Lophelia II 2012:
Deepwater Platform Corals Expedition

Who's Connected?

Image captions/credits on Page 2.

lesson plan

Focus
Connectivity of *Lophelia* coral populations

Grade Level
9-12 (Life Science)

Focus Question
How can ocean explorers determine the extent to which separate populations of *Lophelia* corals are related, and how can this information be used to select effective strategies for protecting biodiversity among *Lophelia* corals?

Learning Objectives
- Students will analyze and interpret genetic data from populations of *Lophelia* corals to identify patterns that indicate how closely these populations are related.
- Students will use results of this analysis as evidence to explain flows and conservation of genetic material between *Lophelia* coral populations, and how this explanation could be used to select effective strategies for protecting biodiversity among *Lophelia* corals.
- Students will explain how the presence of both sexual and asexual reproduction in *Lophelia* corals affects the stability of *Lophelia* reef ecosystems and natural selection among populations of these corals.

Materials
- Copies of of the *Lophelia Coral Reef Connectivity Worksheet*, one copy for each student group

Audio-Visual Materials
- Interactive white board

Teaching Time
One or two 45-minute class periods

Seating Arrangement
Groups of two to three students

Maximum Number of Students
30

These small oil droplets have seeped through the sediment and adhered to the top of methane hydrate. This image was taken at a depth of less than 1,000 m in the Gulf of Mexico. Image courtesy of Ian MacDonald, Texas A&M-Corpus Christi.
http://oceanexplorer.noaa.gov/explorations/06mexico/logs/may08/media/oil_on_methane_600.html

Images from Page 1 top to bottom:
Colonies of *Lophelia* coral with outstretched feeding polyps were discovered on the eastern scarp of the West Florida Escarpment at approximately 400 meters. These corals and Cretaceous rocks hosted crabs and tubeworms (at right). Image courtesy of NOAA *Okeanos Explorer* Program, Gulf of Mexico Expedition 2012.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/hires/leg2sum-1-hires.jpg

Tim Shank and Dave Lovalvo ensure science and operational objectives are met while exploring a shipwreck. Image courtesy of NOAA *Okeanos Explorer* Program.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/hires/mar30_update_hires.jpg

Anchor resting on the top of the Site 15429 wreck. *Lophelia* coral is also visible. Image courtesy of NOAA *Okeanos Explorer* Program.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/hires/mar29_hires.jpg

Photo mosaics are created using a series of photographs that overlap along a straight transect. Several transects are then "stitched" together to form the overall picture. Image courtesy of *Lophelia* II 2010 Expedition, NOAA-OER/BOEM.
http://oceanexplorer.noaa.gov/explorations/10Lophelia/logs/hires/mosaic_hires.jpg

Key Words

Lophelia
Connectivity
Marine protected areas
Natural selection

Background Information

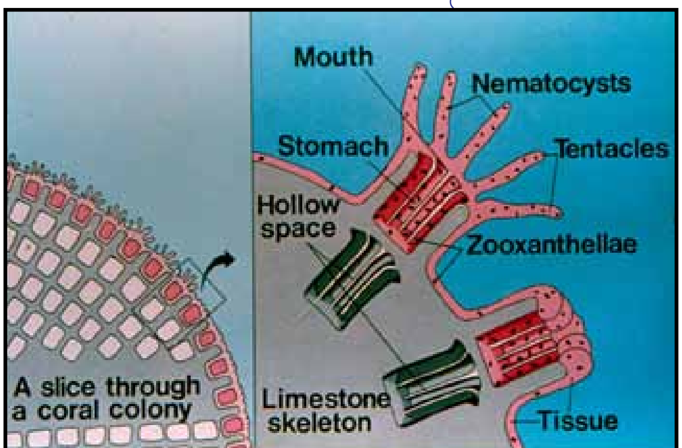
Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

Two types of deepwater ecosystems are typically associated with rocky substrates or hardgrounds in the Gulf of Mexico: chemosynthetic communities and deep-sea coral communities. Most of these hard bottom areas are found in locations called cold seeps where hydrocarbons are seeping through the seafloor. Petroleum deposits are abundant in the Gulf of Mexico: in 2009, oil production from the Gulf accounted for 30 percent of U.S. domestic production and 11 percent of natural gas production. Because deepwater ecosystems are associated with hydrocarbon seeps, 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 whose importance is presently unknown. Since 2002, NOAA's Office of Ocean Exploration and Research (OER) has sponsored nine expeditions to locate and explore deep-sea ecosystems in the Gulf of Mexico.

Deepwater coral reefs were discovered in the Gulf of Mexico nearly 50 years ago, but very little is known about the ecology of these communities or the basic biology of the corals that produce them. The most common deep-sea reef-building coral in the Gulf is *Lophelia pertusa*.

Although deepwater coral reefs are normally associated with hardgrounds, the corals that form them can also grow on artificial surfaces, including shipwrecks and petroleum production platforms. In 2008, there were more than 4,000 active platforms in the Gulf of Mexico, and thousands of others that are no longer active. The focus of the *Lophelia* II 2012: Deepwater Platform Corals Expedition is to investigate the biology and ecology of deepwater corals and associated organisms growing on oil production platforms.

Deepwater coral reefs are quite fragile, and there is increasing concern that they may be in serious danger, along with associated resources. Many investigations have reported large-scale damage due to commercial fishing trawlers, and there is also concern about impacts that might result from exploration and extraction of fossil fuels. These impacts are especially likely in the Gulf of Mexico, since the carbonate foundation for many deepwater reefs is strongly associated with the presence of hydrocarbons. Potential impacts include directly toxic effects of hydrocarbons on reef organisms, as well as effects from particulate materials produced by drilling operations. Since many deepwater reef organisms are filter feeders, increased particulates could clog their filter apparatus and possibly smother bottom-dwelling organisms.



Coral polyp diagram. Courtesy Mel Goodwin.

Corals are members of the phylum Cnidaria whose members are characterized by having stinging cells (nematocysts) that are used for feeding and defense. Individual coral animals are called polyps, each of which has an internal skeleton made of limestone (calcium carbonate). In many corals species, including those that build reefs, the polyps form colonies composed of many individuals whose skeletons are fused together. In other species, the polyps live as solitary individuals. Each polyp has a ring of flexible tentacles surrounding an opening to the digestive cavity. The tentacles contain nematocysts that usually contain toxins used to capture prey or discourage predators. Corals are sessile (they stay in one spot) thus they are dependent upon currents to bring food within the reach of their tentacles. *L. pertusa* feeds on a variety of phytoplankton and zooplankton species, as well as dead materials.

The skeletons of individual corals are basically cup-shaped and provide protection as well as support for soft tissues. The fused skeletons of colonial corals may form boulders, plate-like structures, or complex branches. Large coral reefs develop over hundreds of years; some *L. pertusa* reefs are estimated to be more than 8,000 years old. As the corals reproduce, the skeletons of new corals grow on top of the skeletons of corals that have died (the lifespan of a single polyp is estimated as 10 – 15 years). *L. pertusa* grows at a rate that has been estimated to range between 4-25 mm per year, and produces complex branches and bushy colonies. This growth form aids feeding by reducing fast currents that could otherwise deform the soft polyps, and also produces strong and complex physical structures. Occasionally, highly branched colonies may partially collapse, producing rubble that traps sediments that add to reefs' stability. Over time, repeated cycles of coral growth, collapse, and sediment entrapment can produce large reefs and mounds that provide habitats for many other species.

Although some corals are hermaphroditic (single individuals are male and female at some point in their life cycle), *L. pertusa* is gonochoric (individuals are only one sex during their life cycle). In fact, all of the polyps in a *L. pertusa* colony are the same sex. Corals may reproduce asexually by budding from the body of an adult polyp, by releasing larvae into the surrounding water, or from pieces of coral broken off from a colony. Corals also may reproduce sexually by forming eggs and sperm that produce a larva when a sperm fertilizes an egg. Anthozoan larvae are called planulae, and are pear-shaped with a fringe of cilia that provides limited swimming ability. One study of *L. pertusa* in the North Sea found that sexual reproduction occurred seasonally, and coincided with high rates of phytoplankton production in July. *L. pertusa* in the Gulf of Mexico appear to spawn in September or October.

L. pertusa is found throughout Earth's ocean except in polar areas. Even with such a wide distribution and no obvious physical barriers, *L. pertusa* corals from different ocean regions have genetic differences that suggest these corals belong to different populations (a population is a group of organisms that belong to the same species, live in the same geographic area, and are more likely to breed with each other than with organisms from other areas). These differences can be detected and studied using techniques of molecular biology. Studies of this kind provide information about how *L. pertusa* larvae are dispersed, and are essential to understanding how *L. pertusa* reef ecosystems can be protected and restored. The extent to which individuals are exchanged between different populations is called connectivity. In the case of corals, which do not move once they have settled, connectivity depends upon larval dispersal.

In this lesson, students will analyze and interpret genetic data from populations of *L. pertusa* corals to identify patterns that indicate how closely these populations are related, and use this analysis to make inferences about effective strategies for protecting biodiversity among these corals.

Learning Procedure

1. To prepare for this lesson:
   (a) Review the introductory essay for the *Lophelia* II 2012: Deepwater Platform Corals Expedition, and the background essay on measuring growth rates in *L. pertusa* (http://oceanexplorer.noaa.gov/explorations/12Lophelia/welcome.html). Download one or more images of a *Lophelia* coral colony from this Web site, or from the Photo and Video Log for the *Lophelia* II 2010: Oil Seeps and Deep Reefs expedition (http://oceanexplorer.noaa.gov/explorations/10lophelia/logs/photolog/photolog.html).
   (b) Review the *Lophelia Coral Reef Connectivity Worksheet*, and decide whether students will need to review basic concepts of inheritance and natural selection before completing this activity.

2. Introduce the *Lophelia* II 2012: Deepwater Platform Corals expedition and describe deepwater coral communities. Be sure to

mention the connection to hardgrounds and hydrocarbon seeps, and say that the presence of deepwater coral communities is often an indication that petroleum deposits may be nearby. Emphasize that a central purpose of this expedition is to provide information needed to protect these deepwater coral ecosystems. Tell students that while deepwater coral reefs were discovered in the Gulf of Mexico nearly 50 years ago, very little is known about the ecology of these communities or the basic biology of the corals that produce them. Show one or more images of *Lophelia* reefs and describe the role *L. pertusa* in building deepwater coral reefs. Be sure to include the fact that these reefs are found throughout Earth's ocean, except in polar regions.

3. This activity assumes that students are familiar with the general biology of Cnidaria and the basic concepts of population, heredity, and natural selection. You may wish to review ideas presented in the background section of the *Lophelia Coral Reef Connectivity Worksheet* with the class as a whole before students begin working on the questions.

4. Provide each student group with a copy of the *Lophelia Coral Reef Connectivity Worksheet*, and say that their assignment is to explore a study about how closely related different populations of corals may be. When students have completed their answers to questions on the Worksheet, lead a discussion of their results. The following points should be included:
   - *L. pertusa* corals reproduce asexually by budding from the body of an adult polyp, by releasing larvae into the surrounding water, or from pieces of coral broken off from a colony. This species has separate sexes, and may also reproduce sexually by forming eggs and sperm that produce a larva when a sperm fertilizes an egg. Fertilization may take place within the body of the female coral, or in the water column. When eggs are fertilized within the female, the larvae may develop inside the adult coral (brooding) before they are eventually released to the water column.

   - Connectivity is the extent to which individuals are exchanged between different populations.

   - Since corals do not move once their larvae have settled, connectivity depends upon dispersal during the larval phase.

   - Factors that affect how far *L. pertusa* coral larvae are dispersed include duration of the free-swimming larval phase, strength and direction of ocean currents, larval behavior, and availability of suitable habitat for settlement.

- Students may devise a variety of strategies for analyzing data in Table 1. The simplest approach is to calculate the average number of alleles among all nine loci, and then use these numbers to compare the 16 sites. A more complex approach, similar to the techniques used by Morrison *et al*. (2011), is a pair-by-pair comparison of each locus at each site with the same locus at all the other sites. This is a form of cluster analysis, and would involve over a thousand comparisons. The emphasis here should be that students have a well-reasoned basis for selecting an analytic strategy that can be expected to produce meaningful results.

- Based on a comparison of the average number of alleles among all nine loci, the data in Table 1 generally show greater connectivity among samples from the same region than samples from different regions. There are exceptions, however, such as the samples from Vioska Knoll, which more closely resemble samples from sites in the Southeastern U.S. region than other sites in the Gulf of Mexico.

- Data in Table 1 are consistent with the presence of multiple options for reproduction in *L. pertusa*. The results from Vioska Knoll samples, for example, might result from corals that rely largely on asexual reproduction or brooding rather than larvae that have a long free-swimming stage. In general, connectivity decreases with increasing geographic distance.

- Data in Table 1 suggest that there is limited gene flow between populations of *L. pertusa*, but that long-distance dispersal of larvae occurs often enough to produce similarities among populations from the same geographic region.

- Since data in Table 1 suggest that there is limited gene flow between populations of *L. pertusa*, a single marine protected area in one location probably would not have much influence on distant locations. These data show that *L. pertusa* populations in widely separated locations are genetically different, so protection of biodiversity in these populations would require protection of multiple locations.

- Budding, brooding, and reproduction by fragmentation all help ensure that *L. pertusa* offspring will remain fairly close to their parents and contribute to the development and stability of the parent colony.

Corals that live in a specific location can be expected to have traits that contribute to the survival of individuals exposed to the environmental conditions that are typical of that location. Since these conditions vary among different geographic regions, reproductive strategies that tend to keep coral offspring near the location to which they are adapted are more likely to contribute to survival than strategies that carry offspring into areas where they may encounter conditions to which they are less well-adapted. Some exchange of genetic material among widely separated locations may be useful, however, since natural selection depends upon variation in genetic information that results in traits that affect survival and reproductive ability. This exchange may be particularly important if environmental conditions change so that other traits become important to survival.

The BRIDGE Connection

www.vims.edu/bridge/ – In the "Site Navigation" menu on the left, scroll over "Ocean Science Topics," then "Human Activities," then click "Technology" for links to resources about submersibles, ROVs, and other technologies used in underwater exploration.

The "Me" Connection

Have students write a brief essay about why deepwater coral ecosystems should (or should not) be protected.

Connections to Other Subjects

English/Language Arts, Mathematics

Assessment

Students' answers to worksheet questions and class discussions provide opportunities for assessment.

Extensions

Visit http://oceanexplorer.noaa.gov/explorations/12Lophelia/welcome.html for more information and resources related to the *Lophelia* II 2012: Deepwater Platform Corals Expedition.

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html
Click on the links to Lessons 3, 6, and 12 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Deep-Sea Benthos, and Medicine from the Sea.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

What's the Connection?
(from the Lophelia II 2010 Expedition)
http://oceanexplorer.noaa.gov/explorations/10lophelia/background/edu/media/loph10_connection912.pdf

Focus: Relationship of hardground communities in the Gulf of Mexico to physical and chemical environmental features (Life Science/Chemistry)

Students will define hardgrounds and explain how they are formed in the Gulf of Mexico, and discuss the relationships between hydrocarbon seeps, chemosynthetic communities, and deep-water coral communities in the Gulf of Mexico.

Welcome to My Community!
(from the *Lophelia* II 2010 Expedition)
http://oceanexplorer.noaa.gov/explorations/10lophelia/background/edu/media/loph10_mycommunity912.pdf

Focus: Change detection in biological communities (Life Science/Mathematics)

Students will define the concept of a biological community; perform calculations to identify communities from biological surveys; and describe how biological surveys may be used to detect changes in deep-sea communities.

The Benthic Drugstore
(from the Cayman Islands Twilight Zone 2007 Expedition)
http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/drugstore.pdf

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.

Biochemistry Detectives
(from the 2002 Gulf of Mexico Expedition)
http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_biochem.pdf

Focus: Biochemical clues to energy-obtaining strategies (Chemistry)

Students will be able to explain the process of chemosynthesis, explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps, and describe three energy-obtaining strategies used by organisms in cold-seep communities. Students will also be able to interpret analyses of enzyme activity and 13C isotope values to draw inferences about energy-obtaining strategies used by organisms in cold-seep communities.

What Was for Dinner?
(from the 2003 Life on the Edge Expedition)
http://oceanexplorer.noaa.gov/explorations/03edge/background/edu/media/dinner.pdf

Focus: Use of isotopes to help define trophic relationships (Life Science)

In this activity, students will describe at least three energy-obtaining strategies used by organisms in deep-reef communities and interpret analyses of 15N, 13C, and 34S isotope values.

Chemosynthesis for the Classroom
(from the 2006 Expedition to the Deep Slope)
http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/gom_06_chemo.pdf

Focus: Chemosynthetic bacteria and succession in chemosynthetic communities (Chemistry/Biology)

Students will observe the development of chemosynthetic bacterial communities and will recognize that organisms modify their environment in ways that create opportunities for other organisms to thrive. Students will also be able to explain the process of chemosynthesis and the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.

How Diverse is That?
(from the 2006 Expedition to the Deep Slope)
http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/gom_06_diverse.pdf

Focus: Quantifying biological diversity (Life Science)

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.

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/edu/guide/gomdse_edguide.pdf – Educators' Guide for the Gulf of Mexico Deep-Sea Ecosystems Education Materials Collection.

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.

http://www.gulfallianceeducation.org – Extensive list of publications and other resources from the Gulf of Mexico Alliance

Fisher, C., H. Roberts, E. Cordes, and B. Bernard. 2007. Cold Seeps and Associated Communities of the Gulf of Mexico. *Oceanography* 20(4):118-129; available online at http://www.tos.org/oceanography/archive/20-4_fisher.html

Morrison, C. L., S. W. Ross, M. S. Nizinski, S. Brooke, J. Järnegren, R. G. Waller, R. L. Johnson, and T. L. King. 2011. Genetic discontinuity among regional populations of *Lophelia* pertusa in the North Atlantic Ocean. Conserv Genet 12:713–729.

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/

Standards Correlations

Relationship to A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas

The objectives of this lesson integrate the following Practices, Crosscutting Concepts, and Core Ideas:

Objective: Analyze and interpret genetic data from populations of *Lophelia* corals to identify patterns that indicate how closely these populations are related.

Practices:

4. Analyzing and interpreting data

Crosscutting Concepts:

1. Patterns

Core Ideas:
LS4.A Evidence of common ancestry and diversity

Objective: Use results of the preceding analysis as evidence to explain flows and conservation of genetic material between *Lophelia* coral populations, and how this explanation could be used to select effective strategies for protecting biodiversity among *Lophelia* corals.

Practices:
6. Constructing explanations
7. Engaging in argument from evidence

Crosscutting Concepts:
5. Energy and matter: flows, cycles, and conservation

Core Ideas:
LS4.D Biodiversity and Humans

Objective: Explain how the presence of both sexual and asexual reproduction in *Lophelia* corals affects the stability of *Lophelia* reef ecosystems and natural selection among populations of these corals.

Practices:
6. Constructing explanations

Crosscutting Concepts:
7. Stability and change

Core Ideas:
LS4.B Natural Selection

Correlations to Common Core State Standards for Mathematics

High school – Modeling

Correlations to Common Core State Standards for English Language Arts

SL.1 – Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 6 topics, texts, and issues, building on others' ideas and expressing their own creativity

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 5.
The ocean supports a great diversity of life and ecosystems.
Fundamental Concept d. Ocean biology provides many unique examples of life cycles, adaptations and important relationships

among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.

Fundamental Concept e. The ocean is three-dimensional, offering vast living space and diverse habitats from the surface through the water column to the seafloor. Most of the living space on Earth is in the ocean.

Fundamental Concept f. Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is "patchy". Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.

Essential Principle 6.
The ocean and humans are inextricably interconnected.

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

Fundamental Concept 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 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.

Send Us Your Feedback

In addition to consultation with expedition scientists, the development of lesson plans and other education products is guided by comments and suggestions from educators and others who use these materials. Please send questions and comments about these materials to: oceanexeducation@noaa.gov.

For More Information

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

Acknowledgements

This lesson was developed and written for NOAA's Office of Ocean Exploration and Research (OER) by Dr. Mel Goodwin, Science and Technology Consultant to OER's Education Team.
Design/layout: Coastal Images Graphic Design, Mt. Pleasant, SC.

Credit

If reproducing this lesson, please cite NOAA as the source, and provide the following URL: http://oceanexplorer.noaa.gov

Lophelia Coral Reef Connectivity Worksheet

Deepwater coral reefs are unique and complex ecosystems that are found throughout Earth's ocean except in polar regions. Some of the most extensive deepwater reefs in U.S. waters are found on the continental slope off the southeastern U.S coast, and to a lesser extent in the Gulf of Mexico where they are often associated with hydrocarbon deposits. The major deepwater reef-building coral in the Gulf of Mexico and many other places is *Lophelia pertusa*. Despite their widespread distribution and potential importance, very little is known about the ecology of these communities or the basic biology of the corals that produce them. *L. pertusa* reefs are quite fragile, and there is increasing concern that deepwater reefs and their associated resources may be in serious danger. Many investigations have reported large-scale damage due to commercial fishing trawlers, and there is also concern about impacts that might result from exploration and extraction of fossil fuels.

One of the key questions related to the management and protection of *L. pertusa* reefs is, how closely related are populations of *L. pertusa* corals in different geographic areas? A population is a group of organisms that belong to the same species, live in the same geographic area, and are more likely to breed with each other than with organisms from other areas. It is known that genetic differences in *L. pertusa* corals from different ocean regions suggest these corals belong to different populations. These differences can be detected and studied using techniques of molecular biology.

One such technique uses short repeating sequences of DNA nucleotides called microsatellite DNA markers. The number of copies in the sequence usually varies between individuals, so scientists can tell individual corals apart. The location on a strand of DNA where these sequences (or any sequence of nucleotides) is found is called a locus. The different versions of sequences at a single locus (caused by different numbers of copies of nucleotide sequences) are called alleles. Each allele has a different number of copies of the nucleotide sequence than other alleles at the same locus.

By examining many microsatellite DNA markers, scientists can get an idea about how closely related different populations of corals may be. Studies of this kind provide information about how *L. pertusa* larvae are dispersed, and are essential to understanding how *L. pertusa* reef ecosystems can be protected and restored. This worksheet guides an exploration of one such study (Morrison, *et al.*, 2011).

1. How do *L. pertusa* corals reproduce?

2. What is connectivity?

3. What part of the life cycle of *L. pertusa* corals determines connectivity among populations of this species?

4. What are at least three factors that affect how far *L. pertusa* coral larvae are dispersed from their parent colonies?

5. Table 1 shows the number of alleles in nine microsatellite DNA markers from *L. pertusa* sampled at 16 different geographic locations. How could you analyze these data to decide how closely related corals from these locations may be?

6. Using the technique you described in Question 5, what do you conclude about the connectivity among the populations from the 16 locations?

7. What does your analysis suggest about the flow of genetic material between the sampled populations?

8. If you were responsible for developing a program to protect biodiversity in *L. pertusa* coral populations, and had to choose between establishing one large protected area or establishing three smaller protected areas, how would you justify your choice based on your analysis?

9. How does the reproductive behavior of *L. pertusa* affect the stability of deepwater reef ecosystems and natural selection among populations of these corals?

Table 1

Number of Alleles in Nine Microsatellite DNA Markers from *Lophelia pertusa* in 16 Geographic Locations

(adapted from Morrison, *et al.*, 2011)

Region	Location	Locus								
		LpeA5	LpeC120	LpeC142	LpeC151	LpeC44	LpeC52	LpeC61	LpeD3	LpeD5
Gulf of Mexico	GC	5	5	9	4	8	7	12	9	5
Gulf of Mexico	GP	5	5	8	3	8	6	11	10	4
Gulf of Mexico	VK862	7	11	14	6	17	9	16	13	6
Gulf of Mexico	VK826	9	14	23	8	33	15	34	33	33
Southeast U.S.	MTR	6	10	11	5	20	8	20	14	10
Southeast U.S.	CCN	7	14	15	6	22	13	24	24	10
Southeast U.S.	JAX	8	18	17	7	19	13	25	24	15
Southeast U.S.	SAV	7	12	14	7	15	10	19	19	15
Southeast U.S.	STS	9	24	24	11	31	17	33	37	14
Southeast U.S.	CFR	7	12	17	5	23	12	24	27	18
Southeast U.S.	CLO	10	23	27	9	33	19	28	45	25
Northeast Seamounts	MAN	2	8	6	1	3	2	4	10	5
Northeast Seamounts	REH	3	12	7	1	5	3	5	10	5
Eastern North Atlantic	RB	5	6	11	5	12	2	10	11	5
Eastern North Atlantic	MNG	6	4	10	5	9	1	11	11	5
Eastern North Atlantic	TRF	8	9	15	7	14	1	17	16	6

GC – Green Canyon; GP – Tanker Gulf Penn; VK862 – Viosca Knoll lease #862; VK826 – Viosca Knoll lease #826; MTR –Miami Terrace; CCN – Cape Canaveral; JAX –Jacksonville; SAV – Savannah Banks; STS – Stetson; CF – Cape Fear; CLO – Cape Lookout; MAN – Manning; REH – Rehoboth; RB – Rockall Bank; MNG – Mingulay Reef; TRF – Trondheimfjord