting will be near aquatic plants and have a mixture of substrates such as sand, rock, and decaying wood. Collect the sludge from the pond bottom, and drag a fine-

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mesh net through the water as well. Ideally, you will collect a mixture of amphipods, copepods, and ostracods along with the sludge.

2. Make Nitrate-Poor Fresh Water (NPFW) by adding dechlorinating solution and mineral solution to a gallon of tap water according to directons on the packages. Your teacher may have you do this step with one or two other groups. The water from the pond or the aquarium store is likely to have a lot of algae and nitrates which would allow algae to take over the system. The use of NPFW helps to prevent this.

3. Rinse your 1-quart canning jar, rocks, and shells in the NPFW.

4. Fill your 1-quart canning jar halfway with NPFW. Put rocks in first, then shells, then the shrimp, snails, hornwort, duckweed, and 2 tablespoons of pond sludge. Be sure not to overload your system with extra animals or plants. Use only the amount specified!

5. Add more NPFW to your jar so that the top of the water is 1-inch below the top edge of the jar. Add 1 tablespoon of calcium carbonate powder (this will make the water cloudy for several hours because it dissolves slowly).

6. Place the cap tightly on the jar.

7. Place your ecosystem in a location that has temperature between 70°F and 80°F, and moderate light for about 12 - 16 hours per day. Do not put your system in direct sunlight.

8. Your TSSM is complete! Allow your system to equilibrate for at least a week before beginning any experiments.