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Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition

How Diverse is That?

[adapted from the 2006 Deep Slope Expedition]

Focus
Quantifying Biological Diversity

Grade Level
9-12 (Life Science/Earth Science)

Focus Question
What do ecologists mean when they say a biological community is "diverse?"

Learning Objectives
Students will be able to discuss the meaning of "biological diversity," and will be able to compare and contrast the concepts of "variety" and "relative abundance" as they relate to biological diversity.

Given abundance and distribution data of species in two communities, students will be able to calculate an appropriate numeric indicator that describes the biological diversity of these communities.

Materials
- ❒ Copies of "Species Density of Stony Corals at Two Sites in the Grenadine Islands," one copy for each student group

Audio/Visual Materials
- ❒ Overhead projector, transparencies, and markers, or marker board, or chalk board

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

Seating Arrangement
Groups of 4-6 students

Maximum Number of Students
32

Key Words
Coral reef
Bonaire
Diversity
Diversity index
Species richness
Species evenness

Background Information
Coral reefs provide habitats for some of the most diverse biological communities on Earth. Most people have seen photographs and video images of shallow-water coral reefs, and many have visited these reefs in person. Historically, scientists have believed that reef-building corals were confined to relatively shallow depths because many of these corals have microscopic algae called zooxanthellae (pronounced "zoh-zan-THEL-ee") living inside their soft tissues. These algae are often important for the corals' nutrition and growth, but require sunlight for photosynthesis. The maximum depth for reef-building corals was assumed to be about 150 m, since light levels below this depth are not adequate to support photosynthesis. Recently, though, ocean explorers have discovered extensive mounds of living coral in depths from 400 m to 700 m—depths at which there is virtually no light at all! These deep-water corals do not contain zooxanthellae, and do not build the same

types of reef that are produced by shallow-water corals. But recent studies indicate that the diversity of species in deep-water coral ecosystems may be comparable to that of coral reefs in shallow waters, and that there are just as many species of deep-water corals (slightly more, in fact) as there are species of shallow-water corals.

Coral reefs provide a variety of benefits including value for recreation and tourism industries, protecting shorelines from erosion and storm damage, supplying foods that are important to many coastal communities, and providing promising sources of powerful new antibiotic, anti-cancer and anti-inflammatory drugs (for more information about drugs from the sea, visit the Ocean Explorer Web site for the 2003 Deep Sea Medicines Expedition (http://oceanexplorer.noaa.gov/explorations/03bio/welcome.html). Despite their importance, 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; for additional information about threats to coral reefs, see "More About the Coral Reef Crisis" in the introduction to this Expedition Education Module).

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." This paradox is an example of "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 1800's. 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). 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.

One of the few coral systems that seems to have escaped the recent coral reef crisis is found in the coastal waters of Bonaire (part of the Netherlands Antilles in the southwestern Caribbean). A 2005 survey of the state of Bonaire's reefs (Steneck and McClanahan, 2005) found that they were among the healthiest reefs in the Caribbean, even though dramatic changes have occurred among corals and other reef species. This means that Bonaire's reefs have unique importance as baselines for comparison with other Caribbean coral reef ecosystems. Detailed mapping of Bonaire's shallow- and deep-water coral reefs is a top priority for protecting these ecosystems, as well as for defining a baseline for investigating and possibly restoring other coral reef systems. This mapping is the focus of the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition.

One of the ways scientists describe and compare biological communities is based on the abundance of species and individuals within a specific area. Two measurements are frequently used:

- Species Diversity (S) - the number of species in the environment; and
- Species Evenness (or equitability) - a measure of 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. For example, samples from two separate communities might each contain the same seven species, with distribution of individuals as follows:

Species	**Number of Individuals**	
	Community 1	Community 2
Species a	44	8
Species b	2	8
Species c	2	8
Species d	2	8
Species e	2	8
Species f	2	8
Species g	2	8
Total	**56**	**56**

Our notion of what "diversity" means leads us to consider Community 2 as more diverse than Community 1, even though they both have the same number of species and total individuals.

Because of the importance of both species evenness and species richness to our idea of diversity, some measures of diversity include a way of including both concepts. One commonly used measure of species diversity that includes proportions of individuals is the Shannon-Weaver information function which is:

$H = -\Sigma p_i \ln p_i$

Where:
H is the diversity index
ln is the natural logarithm
i is an index number for each species present in a sample
p_i is the number of individuals within a species (ni) divided by the total number of individuals (N) present in the entire sample

To calculate the diversity index H, you multiply the proportion (p_i) of each species in the sample times the natural log of that same value ($\ln p_i$), then sum (S) the values for each species, and finally multiply by minus 1.

The table below illustrates the calculation:

	Number of Individuals	Proportion (p_i)	$\ln(p_i)$	$p_i \ln(p_i)$
Species a	3	3÷47 = 0.064	-2.749	0.064 • -2.749 = -.176
Species b	5	5÷47 = 0.106	-2.244	0.106 • -2.244 = -.238
Species c	10	10÷47 = 0.213	-1.546	0.213 • -1.546 = -.329
Species d	6	6÷47 = 0.128	-2.056	0.128 • -2.056 = -.263
Species e	12	12÷47 = 0.255	-1.366	0.255 • -1.366 = -.348
Species f	7	7÷47 = 0.149	-1.904	0.149 • -1.904 = -.284
Species g	4	4÷47 = 0.085	-2.465	0.085 • -2.465 = -.123
Total	47			-1.761 (= $\Sigma p_i \ln p_i$)
H				-1 • $\Sigma p_i \ln p_i$ = 1.761

So, the diversity index H = 1.761.

A commonly used index of how evenly individuals are distributed among the species in a sample is Pielou's Species Evenness (J') which is found by dividing the diversity index by the natural logarithm of the number of species in the sample. So for the example above,
$J' = 1.761 \div \ln 7 = 1.761 \div 1.946 = 0.904$

Species diversity is often used as a measure of environmental health. A stressed environment typically has a lower number of species with one or two species (those adapted to the stress) having many more individuals than the other species. Species diversity tends to increase at the edges of environments (ecotones) where conditions are more variable. For more background on species diversity, visit the Arbor Project's Web page on bird biodiversity at http://www.cees.iupui.edu/Education/Workshops/Project_Seam/Exercises/bird_biodiversity_exerciese.htm.

In this lesson, students will use diversity and evenness indices to analyze survey data from coral communities at two Caribbean reef sites.

Learning Procedure

1. To prepare for this lesson, review the introductory essays for the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition at http://oceanexplorer.noaa.gov/explorations/08bonaire/welcome.html.

   If you are not already familiar with coral reefs, you may also want to review the coral reef tutorials at nos.noaa.gov/education/kits/corals/, as well as essays and trip logs from the 2007 Cayman Island Twilight Zone Expedition (http://oceanexplorer.noaa.gov/explorations/07twilightzone/welcome.html).

2. Discuss the importance of coral reefs, and reasons that they are threatened. Discuss the importance of monitoring to identify threatened reef areas and to improve understanding of reef ecosystems. Lead an introductory discussion of the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition. You may want to show students some images from the Ocean Explorer Web sites (oceanexplorer.noaa.gov/gallery/livingocean/livingocean_coral.html).

   Discuss the concept of biodiversity. Show students the sample data given in the "Background Information" and ask them which of the two communities they intuitively feel is most diverse. This should lead to the concepts of species richness and evenness. Say that the Shannon-Weaver information function and Pielou's Species Evenness are two commonly used indices of diversity and evenness. Work through the sample calculation, and be sure students understand the steps involved.

3. Tell students that monitoring coral reefs requires measurements that describe the condition of these reefs over time, and that calculations of diversity and evenness indices are often used for this purpose. Distribute copies of "Species Density of Stony Corals at Two Sites in the Grenadine Islands" to each student group. Tell students that they are to calculate diversity and evenness indices for the two reef sites included in the sample, and use these indices to compare the coral communities at the two reefs. You may want to suggest that students use a spreadsheet program to speed the calculation process. One approach is to set up columns in the spreadsheet to make the calculations described in the sample diversity index calculation in the "Background Information," then enter the species data for the appropriate communities.

4. Have student groups summarize their results on an overhead transparency or marker board. This summary should resemble the following:

	Saline Is.	Jack Adam Is.
Diversity Index H	2.335	1.788
Evenness Index J'	0.679	0.645

Have each student write an individual analysis of their results. Lead a group discussion of these analyses. Students should realize that coral communities at Saline Island had a higher diversity index than those at Jack Adam Island, even though the Jack Adam reef had a higher total coral density. This is because the Saline island reefs had almost twice as many species as those at Jack Adam. There was considerable variation in the density of individual coral species at both reefs, and only six species at each reef had densities equal to or greater than 100 cm^2/m^2; consequently, the evenness indices are quite similar for the two reefs.

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 discussion 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 provides a powerful cancer treatment).

Discuss biodiversity as it relates to the concept of sustainability in coral reef systems. "Reef sustainability" involves the health of many species (not just corals), as well as an overall community structure that is more or less stable over a relatively long period of time. "Community structure" refers to the ecological functions of the various species that inhabit a community (e.g., small algae, large plants, herbivores that eat small algae, herbivores that eat large plants, carnivores that eat large animals, and animals that eat detritus). In general, the structure of coral reefs is defined by the species of corals, algae, and fishes that inhabit a reef community, and the ecological functions, such as primary production and herbivory, that they perform within the community.

Many scientists believe that the widespread decline of coral reefs is the result of accumulating stresses from multiple sources. In the Caribbean, for example, increased harvesting of herbivorous fishes coupled with nutrient-rich runoff from land created conditions favorable for the growth of large algae. The algae were kept in check by the black spined sea urchin (*Diadema antillarum*), which were present in huge numbers on most reefs in shallow water—until a disease outbreak reduced the sea urchin populations by about 99%. Without herbivorous fishes or the sea urchin, large algae grew rapidly, shading and overgrowing reef building corals (Bellwood, *et al.*, 2004). Dramatic changes in community structure and functions, such as the decline of herbivores and corals accompanied by a dramatic increase in large algae, have been called "phase shifts" (Steneck and McClanahan, 2005). Phase shifts in coral reef systems often indicate a loss of sustainability.

Put another way, "reef sustainability" implies resilience to environmental stress. This resilience includes the ability to resist a phase shift, as well as the ability to recover from environmental disturbances such as severe storms or unusually high temperatures. When multiple stresses reduce this resilience, sustainability declines and reefs are more vulnerable to major changes in community structure that we consider to be degradation. Detailed information on the structure of these reefs from the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition may help explain why Bonaire's coral reefs appear to be unusually resilient (and more sustainable) than many other Caribbean coral reefs. This understanding is critical to efforts to protect and restore other reef systems impacted by the coral reef crisis.

The Bridge Connection

http://www.vims.edu/bridge/reef.html and http://www.marine-ed.org/bridge/archive0505.html.

The "Me" Connection

Have students write a short essay contrasting and comparing the importance of diversity in ocean communities to their own communities.

Connections to Other Subjects

English/Language Arts, Earth Science, Mathematics

Assessment

Written and oral group reports provide opportunities for assessment.

Extensions

1. Visit oceanexplorer.noaa.gov to keep up to date with the latest Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition discoveries.

2. The National Ocean Service Coral Reef Discovery Kit (http://oceanservice.noaa.gov/education/kits/corals/welcome.html) contains a variety of other coral reef-related lessons, information, and activities.

3. Discuss the concept of "shifting baselines," and why this is relevant to environmental and conservation issues. Brainstorm examples of shifting baselines from students' own experience. You may also want to visit http://www.shiftingbaselines.org/index.php for more information about this concept and its relevance to ocean conservation.

4. Discuss the "coral reef crisis" and what students might do to help protect and restore coral reefs. Visit http://www.coralreef.noaa.gov/outreach/thingsyoucando.html and http://www.publicaffairs.noaa.gov/25list.html for ideas. A key concept is that the current environmental conditions on Earth are not the result of a single event or human action; they are the result of countless individual decisions that collectively can have huge—and often unforeseen-impacts.

Multimedia Learning Objects

http://www.learningdemo.com/noaa/ – Click on the links to Lessons 3, 12, and 13 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Food, Water, and Medicine from the Sea, and Ocean Pollution.

Other Relevant Lesson Plans from the Ocean Exploration Program

The Benthic Drugstore

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

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

Students will be able to identify at least three pharmacologically-active chemicals derived from marine invertebrates, describe the disease-fighting action of at least three pharmacologically-active chemicals derived from marine invertebrates, and infer why sessile marine invertebrates appear to be promising sources of new drugs.

Watch the Screen!

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

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

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

Now Take a Deep Breath

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

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

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

History's Thermometers

http://oceanexplorer.noaa.gov/explorations/02alaska/background/edu/media/thermo9_12.pdf (5 pages, 80k) (from the 2002 Alaska Seamount Expedition)

Focus: Use of deep-water corals to determine long-term patterns of climate change (Physics)

In this activity, students will be able to explain the concept of paleoclimatological proxies, learn how oxygen isotope ratios are related to water temperature, and interpret data on oxygen isotope ratios to make inferences about climate and climate change in the geologic past.

Cut-off Genes

http://oceanexplorer.noaa.gov/explorations/04mountains/background/edu/media/MTS04.genes.pdf (12 pages, 648k) (from the Mountains in the Sea 2004 Expedition)

Focus: Gene sequencing and phylogenetic expressions (Life Science)

In this activity, students will be able to explain the concept of gene-sequence analysis; and, given gene sequence data, students will be able to draw inferences about phylogenetic similarities of different organisms.

Feeding in the Flow

http://oceanexplorer.noaa.gov/explorations/03bump/background/edu/media/03cbfeedflow.pdf (6 pages, 268k) (from the 2003 Charleston Bump Expedition)

Focus: Effect of water currents on feeding efficiency in corals (Life Science)

In this activity, students will be able to describe at least two ways in which current flow may affect the feeding efficiency of particle-feeding organisms and explain how interactions between current flow and the morphology of a particle-feeding organism may affect the organism's feeding efficiency. Students will also be able to identify at least two environmental factors in addition to current flow that may affect the morphology of reef-building corals.

Cool Corals

http://oceanexplorer.noaa.gov/explorations/03edge/background/edu/media/cool.pdf (7 pages, 476k) (from the 2003 Life on the Edge Expedition)

Focus: Biology and ecology of *Lophelia* corals (Life Science)

In this activity, students will describe the basic morphology of *Lophelia* corals and explain the significance of these organisms, interpret preliminary observations on the behavior of *Lophelia* polyps, and infer possible explanations for these observations. Students will also discuss why biological communities associated with *Lophelia* corals are the focus of major worldwide conservation efforts.

Keep It Complex!

http://oceanexplorer.noaa.gov/explorations/03bump/background/edu/media/03cb_complex.pdf (5 pages, 272k) (from The Charleston Bump 2003 Expedition)

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

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

Are You Related?

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

Focus: Molecular genetics of deepwater corals (Life Science)

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

How Does Your (Coral) Garden Grow?

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

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

In this activity, students will identify and briefly explain two methods for estimating the age of hard corals, learn how oxygen isotope ratios are related to water temperature, and interpret data on oxygen isotope ratios to make inferences about the growth rate of deep-sea corals.

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.

oceanexplorer.noaa.gov – Web site for NOAA's Ocean Exploration program

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

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)

Steneck, R.S., S.N. Arnold, and J.B. Brown, eds. 2005. A report on the status of the coral reefs of Bonaire in 2005 with advice on the establishment of fish protection areas. Pew Charitable Trust Report, 64 pp. (http://www.bmp.org/pdfs/Status-of-coral-reef-2005.pdf)

http://www-biol.paisley.ac.uk/courses/Tatner/biomedia/units/cnid1.htm – Phylum Cnidaria on Biomedia of the

Glasgow University Zoological Museum on the Biological Sciences, University of Paisley, Scotland Web site; includes explanations of the major classes, a glossary of terms and diagrams and photos

http://www.calacademy.org/research/izg/calwildfall2000.pdf – Article from California Wild: "Stinging Seas - Tread Softly In Tropical Waters" by Gary C. Williams; an introduction to the venomous nature of tropical cnidarians, why and how they do it

http://www.cees.iupui.edu/Education/Workshops/Project_Seam/Exercises/bird_biodiversity_exerciese.htm – Biodiversity exercises from the Center for Earth and Environmental Science, Indiana University – Purdue University, Indianapolis

http://www.mcbi.org/publications/pub_pdfs/Deep-Sea%20Coral%20issue%20of%20Current.pdf – A special issue of *Current: the Journal of Marine Education* on deep-sea corals.

http://www.mesa.edu.au/friends/seashores/index.html – "Life on Australian Seashores" by Keith Davey on the Marine Education Society of Australasia Web site, with an easy introduction to Cnidaria, including their method of reproduction

Diamante-Fabunan, D. 2000. Coral Bleaching: the Whys, the Hows and What Next? OverSeas, The Online Magazine for Sustainable Seas. http://www.oneocean.org/overseas/200009/coral_bleaching_the_hows_and_whys_and_whats_next.html

http://www.crc.uri.edu/download/COR_0011.PDF – "Coral Bleaching: Causes, consequences and response;" a collection of papers from the Ninth International Coral Reef Symposium.

http://www.nmfs.noaa.gov/habitat/habitatconservation/publications/Separate%20Chapters/Cover%20and%20Table%20of%20Contents.pdf – "The State of Deep Coral Ecosystems of the United States," 2007 report from NOAA providing new insight into the complex and biologically rich habitats found in deeper waters off the U.S. and elsewhere around the world.

http://www.latimes.com/news/local/oceans/la-oceans-series,0,7842752.special – "Altered Oceans," five-part series from the Los Angeles Times on the condition of Earth's ocean; published July 30 – August 3, 2006

Goodwin, M.H., M.J.C. Cole, W.E. Stewart, and B.L. Zimmerman. 1976. Species density and associations in Caribbean reef corals. J. Exp. Mar. Biol. Ecol. 24:19-31.

National Science Education Standards

Content Standard A: Science As Inquiry
- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard B: Physical Science
- Interactions of energy and matter

Content Standard C: Life Science
- Interdependence of organisms

Content Standard D: Earth and Space Science
- Geochemical cycles

Content Standard F: Science in Personal and Social Perspectives
- Environmental quality

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 4.
The ocean makes Earth habitable.

Fundamental Concept b. The first life is thought to have started in the ocean. The earliest evidence of life is found in the ocean.

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.

Fundamental Concept b. Most life in the ocean exists as microbes. Microbes are the most important primary producers in the ocean. Not only are they the most abundant life form in the ocean, they have extremely fast growth rates and life cycles.

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 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.

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

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

Essential Principle 7.
The ocean is largely unexplored.

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

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

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

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

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

Send Us Your Feedback

We value your feedback on this lesson.
Please send your comments to:
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For More Information

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Student Handout

Species Density of Stony Corals at Two Sites in the Grenadine Islands

(adapted from Goodwin, et al., 1976)

Species Density (cm^2/m^2)

	Saline	**Jack Adam**
Stephanocoenia michelini	69	11
Madracis decactis	1	0
Acropora palmata	44	347
Acropora cervicornis	0	169
Agaricia agaricites	48	100
Agaricia agaricites crassa	164	45
Agaricia agaricites purpurea	72	0
Agaricia fragilis	1	0
Agaricia nobilis	10	0
Siderastrea radians	2	13
Siderastrea siderea	242	19
Porites astreoides	318	0
Porites furcata	78	263
Porites porites	822	653
Favia sp.	16	74
Diploria clivosa	6	0
Diploria labyrinthiformis	5	10
Diploria strigosa	44	49
Colpophyllia amaranthus	59	0
Colpophyllia natans	51	0
Manicina areolata	1	0
Montastrea annularis	460	1415
Montastrea cavernosa	114	4
Meandrina meandrites	20	0
Meandrina braziliensis	2	0
Dichocoenia stokesii	30	0
Scolymia lacera	7	0
Isophyllastrea rigida	11	0
Mycetophyllia lamarckiana	3	0
Isophyllia multiflora	24	9
Eusmilia fastigiata	11	0
Millepora alcicornis	21	91