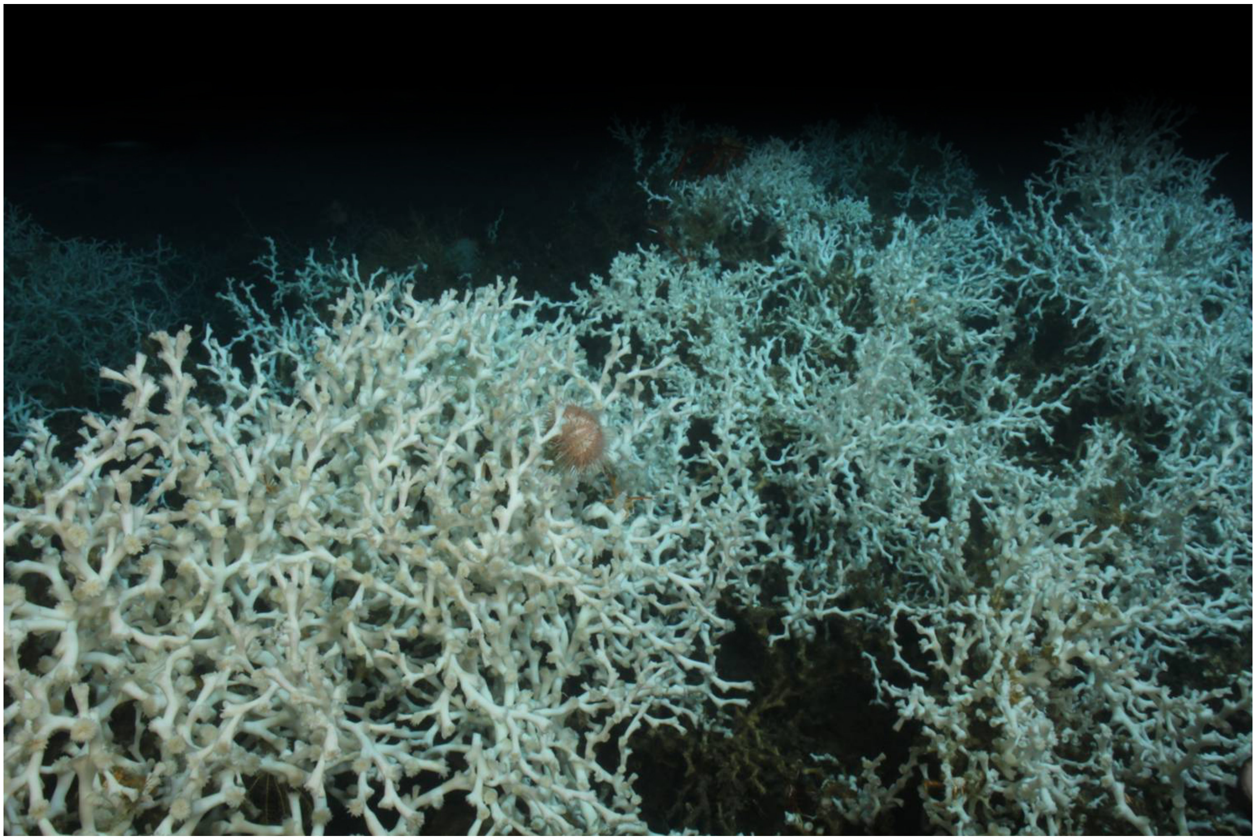

Lophelia II: Understanding Deep-Sea Coral Ecology

A problem-based curriculum

BOEM
Bureau of Ocean Energy Management

Lophelia II - Understanding Deep-Sea Coral Ecology: A Problem-Based Curriculum was developed as part of the "Exploration and Research of Northern Gulf of Mexico Deepwater Natural and Artificial Hard Bottom Habitats with Emphasis on Coral Communities: Reefs, Rigs, and Wrecks" project ("Lophelia II"). Study concept, oversight, and funding were provided by the U.S. Department of the Interior, Bureau of Ocean Energy Management, Environmental Studies Program, Washington, D.C. under contract number M08PC20038 with additional funding from NOAA/OER. Additional support and collaboration was provided by the U.S. Geological Survey.

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- And their students

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- Members of the *Lophelia* II Science Party
- R/V Brooks McCall ship crew

Contracting Officer's Representative
- Greg Boland (Bureau of Ocean Energy Management)

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Introduction

Public awareness, education, and outreach are important components of scientific research projects funded by the Bureau of Ocean Energy Management (BOEM) and NOAA's Office of Ocean Exploration and Research (NOAA OER), in support of recommendations for an informed public and an ocean literate society made by the Pew Oceans Commission (2003), the U.S. Commission on Ocean Policy (2004), and the U.S. Ocean Action Plan (2004). As such, this curriculum was developed as the educational outreach component of the scientific research study "Exploration and Research of Northern Gulf of Mexico Deepwater Natural and Artificial Hard Bottom Habitats with Emphasis on Coral Communities: Reefs, Rigs, and Wrecks." The study, referred to as "*Lophelia* II," was initiated in 2009 under contract between BOEM and TDI Brooks International Inc. and had the primary goal of "obtaining a robust predictive capability for the occurrence of rich cnidarian (primarily coral) hard ground communities in the deep Gulf of Mexico."

The purpose behind the research study sponsored by the BOEM was to understand the ecology of seafloor communities, particularly those potentially impacted by development for offshore energy resources. Acting under acts of Congress, BOEM serves as a prudent manager of the nation's seafloor mineral resources. This management role requires development of critical energy resources without unacceptable impact on other ocean users, the natural environment, and the human environment. The primary strategy that BOEM employs to eliminate or minimize environmental impact is to identify sensitive habitat and then restrict or otherwise mitigate exploration, development, and production activity there. BOEM sponsors scientific research to identify and understand the needs and extent of these sensitive ecosystems. Deep-sea coral communities and hydrocarbon seep communities, for example, have been studied extensively in the last 10+ years through independent research projects sponsored by this agency. In addition to adding to the scientific body of knowledge about deep-sea marine ecosystems, results from these research projects are used by BOEM's scientists to advise policy makers when making decisions about development of resources offshore.

Problem Based Learning

Recognizing the value of helping students understand the mission, importance and challenges of energy management, this curriculum was based on the real-life practices of prioritizing exploratory energy drilling sites while minimizing ecosystem impact. Our approach in developing this curriculum follows the principles of Problem Based Learning (PBL). According to Barrows and Kelson (1993), PBL is a curriculum and a process. The PBL *curriculum* typically consists of carefully selected problems that demand from the learner acquisition of critical knowledge and problem solving proficiency, and the PBL *process* typically replicates the commonly used approach to resolving problems or meeting challenges encountered in life and career. The *Lophelia* II curriculum is designed around a Challenge Scenario – an activity in which students adopt the role of marine scientist to address the challenge of prioritizing potential drilling sites while minimizing ecosystem impacts. To address the challenge, students work through the six lessons to obtain the necessary background knowledge to determine which exploratory sites represent the least impact to deep-sea coral communities. These six lessons introduce students to the organisms typically found in deep-sea coral communities, to the basic biology of corals, to the requirement for hard-bottom substrate for coral development and the importance of currents for dispersal and food delivery, to the impact of ocean acidification on corals, and to the food web supported in a coral ecosystem. Techniques for how scientists approach studying such ecosystems are also embedded in the lessons. Through these lessons, students learn what *Lophelia* needs to survive and where this may be found on the seafloor, so that students can then identify which areas may be considered sensitive habitat. In the scenario, students learn about trade-offs in resource and ecosystem management, and develop an understanding of the processes and information used in making decisions around resource management as they prepare their "Environmental Impact Assessment and Prioritization" Reports.

This curriculum was designed to be used in its entirety (i.e., Challenge Scenario with six supporting lessons). Use of the curriculum, however, depends on classroom needs. Teachers may find that some of the individual lessons fit their course objectives but they do not have time for the entire suite of lessons. Lessons may be used individually with minimal modification.

Ocean Literacy Principles and Fundamental Concepts
This curriculum was developed in accordance with National Science Education Standards and Ocean Literacy Principles. Ocean literacy is defined by seven essential principles supported by detailed fundamental concepts. The fundamental concepts are comparable to those underlying the National Science Education Standards. Each lesson in the curriculum touches on one or more ocean literacy essential principle and fundamental concept. These principles and concepts are identified within each lesson.

Teacher Notes and Support Materials
For each lesson, teacher notes contain focus questions, learning objectives, ocean literacy principles addressed, appropriate background information, and links to appropriate reference material available on the Internet. Lessons also come with support materials necessary for the particular lesson. The Challenge Scenario includes 5 seafloor maps, map notes and a student handout describing the challenge. Lesson 1 includes three photomosaics, each with six high-resolution images, a dichotomous key of seafloor organisms, and a teacher's key to the organisms in each photomosaic. Lessons 3, 4 and 6 include PowerPoint presentations along with slide notes to help teachers present new material to students. All lessons include reproducible student handouts. All of these support materials are found either within this Teachers' Guide or on the accompanying files on the DVD.

References:
Barrow, H.S., & Kelson, A. (1993). Problem-based learning in secondary education and the Problem-based Learning Institute (Monograph). Springfield: Southern Illinois University School of Medicine.

Challenge Scenario Activity: Pinnacle Petroleum Permit

Focus
This Challenge Scenario, based on the real-life practices of prioritizing exploratory drilling sites to minimize ecosystem impact, is a problem-based activity in which students adopt the role of marine scientist to address the challenge. Students work through the Unit's six lessons to obtain the necessary background knowledge to determine which exploratory sites represent the least impact to deep-sea coral communities. In this scenario, students learn about trade-offs in resource and ecosystem management, and develop an understanding of the processes and information used in making decisions around resource management as they prepare their "Environmental Impact Assessment and Prioritization" Reports.

Grade Level
9-12 (Biology/Earth Science)

Focus Question
What are sensitive seafloor areas and how are they protected?
What are the trade-offs when deciding how certain areas will be managed and developed?

Learning Objectives
Students will be able to:

- Explain how installing oil platforms to drill for oil can alter ocean ecosystems;
- Explain how a scientist can provide information to help understand public issues, consider trade-offs and use analytical skills to make decisions based on evidence;
- Support claims with evidence learned in previous lessons;

Ocean Literacy Essential Principles and Fundamental Concepts
6 – The ocean and humans are inextricably interconnected.
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.
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 (point source, non-point source and noise pollution) and physical modifications (changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.
7 - The ocean is largely unexplored.
B. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.
C. Over the last 40 years, use of ocean resources has increased significantly, therefore the future of sustainability of ocean resources depends on our understanding of those resources and their potential and limitations.

Materials

- Copies of MEMO to Marine Research Science Group; one per student

- Copies of map set, with specific map notes attached on back of each map; one set per group of students
- Copies of EIAP Report rubric; one per student
- Post-It notes

Seating Arrangement
Groups of 3-4 students

Key Words
Outer continental shelf (OCS)
Oil and gas reserves
Bureau of Ocean Energy Management (BOEM)
Lease
Drilling permit
Scientific Committee
Acoustic amplitude
Bathymetry
Contour line
Drilling restriction

Background Information
The Bureau of Ocean Energy Management (BOEM), a bureau within the U.S. Department of the Interior, is the federal agency responsible for overseeing the safe and environmentally sound management of offshore energy and minerals on the 1.76 billion acres of the Outer Continental Shelf (OCS). The OCS is a significant source of oil and gas for the Nation's energy supply. Approximately 43 million leased OCS acres account for about 15 percent of America's domestic natural gas production and about 27 percent of America's domestic oil production. The OCS, defined by federal statute, refers to all submerged lands lying seaward and outside of the area of lands beneath navigable waters of each State. The OCS is subject to the jurisdiction and control of the United States federal government.

Oil and gas companies interested in drilling for oil on the OCS must purchase a 5-year lease agreement through BOEM for access to the area they are interested in developing and then must apply for drilling permits to ensure compliance with regulations. More information on this process of leasing including a history of offshore petroleum exploration and development can be found at http://www.boem.gov/Oil-and-Gas-Energy-Program/Leasing/Leasing.aspx, see link "Oil and Gas Leasing on the Outer Continental Shelf" for downloadable pdf.

To help protect the environment of the OCS, BOEM sponsors scientific research to understand the needs and extent of ecosystems found there. Deep-sea coral communities and hydrocarbon seep communities, for example, have been studied extensively in the last 10+ years through independent research projects sponsored by this agency. In addition to adding to the scientific body of knowledge about deep-sea marine ecosystems, results from these research projects are used by BOEM's scientists advise policy makers when making decisions about development of resources on the OCS.

Because drill sites typically discharge a great deal of mud and drill cuttings that can damage benthic communities and historic archaeological sites, BOEM currently provides strict guidelines for the placement of drilling platforms to ensure protection of sensitive sites. Consequently drill sites may not be within 2000 ft of a sensitive site. Additionally, if the drill site platform has anchors, there must be an additional 1000 ft buffer surrounding the anchor lines when in the area of a known sensitive feature.

This challenge scenario, a problem-based learning activity, is designed to simulate a real process that occurs when oil companies apply for permits to install oil platforms in off-coast areas around the United States. The basic challenge for students is to prioritize proposed drilling sites so as to minimize impact to sensitive seafloor ecosystems and other resources, and to justify the prioritization based on information learned in the unit. Students will have to interpret seafloor maps and apply their understanding of *Lophelia* biology to determine where they think additional communities of *Lophelia* may be found. At least one of the proposed sites is in an area that could support a *Lophelia* community. Students are asked to play the role of advisory scientist (i.e., a biologist who studies deep-sea corals such as *Lophelia*) in the permitting process. Their final product will be an Environmental Impact Assessment and Prioritization (EIAP) Report (see below for components), in either a formal presentation or written report. A rubric details the requirements and helps students understand how the project will be evaluated. The overall activity is sufficiently challenging that all members of a group will have something to contribute to the solution.

The scenario is intended to function as both a motivator to engage learners and as a performance assessment for the lessons presented in this unit. Student groups are introduced to the scenario early in the unit and must consider the relevance of concepts in each lesson to complete the challenge.

Learning Procedure

1) Before introducing this Challenge Scenario, prepare Scenario maps by attaching specific map notes to the back of each map. You may also wish to laminate maps. Do not give all of the maps out to students at once – rather the activity is designed to have student groups receive specific maps following particular lessons within the unit. The following instructions indicate which map should be distributed after which lesson.

2) Introduce the Challenge Scenario either at the beginning of the unit or after students have had an opportunity to see the *Lophelia* communities (**in Lesson 1**). Give each group of students a copy of the MEMO with background notes on BOEM, and introduce the various players. Pinnacle Petroleum is the oil and gas company interested in developing the area for new wells. The federal regulatory agency responsible for granting the drilling permit is requesting your assistance. Student groups are the various Marine Research Science Groups conducting research on *Lophelia* and advising on environmental impacts from drilling. Review with students that their groups will help advise the BOEM on appropriate sites for development for oil and gas, and to do so each group will need to learn as much as they can about *Lophelia* communities. Explain to students that each group will create an

Environmental Impact Assessment and Prioritization report as a final product. You may also wish to distribute and review the rubric with them at this time.

3) **At the end of Lesson 2**, give students the first map (**1-Amplitude**) and explain that this is a map of the area of interest to Pinnacle Petroleum – *Lophelia Gardens 100*. This is an area in the Gulf of Mexico, off the coast of Texas. This map is a representation of the seafloor surface, as measured by sonar. Review the accompanying map notes (attached to back of map) explaining how the map was created and what the acoustic amplitude indicates. Be sure to review the scale bar with students (each square block is ~ 3 square miles) and help them determine the approximate size of the entire area (~72 square miles). *Note: the Lat/Long lines have been removed to keep the actual location designated in the maps unknown. Maps are provided courtesy of WesternGECO.*

4) Distribute Post-It notes to student groups, and give students time to examine the map and to pick 3 areas where they would *consider* looking for *Lophelia.* At this point, students know enough to look for areas with hard ground (high amplitude), so they should pick areas where there are pinks and yellows on the map. Students can use Post-it notes to mark where they think *Lophelia* may be found, and include justification notes on each Post-It.

5) **At the end of Lesson 3**, after students have learned basic biology of *Lophelia,* give student groups the second map (**2-KnownLopheliaSites**) and explain that we have new information on the location of one known *Lophelia* community in the region (marked by an L on the map). Again review the accompanying map notes explaining that only a small section of the *Lophelia Gardens 100* area was explored previously (the western most section) so there are likely to be more *Lophelia* communities in other *similar* areas. Have students examine the map again and decide where they think other *Lophelia* may be found. They should look for characteristics similar to the known location. Again, have students mark their predicted sites with Post-it notes.

6) **At the end of Lesson 5,** after students have learned about currents, the effects of topography on current flow and how current flow can affect particle distribution, give students the third map (**3-Bathymetry**). This is a map showing the bathymetry of the region. Review the accompanying map notes explaining what the contour lines indicate. Help students decipher the lines on the maps, explaining that it is just like a topographical map. Point out a few contour lines with depth markings. It might be helpful to have students trace the 400, 450, 500, and 550 contour lines in different colors to help these contours stand out. Ask students to identify where the highest and lowest areas are, and also to describe some general features of the seafloor in LC100. *Note: There is a trough running from the northwest corner down to the south/southeast, with the deepest portion of this trough approaching 600 meters depth down along the southern most portion of the map. There are two high areas, of 400+ meters depth, one along the western edge of the map and the other in the north central portion of the map. In the center of the map, there is a steep "wall" of at least 150 meters, on the eastern side of the trough.*

7) After students have become familiar with the seafloor topography in the LC100 area, explain to students that the peaks and valleys in Gulf of Mexico seafloor topography are due to underlying salt tectonics, underneath the deep sediment. For an excellent review of the geology in this region, you may choose to have students read Dr. Harry Roberts' online essay: "A complex geologic framework prone to fluid and gas leakage" (http://oceanexplorer.noaa.gov/explorations/06mexico/background/geology/geology.html).

8) Next, explain to students that **bottom currents** in the area run generally from east/southeast to west/northwest. Ask students to think about and discuss what the current would do when it encountered a "wall" or steep elevation, and have students indicate areas on the map where this happens. *Note: current will speed up in this situation, which could help distribute food particles and larvae. Faster currents would also help keep corals free from too much sedimentation.*

9) After students have visualized the current flow along the seafloor topography in the LC100 area, give students the fourth map (**4-Amplitude_Bathymetry**) that combines the bathymetry with the amplitude. Have students examine how the depths line up with the hard ground, and ask them to estimate the average depth of the some of the 'hardest' seafloor. *Note: keep in mind that the hard ground that we see dotted along the tops of these elevated areas are carbonate rocks formed by precipitation of Ca-Mg as a result of bacterial processing of hydrocarbons seeping up through the sediments.*

10) Using this fourth map, ask students to revisit their predictions for where they would likely find *Lophelia* communities. At this point they should be thinking about how currents flow over the domes and ridges and hard ground, delivering food particles and keeping corals clear of too much sediment. Remind them to look for clues from the one known *Lophelia* site.

11) **At the end of Lesson 6,** after students have learned about food webs and the important role *Lophelia* plays in the seafloor community, students are now ready to address the Challenge Scenario. Give student groups the final map (**5-Amplitude_Bathymetry_Wells_Interpretation_DrillSites**). Review the accompanying notes that explain the additional markings and review these markings with the students. This map shows an existing drilling platform with approximately 20 wells. There is a shipwreck in the southeast area. Shipwrecks are considered sensitive archaeological areas and are protected. Consequently, drilling **may not occur near this site**. This map also includes markings made by the BOEM geologist showing his interpretation of the hard ground areas. Students can use these markings to fine-tune their estimates of where they would find *Lophelia.* Finally, this map includes the five possible exploratory sites along with the drilling restrictions, labeled S1..S5.

12) Provide student groups time to work through all of the information provided to prioritize the proposed drilling sites. Remind students that they will need to provide a justification for their prioritization and present that in their final report. Review with students the components of their report and the report rubric.

13) Have student groups present their final report and encourage discussion.

Maps Notes

A description of each of the five maps follows. You may wish to attach the description of each map to the back of the actual map.

Map Notes: 1-Amplitude

This map shows an area of seafloor approximately 72 square miles. Most of the Gulf of Mexico (GoM) seafloor is covered in sediment that has been deposited from erosion processes flowing down from the continent. However, it's not all sediment. There are areas of "hard ground" or rocks on the GoM seafloor formed as a bi-product of bacteria in the sediment living off of oil and gas seepage coming up from deep, underneath the sediments. To find this "hard ground", geologists use sonar to "visualize" the seafloor from their station on a ship. Sonar involves sending out a sound signal (e.g., a "ping" from an airgun) that travels to the seafloor and then reflects back off the seafloor surface. Acoustic monitors called geophones, towed in the water behind the ship, listen for this reflected sound and record both the time the signal takes to return (giving an indication of depth) and the strength of the signal (giving an indication of surface hardness). A soft surface does not reflect sound as well as a hard surface, and therefore has a low acoustic amplitude. **Hard surfaces** reflect well and have **a high acoustic amplitude.**

Note: there are a few "artifacts" on these maps. An "artifact" on a map is a feature that is not actually present but shows up because of the way the map was made. For example, the large white rectangular area towards the top of the map is an area that was not actually mapped by sonar, so it is "blank" or white in this case. So the white color in this case is NOT a measure of extremely low amplitude. Also, the striped pattern of green and blue does not reflect actual differences in seafloor hardness but rather reflects track lines from the ship's mapping process. It takes a little practice reading maps like this to learn how to interpret them properly.

Can you tell where the hard surfaces are? Hint: look for areas of high amplitude.

Map Notes: 2-KnownLopheliaSites

This map is the same map as #1 but it also shows **one *Lophelia* community discovered and actually seen** by scientists, marked by an "L" on the map. This *Lophelia* community is growing on the eastern edge of an area of hard ground. It should be noted that the entire area in this map has **not** been explored for *Lophelia*. It is expected that there are additional *Lophelia* communities elsewhere in this area, probably in areas that are similar to the known one. *Where do you think there will be additional Lophelia communities?*

Map Notes: 3-Bathymetry

This map shows the topographical relief of the seafloor, in the same area as the amplitude map. The curving lines represent contours along the seafloor, and the number on a contour line represents the depth in meters along that contour. For example, "500" means 500 meters from the surface to seafloor all along that contour line. Contour lines are drawn at 10-meter intervals, with major contour lines marked every 50 meters depth. *Can you tell where the deepest area is, and where the highest points are on the seafloor?*

Map Notes: 4-Amplitude_Bathymetry

This map is a combination of the 1-Amplitude and the 3-Bathymetry maps. This map overlays the bathymetric map overtop the amplitude map so you see the depth of various hard ground areas. *What is the average depth of the areas of high amplitude (i.e., the areas in pink)?*

Map Notes: 5-Amplitude_Bathymetry_Wells_Interpretation_DrillSites
This map shows bathymetry overtop the amplitude map, and also includes some new markings provided by our engineer at Pinnacle Petroleum and our scientist at the BOEM. The engineer gave us information about an active drilling platform (marked in purple) in the area near the center top of the map. Notice the lines all coming from a central square, called the drill site. Each circle represents a different well. To minimize impact to the seafloor and to prevent having to move the platform for every well, drilling companies can minimize the number of holes by drilling vertically for ~2000 ft, and from there drill out diagonally to tap surrounding reserves and create a well. This particular drilling platform has 10 wells to the south of the drill site, and another 10 wells to the north of the drill site. All of the oil and gas from these 20 wells flows up to the same location on one platform. Each well is approximately 10,000-12,000 ft deep. It is likely that the southernmost wells are tapping into the same subsurface oil and gas reserves that seeped to the surface many years ago and formed the hard ground in that area.
The drill platform shown on this map is at least 7000' from the nearest hard ground area where *Lophelia* could be found.

The other markings on this map, the red and green polygons, are areas where our BOEM scientist believes there is actual hard bottom given his interpretation of the amplitude map. From experience, he typically sees hard bottom (or rock) occur in areas of high acoustic amplitude (i.e., yellows and reds) AND high elevations on the seafloor. He has circled these areas in red. The green polygons, inside the red polygons, are areas of very low amplitude where gas is bubbling out. If sediment comes up with the gas, mud volcanoes and flows of sediment are likely to occur. Notice some areas of high amplitude are not marked as hard bottom because they occur on a slope. These areas are typically gas and crusty sediment flowing down the side of the slope. They are not necessarily good sites for *Lophelia* because 1) they are not elevated providing good access to current flow, and 2) they are not hard rock for substrate.

Note the shipwreck marked on the map. Under various Federal laws and regulations, the BOEM is also responsible for overseeing the protection of archaeological resources (e.g., shipwrecks). The same distance restrictions apply to shipwrecks as to sensitive benthic communities.

Finally, the map has a number of potential drill sites shown on it, marked S1 to S5, indicating five areas where Pinnacle Petroleum is considering drilling for oil. *Your job as a Lophelia expert (i.e., a biologist who studies deep sea corals) will be to prioritize these potential drill sites to minimize damage to potential Lophelia sites.*

MEMO

TO: Marine Research Science Group
FROM: Deep-water Resources Management Office, Bureau of Ocean Energy Management (BOEM)
RE: Recommendations within area *Lophelia Gardens 100 (LG100)*

Pinnacle Petroleum has expressed interest in doing exploratory drilling within the *Lophelia Gardens 100* (LG100) area of Bluewater Gulf. We need to know which areas within the LG100 section need to be off limits to any drilling activity and which of their five proposed exploratory sites could be opened to Pinnacle for drilling. Your group will need to prioritize these five sites within LG100 as to risks to corals and coral habitat from drilling (High/Medium/Low) as well as to other sensitive areas (i.e., archaeological sites) and support your claims with evidence. Please also indicate trade-offs that scientists, resource managers and representatives from Pinnacle Petroleum must consider when negotiating a permit.

In addition to information on BOEM attached to this memo, your group will receive various maps with notes describing each map. These will include 1) a map of possible hard surfaces (i.e., referred to as "amplitude"), 2) a map showing known coral occurrences, 3) a map showing seafloor topography (a.k.a. "bathymetry"), 4) a map combining potential hard surfaces and bathymetry, and 5) a map with existing wells, known shipwrecks, and other notations. Be sure to read the notes on the back of each map carefully.

At this time, one known *Lophelia* community has been located in LG100 although the entire area has not been explored. There will not be time for additional observations of the sea floor before your report is due so you will have to use your expertise to predict where other *Lophelia* sites may be. You must work with the information currently available and draw upon your expertise of *Lophelia* biology to help with this task.

We welcome any additional suggestions or ideas your group may have that might help us in developing a more comprehensive management plan for LG100 and other deep-water communities in the future.

Background Notes on BOEM and the OCS

The Bureau of Ocean Energy Management (BOEM), a bureau within the U.S. Department of Interior, is the federal agency responsible for overseeing the safe and environmentally sound management of offshore energy and minerals on the 1.76 billion acres of the Outer Continental Shelf (OCS). The OCS, defined by federal statute, refers to all submerged lands lying seaward and outside of the area of lands beneath navigable waters of each State. The OCS is a significant source of oil and gas for the Nation's energy supply. Approximately 43 million acres of the OCS account for about 15 percent of America's domestic natural gas production and about 27 percent of America's domestic oil production. The OCS is subject to the jurisdiction and control of the United States federal government.

Oil and gas companies interested in drilling for oil on the OCS must purchase a 5-year lease agreement through BOEM for access to the area they are interested in developing and then must apply for drilling permits to ensure compliance with regulations. More information on this process of leasing including a history of offshore petroleum exploration and development can be found at http://www.boem.gov/Oil-and-Gas-Energy-Program/Leasing/Leasing.aspx.

To help protect the environment of the OCS, BOEM sponsors scientific research to understand the extent of ecosystems found there. Deep-sea coral communities, for example, have been studied extensively in the last 10+ years through independent research projects sponsored by this agency. In addition to adding to the scientific body of knowledge about deep-sea marine ecosystems, results from these research projects are used by BOEM's scientists to advise policy makers when making decisions about development of resources on the OCS.

Drilling Restrictions: Because drill sites typically discharge a great deal of mud and drill cuttings that can damage benthic communities and historic archaeological sites, BOEM currently provides strict guidelines for the placement of drilling platforms to ensure protection of sensitive sites. Drill sites may not be within 2000' of a sensitive site. Additionally, if the drill site platform has anchors, there must be an additional 1000' buffer surrounding anchor lines when in the area of a known sensitive feature.

Pinnacle Petroleum "Environmental Impact Assessment and Prioritization" Report Rubric

Your report should have the following components:

- Purpose of the environmental impact assessment and prioritization.
- Members of your scientific research group.
- General description of each exploratory drill site:
  - A general description of the site to include depth, topography of the area, and seafloor surface characteristics;
  - Distance to and description of nearby sensitive sites, or in unexplored areas, *potentially* sensitive sites;
  - With respect to potential *Lophelia* communities, description of suitability of site for deep coral community (i.e., potential for current flow);
  - Benefits and disadvantages of drilling at this site.
- Final recommendation of site with lowest potential for disturbing *Lophelia* communities or archeological sites (e.g., shipwrecks); your recommendation should be supported with evidence from the maps and from your understanding of *Lophelia* corals and coral communities. You should also indicate why the other sites are less desirable for drilling.

Report Rubric

4 - Exceptional	**3 - Well Done**	**2 - Needs More Work**	**1 - Not Acceptable**
Clearly states purpose that includes an explanation of importance of the report	Clearly states purpose for environmental impact assessment	Purpose for report is vague, incomplete, or misleading	Purpose for report is missing
General description of each site includes everything mentioned in 3-WellDone plus inferences about the current	General description of each of the five sites includes depth, seafloor surface characteristics, topography, and distance to nearest sensitive sites (shipwrecks, *Lophelia* communities or areas where *Lophelia* is likely to occur)	General description of each of the five sites is present but missing some information listed in 3-WellDone	Only two or fewer sites are described.

4 - Exceptional	**3 - Well Done**	**2 - Needs More Work**	**1 – Not Acceptable**
Presents recommendation for best site for petroleum exploration	Presents recommendation for best site for petroleum exploration	Presents recommendation for best site for petroleum exploration	Recommendation for petroleum exploration site is unclear or not present
Supports recommendation with evidence from 4 or 5 maps	Supports recommendation with evidence of seafloor surface characteristics, topography, possible effects of topography on currents	Supports recommendation with evidence from 1 or 2 physical features of the site	Does not support recommendation with information of physical features from maps
Clearly and directly connects recommendation with evidence from understanding of *Lophelia* biology and ecology	Supports recommendation with evidence from understanding of *Lophelia* biology and ecology	Mentions *Lophelia* biology and ecology but does not explain direct relationship to recommended location	Does not support recommendation with evidence from understanding of *Lophelia* biology and ecology
Presents evidence for remaining 3 or 4 exploration sites to explain why the areas should not be opened to exploration	Presents additional recommendation for an alternative exploration site supported with evidence from maps and *Lophelia* biology & ecology	No alternative exploration site presented	No alternative exploration site presented

Lesson 1 - On the Bottom of the Gulf of Mexico

Focus

This lesson introduces students to conditions on the seafloor, and to communities of cold-water corals and associated species.

Grade Level

9-12 (Biology/Earth Science)

Focus Question

What are conditions like on the bottom of the Gulf of Mexico?
What organisms live there?

Learning Objectives:

- Students will be able to characterize the general environmental conditions at 500 meters depth on the bottom of the Gulf of Mexico;
- Students will be able to identify the more common macrofauna on the bottom of the Gulf with emphasis on *Lophelia* and its associates;
- Students will be able to make generalizations about patterns in the distribution of organisms within cold-water coral communities.

Ocean Literacy Essential Principles and Fundamental Concepts

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

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.

7 - The ocean is largely unexplored.

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.

Materials

- Copies of *Journey to the Bottom of the Sea*; one copy per student
- Video clip (on-line) of ROV *Jason* launch and maneuvering on the bottom http://www.whoi.edu/ndsfVehicles/Jason/ .
- Video clips (on-line) of several cold-water coral communities (especially August 31 - *Lophelia pertusa* in Garden Banks region, September 3 – newly discovered *Lophelia* reef structure, September 6 – Viosca Knoll shipwreck with *Lophelia* community, September 8 – Ewing Banks shipwreck with *Lophelia* community) http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/photolog/photolog.html
- Color copies of photomosaics with corresponding high resolution photos (6 per mosaic); one photomosaic set for each group of students (**note**: three different mosaics are provided: F, H1, and Q)

- *Deep Gulf of Mexico Organisms Dichotomous Key* (pdf); two copies for each student group
- *Photomosaics Organisms Key*; one copy for reference (teacher use)
- Poster paper or poster-size white boards; one for each group of students
- Water-color markers or Dry-erase markers; 3 different colors for each group of students

Audio-Visual Materials

- Computer with projector
- Student computers if using electronic copies of photomosaics and high resolution pictures

Teaching Time

Two 45-50 minute class periods

Seating Arrangement

Groups of 3-4 students

Key Words

Lophelia
Cold-water coral
Macrofauna
Substrate
Sessile/Motile
Dichotomous key
ROV

Background Information

History of Ocean Exploration – This first website presents a general timeline of major oceanographic discoveries and events from 1807 to 1995.
http://oceanexplorer.noaa.gov/history/timeline/timeline.html
At the following website, you can read about 3 types of underwater research vehicles developed in the 1960's and in use today. This site includes information on the ROV *Jason*.
http://www.divediscover.whoi.edu/robotics/vehicles.html

Jason, Woods Hole Oceanographic Institute (WHOI), Remotely Operated Vehicle (ROV) - http://oceanexplorer.noaa.gov/technology/subs/rov/rov.html and http://oceanexplorer.noaa.gov/technology/subs/jason/welcome.html.
To include an activity or for more background information on ROVs, see the Ocean Explorer lesson "My Wet Robot" from the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition at http://oceanexplorer.noaa.gov/explorations/08bonaire/background/edu/media/wetrobot.pdf.

Photomosaics – http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug30/aug30.html - Essay written by one of the scientists who created the photomosaics the students will

use. She describes the process using language easily accessible by high school students. Students could read the essay for homework between the first and second days of this lesson.
http://oceanexplorer.noaa.gov/explorations/10lophelia/logs/oct18/oct18.html - Information and pictures of how the photomosaics from a previous expedition are used in seafloor ecology studies is presented within a log entry from the 2010 expedition.
http://oceanexplorer.noaa.gov/explorations/10lophelia/background/intro/media/intro2.html - This photomosaic clearly shows the hard rock needed for coral communities.

Lophelia: Reefs, Wrecks, and Rigs Study – These sites provide an overview and details of the 3 expeditions to explore *Lophelia* and associated communities in the Gulf of Mexico.
http://oceanexplorer.noaa.gov/explorations/08lophelia/welcome.html
http://oceanexplorer.noaa.gov/explorations/09lophelia/welcome.html
http://oceanexplorer.noaa.gov/explorations/10lophelia/welcome.html

Learning Procedure

1) Tell the students that they will be studying a part of the Earth that has not been completely explored but contains important resources – the bottom of the Gulf of Mexico. Ask them what they think they might find if they went 500 meters (approximately 5 football fields) deep to the bottom of the Gulf of Mexico. After accepting answers from several students, hand out the *Journey to the Ocean Bottom* probe and ask each student to answer the questions. Collect the probes from each student.

2) Ask the students how scientists could find out what the bottom of the Gulf of Mexico is like? Accept answers from a few students. If students don't mention it, tell them about these methods:
   - The earliest information came from fishermen who dragged fishing nets across the bottom, called bottom trawling;
   - Engineers and scientists sent drills down from cranes on ships to take core samples of the ocean bottom. This has been important in the Gulf of Mexico as petroleum companies have explored to locate large reservoirs of petroleum;
   - ROVs (Remotely Operated Vehicles) are used to take photos and collect samples from the bottom of the ocean;
   - HOVs (Human Occupied Vehicles) are used to take photos and collect samples from the bottom of the ocean. These are miniature submarines and must be carefully designed to protect their human occupants from the intense pressures.

3) Show the class the 3-minute video clip of *Jason*, an ROV from Woods Hole Oceanographic Institute (WHOI), http://www.whoi.edu/ndsfVehicles/Jason/**.** While they watch the video clip, ask students to jot down 3 facts about Jason that make it suitable for exploring the bottom of the Gulf of Mexico, or any ocean. After the video, discuss some of these and create a master list of the features that make it possible to explore the bottom of the Gulf of Mexico. You may want to play the clip a second time to see if there are important points that students didn't catch the first time.

4) Tell the class that now they will look at photographs and video taken from *Jason* at a location on the bottom of the Gulf of Mexico. This is what scientists could see while on-board the ship to which *Jason* was tethered. Show a couple of the video clips, http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/photolog/photolog.html, to introduce students to the photos they will be examining. Try to communicate the excitement of exploring a new area and only being able to see what *Jason's* lights and cameras reveal. The purpose of the work is for students to see actual locations and communities on the bottom of the Gulf of Mexico and to identify some of the organisms. Students will work in groups of 3-4 to examine pictures, use a dichotomous key to identify organisms, and present their findings to the class.

5) Provide each group with a photomosaic (photo) and the high resolution photos that go with it or computer access to the photomosaic file and high resolution photo files. Each group should also receive a copy of the dichotomous key. If students aren't familiar with dichotomous keys, teach them how to use one. Emphasize that they are scientists trying to understand what they've seen as Jason explores the bottom of the Gulf. Describe how the photomosaics are created (see background information). They should identify organisms and look for any patterns in their distribution. A lab sheet (Lesson 1: *On the Bottom of the Gulf of Mexico*) has been provided to help with making the observations and looking for patterns. Although students could spend much more time on this task to do a thorough job, the idea is for this to be an introduction rather than a detailed study of the diversity. A black and white key of organisms found in each of the high resolution images is provided for your use.

6) Have each group present their findings. If more than one group has the same picture, the second group can present anything new that the first group didn't mention. It's likely that each group will have identified different organisms. At the conclusion of the presentations, have the class resolve any disputes around organism identifications and generate a list of major findings based on the information from the presentations. It should be clear to students that the corals are found attached to hard surfaces, like rock, shipwrecks or oil platforms and not on mud (see Materials for videos that can be used to emphasize this point). It should also be clear that a community of organisms can be found in the same area as the corals, even though these associated organisms are not directly dependent on the hard surfaces. Record any questions that arise, saying only that we will explore the questions more in future lessons. Introduce the students to *Lophelia,* the white, branching coral prominent in many of the pictures as an important organism in these cold-water communities and the focal organism for the unit. Students will learn more about the biology of *Lophelia* in lesson 3

7) At the close of the lesson, ask the students why they think scientists bother to study such remote areas. It takes a lot of resources (e.g., money, time) to collect a limited amount of information. Why might scientists think this is important? Why might the organizations that fund such expeditions think it's important? Accept all answers, including those that claim it is not important to study the bottom of the ocean. In upcoming lessons, students will have additional time to reflect on their learning.

Take notes of their thinking at this time so you can continue to probe for changes in their thinking as the unit progresses.

8) After the first class session, look over the student responses to the *Journey to the Ocean Bottom* probe. Select 5 - 6 of the most common responses as to what could be found on the bottom and select 5 – 6 of the most common responses as to what would not be found on the bottom. There might be a few items where students are unsure and where there are a fairly equal number of students who said they could find this as those who said they would not find it on the bottom. List these as "Uncertain." Pay attention to responses to 'light,' and any plants. Finding out that there is no light and consequently no primary producers/plants will be a surprising discovery for some students.

9) On the second day, post the most common and uncertain responses in the room and briefly discuss with the class how you selected these. Also share with them some of their reasoning as to why or why not they might find certain things. The point is to demonstrate and validate a wide range of thinking and reasoning. You aren't telling them that any of these are correct or incorrect, but that they will learn much more about in the next two weeks. You can refer back to these responses when the topic comes up throughout the unit.

The "Me" Connection

Have students write a brief essay describing how ocean ecosystems might be of importance to their family's food supply, the climate and weather in their region, future employment and career possibilities, or some other aspect of their lives.

Assessment

Students' presentations of identified organisms and distribution patterns provides an opportunity to check whether they have reached the conclusions described in Learning Procedure 6 above and the overall Learning Objectives.

Extensions

Read the Cruise Overviews from the *Lophelia II* cruises in 2008-2010. Students can explore these sites on their own or as homework.

http://oceanexplorer.noaa.gov/explorations/08lophelia/welcome.html
http://oceanexplorer.noaa.gov/explorations/09lophelia/welcome.html
http://oceanexplorer.noaa.gov/explorations/10lophelia/welcome.html

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html
Click on the links to Lessons 3, 5, and 6 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals.

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

http://www.coast-nopp.org/ - Resource Guide from the Consortium for Oceanographic Activities for Students and Teachers, containing modules, guides, and lesson plans covering topics related to oceanography and coastal processes

http://cosee-central-gom.org/ - Web site for The Center for Ocean Sciences Education Excellence: Central Gulf of Mexico (COSEE-CGOM)

Journey to the Bottom of the Sea Name: ___________

What would you see if you went to the bottom of the ocean?

In the list below, place an "X" next to each item that you think you could find on the bottom of the ocean if you were 500 meters (about 1600 feet) from the surface of the ocean on the bottom. Mark a "U" if you don't know what something is. Use the empty blanks to add anything you think you would find but isn't on the list.

____ rocks	____ fish	____ sharks	____ snails
____ people	____ seaweed	____ crabs	____ plants
____ corals	____ sea jellies	____ worms	____ flowers
____ trees	____ light	____ mud	____ shrimp
____ cold water	____ hot water	____ fishing nets	____ clams
____________	____________	____________	____________

In the space below, explain why you think you'll find the things you marked an "X" by on the bottom of the ocean.

In the space below, explain why you think you won't find each of the other things on the bottom of the ocean.

On the Bottom of the Gulf of Mexico Name: __________

Photomosaic Name or Number ______________________________

Organism Name & Number Observed	Description or Sketch of Organism (e.g., size, color, shape, sessile or motile)	Description of Habitat & Community Conditions (e.g., location, proximity to other organisms, substrate)	Notes

Conclusions on Patterns or Trends:

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Lesson 2 - What Are the Secrets for Life on the Bottom of the Gulf of Mexico?

Focus

This lesson continues students' exploration of Gulf of Mexico bottom conditions and emphasizes the formation seafloor rock and its importance to *Lophelia pertusa.*

Grade Level

9-12 (Biology/Earth Science)

Focus Question

What questions do we have about *Lophelia* and other organisms observed in Lesson 1?

Learning Objectives:

- Students will be able to articulate questions about the deep Gulf environment and the coral communities they observed in pictures;
- Students will be able to identify that coral communities develop in areas with a hard surface and that the rocks tend to be formed by bacteria in hydrocarbon seep areas;
- Students will be able to describe some of the difficulties associated with studying remote areas and organisms.
- Students will develop a sense of ownership in the unit as they raise questions that they would like to learn more about.

Ocean Literacy Essential Principles and Fundamental Concepts

2 – The ocean and life in the ocean shape the features of the Earth.

A. Many earth minerals and geochemical cycles originate in the ocean. Many of the sedimentary rocks now exposed on land were formed in the ocean. Ocean life laid down the vast volume of siliceous and carbonate rocks.

C. Erosion – the wearing away of rock, soil and other biotic and abiotic earth materials – occurs in coastal areas as wind, waves, and currents in rivers and the ocean move sediments.

Materials

- Photomosaics and high-resolution photos from Lesson 1
- Poster paper or poster-size white boards; one for each group of 3-4 students
- Water-color markers or Dry-erase markers; 3 different colors for each group of 3-4 students
- Sticky notes (optional)
- Bookmark the following websites so you can get to them easily, http://oceanexplorer.noaa.gov/explorations/06mexico/logs/may30/media/garden_600.html and http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug25/media/movies/coral_hard_bottom_video.html#

Audio-Visual Materials

- Computer and projector with internet access

Teaching Time

One 45-50 minute class periods

Seating Arrangement

Groups of 3-4 students

Key Words

Benthic zone
Hydrocarbons
Authigenic carbonate
ROV

Background Information

This lesson continues to introduce students to conditions in the cold-water coral communities in the Gulf of Mexico by explaining the formation of rock, called authigenic carbonate rock, essential for coral dispersal and survival. Authigenic carbonate rock is closely associated with seep areas where oil and gases leak out of the sediments and provide energy for microorganisms. While you might first think that rock and seeps are not connected, you will find that there is a very close connection. The remainder of the lesson provides students with an opportunity to voice questions about the communities on the bottom of the Gulf. You will use these questions to help introduce and develop subsequent lessons.

Formation of Authigenic Carbonate Rock - The first website is an article with basic information on the formation of rock by microorganisms at seep sites. A portion of the article has been included below. The second link shows a map of an area on the bottom of the Gulf of Mexico illustrating the prevalence of sediments compared to hard rock surfaces. The third link is a video that shows a bamboo coral attached to authigenic carbonate rock. It is a very clear picture of the rock. The fourth website provides a link to more background information on the formation of authigenic rock. An excerpt is included below.
http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug25/aug25.html
http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug25/media/bathy_map.html

http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug25/media/movies/coral_hard_bottom_video.html#
http://oceanexplorer.noaa.gov/explorations/06mexico/background/geology/geology.html

Bill Shedd, Bureau of Ocean Energy Management (BOEM, formerly the U.S. Minerals Management Service, MMS)

> "Seeps are areas where oil or gas leaks to the seafloor. The Gulf of Mexico, like other ocean basins across the world, has many active natural oil and gas seafloor seeps. The same deep, organic-rich formations of rock from which oil companies drill and produce hydrocarbons are also "feeding" these seafloor seeps. Under the right amount of heat and pressure, the rock formations expel oil and gas, through fractures and faults, upward to the shallower porous and permeable reservoirs. The oil and gas may eventually reach the seafloor, rise to the sea surface, and then

form oil slicks or enter into the atmosphere. In the atmosphere, natural gas acts as a powerful greenhouse gas.

In the seep sediments, bacteria consume hydrocarbons, such as oil and gas, voraciously. The chemical processes involved in devouring the hydrocarbons causes a calcium carbonate rock to form near the surface of the seafloor. The 3-D geophysical data help us locate these carbonate rocks. Where adequate currents carry sediment away from the rocks, the exposed rocks become good places for various larvae to settle and grow.

At the most actively seeping sites, "chemosynthetic" organisms thrive. These are clams, mussels, and tube worms that contain bacteria living in their tissue. The bacteria that consume oil, natural gas, and hydrogen sulfide provide energy for their host organisms. Where the seepage has subsided and the chemosynthetic organisms die off, deep-water corals and other sessile animals can potentially colonize the carbonate rocks. Any other suitable hard surface, such as the legs of oil and gas producing platforms and shipwrecks, can support these animals as long as the conditions are right."
http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug25/aug25.html

"In cases where hydrocarbons slowly seep to the seabed, microbes catalyze the precipitation of Ca-Mg carbonates, resulting in hardgrounds and mound-like carbonate buildups. In many areas, these carbonates are the hard substrates for deep-water coral communities and other communities requiring hardbottom conditions."

Harry Roberts, Louisiana State University

http://oceanexplorer.noaa.gov/explorations/06mexico/background/geology/geology.html

General Information on *Lophelia pertusa* in the South Atlantic, including age estimates.

http://www.safmc.net/HabitatManagement/DeepwaterCorals/Lophelia/tabid/247/Default.aspx

Learning Procedure

1) Review with students the patterns they observed in the photos from the previous lesson. Project one of the pictures that best illustrates these patterns. Discuss briefly any new observations that were overlooked during Lesson 1. Students should be able to state at this point that the corals form on hard surfaces like rock, not on mud.

2) Show the picture at http://oceanexplorer.noaa.gov/explorations/06mexico/logs/may30/media/garden_600.html and the video at http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug25/media/movies/coral_hard_bottom_video.html#. Point out the rocks on which the corals are attached. Students will be able to see in the video how the coral is attached and why the rock is critical for coral communities. Tell the students that this rock has an interesting history. As hydrocarbons (oil and methane gas) from layers of rock

underneath the sediments of the Gulf of Mexico leaked or seeped through the mud, up to the water, bacteria in the sediment consumed these chemicals and transformed them into the rock. Without the oil and gas reservoirs deep under the Gulf of Mexico, we wouldn't have the carbonate rocks on which the corals and other sessile (i.e., fixed, stationary) organisms depend. Project a couple of the pictures and video clips used in Lesson 1 to look more closely at the rock and how the coral are attached to it. Emphasize that for the most part, once the coral communities form, very little hydrocarbon seepage is occurring.

3) Tell the students to pretend that they are scientists who have seen the very first images of cold-water coral communities. The scientists are eager to study these systems and learn as much as they can about them. Ask the students to individually write down three questions they have about the coral communities they have observed. Remind them to use scientific words as much as possible as they write their questions.

4) In groups of 3 – 4, ask the students to take turns sharing their questions and then categorizing them following the Question Sharing Protocol below.

   Question Sharing Protocol: Lead a class discussion by first sharing the categories of questions compiled by each group. From this list, combine similar categories and adopt a class set of categories. Then ask each group to share two of their best questions (let them decide what "best" means) and list them underneath the corresponding category. Ask the groups to elaborate on why they think this is an important or interesting question. At the end of the discussion, the class will have a list of categories (i.e., biology of corals, life cycle of corals, ocean currents, interactions within coral ecosystems, water quality) and questions of interest for each category.

5) Tell the students that many of the questions they have raised, scientists have also asked. Some of them can be answered, but for many of the questions, scientists continue to conduct investigations to test various hypotheses. In the next 2 weeks, the class will investigate many of the questions they have raised. Ask students why they think learning more about these remote communities is important. There will be a variety of answers. Tell them they will need to learn more about the coral communities to determine how to handle the real issue of conserving coral communities on the bottom of the Gulf of Mexico and allowing oil drilling.

6) If you haven't already done so, introduce the "Pinnacle Petroleum Permit" Challenge Scenario that synthesizes and applies the concepts learned in all the lessons. Tell students that although the age of the coral communities they have looked at is unknown, some *Lophelia pertusa* colonies off the Atlantic coast of Florida are believed to be approximately 700 years old (see www.safmc.net website in Background Information). Cold-water corals grow very slowly, depending on water temperature and food availability, and they are fragile. Ask students to think about threats to deep-water coral communities that might exist. Possible responses include any type of activity that disturbs the seafloor surface, such as bottom trawling (i.e., a fishing method where boats drag nets along the bottom), oil drilling, and oil spills. You can show pictures of drilling platforms and platforms in the Gulf of Mexico (http://www.cruisebruise.com/gulf_of_mexico_oil_platorms.jpg, http://en.wikipedia.org/wiki/Oil_platform), and fishing gear (http://en.wikipedia.org/wiki/Trawling). Students may also mention global climate change (global warming) and may have heard that the oceans are becoming more acidic because they are absorbing more carbon dioxide from the atmosphere. Tell the students that at the end of the unit, they will work in teams to analyze an exploratory drilling proposal submitted by a company interested in expanding their oil production. The job of the students will be to evaluate and respond to the company's drilling application. To do this, they will need to understand more about the biology and ecology of cold-water coral communities in the Gulf of Mexico. If students are concerned about oil drilling and tend toward banning all drilling, remind them that we all rely on petroleum for many things, including gasoline for cars, plastics, heating oil and gas, and tar for roads. In addition, many, many jobs depend on the availability of oil and on oil companies working profitably. Consider the question: How can oil drilling continue but in a way that doesn't harm the coral communities at the bottom of the Gulf of Mexico? This is the question students will address in the next couple of weeks.

7) At this time, return to the Challenge Scenario and present students with map 1-Amplitude.

The "Me" Connection

Have students research various products that are based on petroleum. How many of these do they use in one day? Make a list.

Assessment

Students will reveal their thinking when they present reasons for why they feel their questions are interesting to investigate or important to understand. Assess whether or not the reasons they give relate directly to the context of understanding deep benthic (ocean bottom) communities below the photic (light) zone. If the questions and reasons seem unrelated to this habitat, go back to the pictures and video clips in Lesson 1 and guide the students to restate their questions within the context of these pictures.

Extensions

Read the Cruise Overviews from the *Lophelia* II cruises in 2008-2010. Students can explore these sites on their own or as homework.

http://oceanexplorer.noaa.gov/explorations/08lophelia/welcome.html
http://oceanexplorer.noaa.gov/explorations/09lophelia/welcome.html
http://oceanexplorer.noaa.gov/explorations/10lophelia/welcome.html

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html
Click on the links to Lessons 3, 5, and 6 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals.

Lesson 3 - *Lophelia* Biology

Focus
In this lesson, students learn about basic coral biology and *Lophelia pertusa* natural history.

Grade Level
9-12 (Biology/Earth Science)

Focus Question
How does *Lophelia* survive on the bottom of the Gulf of Mexico?

Learning Objectives:
- Students will be able to label a diagram of a coral polyp to show the tentacles, mouth, stomach, nematocysts, and skeleton
- Students will be able to describe the basic biological processes of *Lophelia* coral that allow survival on the bottom of the Gulf of Mexico (e.g., gas exchange (O_2 & CO_2), eliminate waste, obtain water, grow, reproduce, consume nutrients for energy, respond to stimuli).

Ocean Literacy Essential Principles and Fundamental Concepts
5 - The ocean supports a great diversity of life and ecosystems.
D. Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.

Materials
- Copies of "Coral Polyp, Student Handout" note-taking sheet; one copy per student
- *Lophelia pertusa* Biology PowerPoint
- List of questions generated in Lesson 2
- Slide script of PowerPoint presentation; for teacher use

Audio-Visual Materials
- Computer and projector with internet access

Teaching Time
One 50 minute class period

Seating Arrangement
Facing projection screen

Key Words
Polyp
Cold-water coral
Photic zone
Diffusion
Nematocyst
Sexual and asexual reproduction

Gas exchange
Waste elimination

Background Information

This lesson provides details on the biology and life history of *Lophelia pertusa,* a cold-water coral species that is important in creating habitat for other deep-sea organisms. Students participate in an interactive PowerPoint presentation and complete a worksheet to summarize the information. The following websites provide excellent background information on deep-sea corals in general and, specifically, *Lophelia pertusa.*

www.lophelia.org

http://oceanexplorer.noaa.gov/explorations/10lophelia/background/biology/biology.html

http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug21/aug21.html

http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug24/aug24.html

http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/sept2/sept2.html

Much more is known about shallow-water coral and coral reefs. The following website describes some of what we know about the biology and ecology of coral found in shallower, warmer waters. http://coris.noaa.gov/about/biology/

Learning Procedure

1) Bring out the questions from Lesson 2 and reread any questions related to how *Lophelia pertusa* or other organisms associated with cold-water coral communities survive **below the photic zone** (i.e., with no sunlight). Tell students that in this lesson, they will learn more about the anatomy and biology of *Lophelia.*

2) Begin the PowerPoint presentation, using the slide script (found following and in the notes of the PowerPoint presentation). Have handouts of the coral polyp ready to give to students when you get to slide 7. Be sure to read through the script and look at the presentation before you do this with students. If you have questions, you can check the websites listed above. Try to involve the students as much as possible during the presentation. Ask questions (use prompts in script) and build from concepts they have already encountered in biology class.

3) Distribute the handout when you get to slide 7. Ask them to predict, based on what they know about living organisms' needs to survive and the anatomy of the coral polyp, the biological functions of the organism. They will write this in part of each box on the handout. As they go through the PowerPoint, or at the end, they can correct their predictions and fill in each box with the details of each process based on the information in the presentation.

4) At the end of the presentation, there is a game with a phrase that is only identified by blanks for each letter in each word. Students must answer a question (provided in script) about *Lophelia* biology before they can guess a letter. If they guess a letter

that is part of the phrase, fill in the blanks with that letter (either in the PowerPoint slide or on a whiteboard or poster paper) and award the team 5 points for each time the letter appears. If the letter does not appear, you will need to record that the letter is not in the phrase and the team does not receive any points. Set up as many teams as you'd like. Four or five teams work well in a class.

5) Once a team has guessed the phrase (they get 5 points for each of the remaining letters), discuss with the class what the phrase means. *How are we connected to coral communities on the bottom of the sea? What do we have in common with them? How might these organisms benefit humans? How might humans harm the communities? Do human societies have an ethical responsibility to protect diverse biological communities on Earth?* Students will express a range of responses to these questions as they speculate about various connections. Let them hear and respect the opinions of different classmates. You can come back to this discussion whenever you want and feel that there is new information or a new perspective to consider.

The "Me" Connection

Have students research the benefits of coral reefs. The Coral Reef Alliance website, http://www.coral.org/resources/about_coral_reefs/why_care, has information about some of the benefits associated with shallow-water coral reefs. Could the coral communities on the bottom of the Gulf of Mexico provide any of these same benefits?

Assessment

Collect the completed handouts for evidence of understanding the biology of *Lophelia.* You can hand these back to students and go over any of the aspects of biology you feel the students may not have understood.

Listen as the students respond to the game questions. Are there any particular topics or questions that seem to stump many of the students? If so, consider going back over the slides that relate to these questions. You can also print information from one of the Background Information websites and have students read it and write a story about the area they were unsure about for homework.

Extensions

Read the final log entry for the *Lophelia II* cruise in October/November 2010 to learn more about dying corals, possibly due to exposure to chemicals or oil related to the Deepwater Horizon explosion on April 20, 2010.
http://oceanexplorer.noaa.gov/explorations/10lophelia/logs/nov3/nov3.html

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html
Click on the links to Lessons 3, 5, and 6 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals.

Lophelia Biology, PowerPoint Script

Slide 1
How do coral survive on the bottom of the Gulf of Mexico?
Today we will unravel part of the mystery of how coral, such as *Lophelia* survive on the bottom of the Gulf of Mexico. Many of the questions you asked in Lesson 2 could be answered today.

Slide 2
To begin to unravel the mystery of coral survival on the bottom of the Gulf of Mexico, we must first answer the question: Is *Lophelia* coral a plant, animal, fungi, or microorganism? How do you know? Take a minute to jot down on a piece of scrap paper what you think.
Now, turn to your table partner and compare your answers. Listen carefully to your partner's reasoning. Is it persuasive? Has it changed your thinking?
Let's hear from several different people what they are thinking.
[Accept various student answers and push for justifications and evidence that are probable.]

Slide 3
What evidence in this picture can help you decide whether the coral is a plant, animal, fungus or microorganism?

Possible student responses:	Possible teacher questions:
I see crabs that look like they might be eating the coral. Therefore I think the coral is some type of animal because crabs eat animals.	How would you classify crabs: herbivore, carnivore, or omnivore? How could we find out? *(crabs are omnivores, eating plants, animals, fungi, and bacteria)*
I see crabs that look like they are hiding in the coral. Therefore I think the coral is some kind of plant because plants often provide cover and camouflage animals.	What are some of the characteristics of aquatic plants? *(brown to green, need light, tend to flow back and forth in the water column, don't have stiff structures like wood)* How much light do you think gets to 515 meters?
I think the coral looks more like a rock with some kind of slimy tentacles on it. Could this make it some type of mold? Mold is a type of fungus.	How does mold form? Where does it form? How does mold get nourishment? *(molds form on organic materials and derive their nutrition from the materials)* How do you think the coral in this picture might get nutrients?
The white part looks like a hard shell. Could they be some type of animal that produces a shell?	I see the shell part; what part of the picture looks like the animal part? Do you think this is all one animal or a colony of animals? Explain your reasoning.
This just looks too weird. It must be some type of colony of microorganisms. Only some type of extremophile	Does anyone know of any microorganism that produces a hard part like the white in the picture?

microorganism could live on the bottom of the ocean.	

Slide 4
Time to vote! Raise your hand if you think *Lophelia* coral is a plant? An animal? A Fungus? A microorganism? Let's find out who's correct.

Slide 5
Yes, *Lophelia* is an animal, an invertebrate with its skeleton on the outside. The story about how coral polyps (each individual animal) build their exoskeleton is very interesting and could be negatively affected by the increase of CO_2 in the atmosphere. We'll discover more about this in a later lesson.

The top picture shows different types of coral in a shallow, warm water coral reef. You can see these close up when you snorkel in places like Hawaii or if you go to an Aquarium.

The lower picture shows *Lophelia* coral found in deep, cold waters on the bottom of the Gulf of Mexico. They have been found in places on the bottom of the Atlantic, Pacific, and Indian Oceans.

Corals are closely related to sea anemones and sea jellies (aka jelly fish). You may notice some of the similarities between these organisms as we look at the biology of coral more closely.

Slide 6
Note: This slide contains a video clip of a *Lophelia* community, set up to play twice automatically. Let students contemplate the question "What do living organisms need to survive?" as they watch the video. In other words, prompt them to think about the basic functions of a living organism, including *Lophelia* coral. (Let students generate a list with as much as possible: exchange gases (O_2 & CO_2, eliminate waste, obtain water or osmoregulate, grow, reproduce, consume nutrients for energy, respond to stimuli). Somehow, the body of a coral polyp needs to have structures to perform all of these functions. Let's look at the anatomy of one, individual coral animal known as a polyp.

When you are ready to advance to the next slide, hit 'enter.'

Slide 7
If this is an animal, does it have a head? Tail? Body? Mouth? How does it do all the things that living organisms do to survive? Take a look at the sketch (on slide and on handout 3A) of one individual coral animal, called a coral polyp. Talk with the person sitting next to you and make predictions of how a coral polyp carries out these life functions. For example, look at the diagram. How do you think the animal consumes nutrients or eats to get energy? (accept several answers) Write down one of these as your prediction. Continue making predictions on your handout of how a coral polyp carries on as many of these basic life functions as you can. You have 5 minutes.

(You can have students make corrections on the handout as you go through each of the following slides, or you can wait and at slide 14 there is a prompt for them to make corrections.)

Slide 8
A coral polyp is one of the simplest animals. It has a sac-like body plan, and is only two layers thick. There is the outer epidermis and the inner gastrodermis, and in between is a jelly like substance that helps provide structure to the polyp. Because of this simple two layer body, the coral polyp does not need organs, like gills or lungs, for exchanging O_2 & CO_2. The oxygen diffuses from the seawater, through their cell membranes, directly into the cells throughout their bodies. Likewise, carbon dioxide diffuses from the cells, through the cell membranes, out into the seawater.

Slide 9
Water needed by cells diffuses through the cell membrane.
Metabolic wastes produced by the cells also diffuse out of the cells, through the cell membranes, and into the surrounding seawater.

Slide 10
This picture shows an area of new growth, actually a new coral polyp. This animal is a clone of the other polyps in the colony. Coral can reproduce asexually as well as sexually, which we will learn more about in the next few slides. Asexual reproduction allows *Lophelia* to grow into large colonies, forming reef structures that can provide habitat for many other organisms.

Temperature seems to have a big effect on rates of coral growth with cold water corals growing much more slowly than those in warmer waters. The salinity (concentration of salt in the water), turbidity (cloudiness of water), and food availability also seem to affect growth rates. Each year, the skeleton grows thicker and longer. We'll learn more about this in Lesson 4.

Slide 11
Coral reproduce sexually and asexually. In *Lophelia,* a polyp is either male or female, and a colony of polyps (produced asexually) is either all male or all female. Males produce sperm cells and females produce egg cells. In the fall they broadcast spawn. This means that each colony releases sperm or egg cells into the water similar to the coral in the top picture. Once an egg is fertilized, a larva forms, swimming and drifting in the water until it settles (hopefully) on a hard surface. The vast majority of larvae ends up on the soft bottom and does not survive. The hard surface can be a rock, a pipe, a piece of metal, or part of a ship. The larva will develop into a new adult polyp and spend its entire adult life in this location.

Although it may seem that a lot is known about *Lophelia* reproduction, scientists still have lots of questions. They don't know how far larvae will disperse before they settle and develop into adult polyps. They also don't know exactly how closely related various colonies of *Lophelia* are in one small area or across much larger areas. For example, how closely related are the colonies in the eastern part of the Gulf of Mexico to those in the western part of the Gulf? And how closely related are the colonies found in the Gulf to those found in the South Atlantic?

Additional Resource: Coral spawning video - http://www.youtube.com/watch?v=LSCSINHbgg0&feature=fvw

Slide 12

Asexual reproduction produces clones and happens through a process called budding and by simply dividing in half. Budding occurs when a new polyp begins to grow off of a small area on an adult polyp. The new polyp remains a part of the parent until it is mature and can carry on all basic life functions. The new polyp is genetically identical to the parent.

If a polyp is damaged and split in half, both halves can regrow, forming 2 genetically identical polyps.

In one cluster or coral colony, the polyps are usually genetically identical clones.

Slide 13

How do coral polyps get energy? They need to eat and they do this by consuming food particles that drift in the water into their tentacles. Along the tentacles are tiny cells that contain a harpoon-like organelle called a nematocyst. When the cell is stimulated, the nematocyst discharges or shoots out of the cell, injecting a neurotoxin that immobilizes the prey. The tentacles move the food item toward the mouth at the center of the polyp.

The tentacles also secrete mucus that can collect particles of organic matter. Small hairs on the tentacles called cilia move the particles toward the mouth. Any waste from the food is expelled through the mouth into the water. The digestive tract is so simple there are no other openings for eliminating food wastes.

Slide 14

All living organisms respond to stimuli. We have seen many of the responses used by coral, and specifically *Lophelia* already. Can you name some of them? [Let students list as many ways as they can remember before showing the bulleted list in the slide. Then read the list to reinforce what the students have already stated.]

Slide 15

Now look back at the handout you made predictions on at the beginning of the slide show. Make corrections to incorporate the new information you just learned. Use arrows or write on the diagram if you want. If you want to go back to look at some of the slides again, just ask. When you have finished, we're going to play a game similar to the Wheel of Fortune to review some of the basic biology of corals.

Slide 16

Time for our game. The dashes are for a letter in a word. There are a total of 12 words in this phrase. Each team will have to answer a question correctly before they can guess a letter. If you guess a letter that is in the phrase, your team will receive 5 points for each time the letter appears. If you guess a letter that doesn't appear in the phrase, your team does not receive points. Are you ready? Let's start.

Phrase: WE ARE CONNECTED TO LIVING TREASURES ON THE BOTTOM OF THE SEA

Questions:

1. How does *Lophelia* eliminate wastes? diffusion through cell membranes to the water
2. What type of food does *Lophelia* consume? small organic particles and other animals in the water (plankton, detritus, organic matter, small fish)
3. What type of living organism is *Lophelia*? an animal
4. What is the habitat like where *Lophelia* are found? dark, cold, high pressure, on a hard surface
5. Name one process that all living things need to do. exchange gases, eliminate wastes, reproduce, grow, respond to stimuli, obtain nutrients and water (use this question more than once)
6. How does *Lophelia* obtain oxygen? diffusion through cell membranes to the water
7. How does *Lophelia* get rid of carbon dioxide? diffusion through cell membranes
8. Where does fertilization of egg cells occur? in the ocean water
9. Do adult *Lophelia* raise their young? No
10. Name two things that could happen to *Lophelia* during the larval stage? die, get eaten, attach to a hard surface and become an adult
11. How does *Lophelia* protect itself from predators? it pulls it's body inside the skeleton
12. How could you measure growth in *Lophelia*? mark the skeleton, measure the length, return at a later time and remeasure from the mark to see if it has grown (accept other reasonable answers, like weighing the same animal before and after)
13. Why is so little known about *Lophelia*? they are found in deep waters that require special equipment to study
14. How do scientists get close to *Lophelia*? they use submersibles such as *Jason* and *Alvin*
15. What is responsible for the presence of carbonate rock on the bottom of the Gulf of Mexico? microorganisms and hydrocarbon seeps? Bacteria
16. How does *Lophelia* capture prey? With its tentacles
17. What two other animals might you see living in and around *Lophelia*? (crabs, fish, hydroids, tubeworms, anemones, other types of coral, sea star, brittle star, clams – all in lesson 1 mosaics)
18. How does *Lophelia* obtain water? Diffusion through cell membranes from the ocean water
19. Name one body of water where *Lophelia* can be found. Gulf of Mexico, Atlantic Ocean, Pacific Ocean and Indian Ocean.
20. Why do you think scientists are interested in studying *Lophelia*? Accept any reasonable response including: it is unusual to find corals growing in water with no light, *Lophelia* are found near areas where oil and other resources are extracted, *Lophelia* are beautiful, scientists may be looking for new chemicals that can be used to make life-saving drugs, studying organisms in areas that are hard to get to is an interesting challenge for scientists

Coral Polyp – A Living Organism

Name: ___________

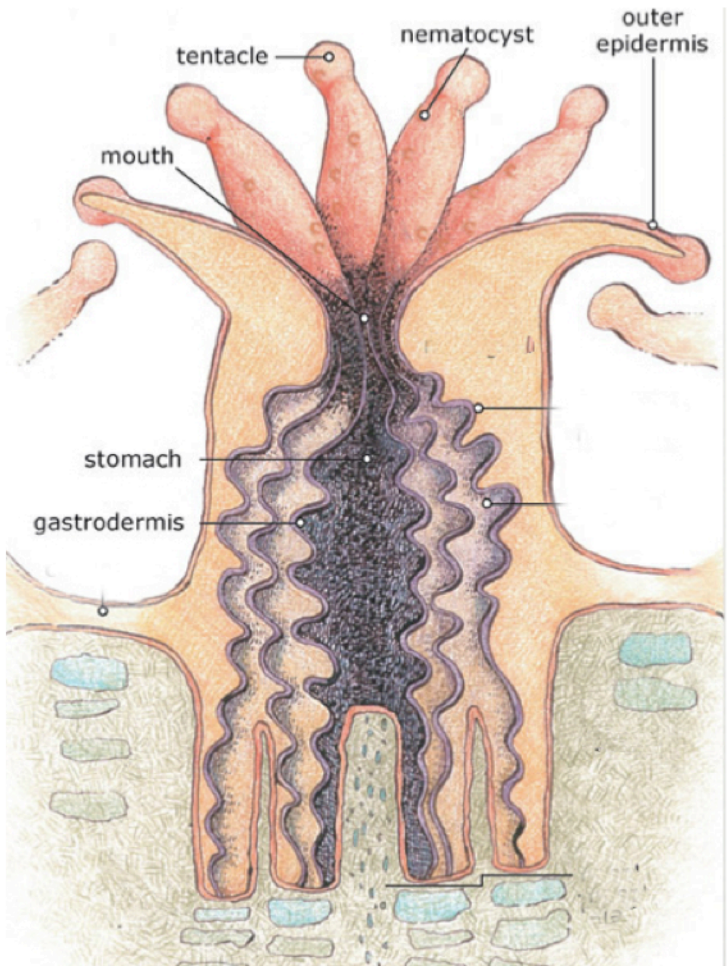
PREDICTIONS

Exchanging O_2 & $C O_2$:

Eliminating Waste:

Obtaining Water:

Reproduction:



Growth:

Consuming Nutrients for Energy:

Responding to Stimuli:

Other notes and interesting facts about coral:

Coral Polyp – A Living Organism   Name:____________

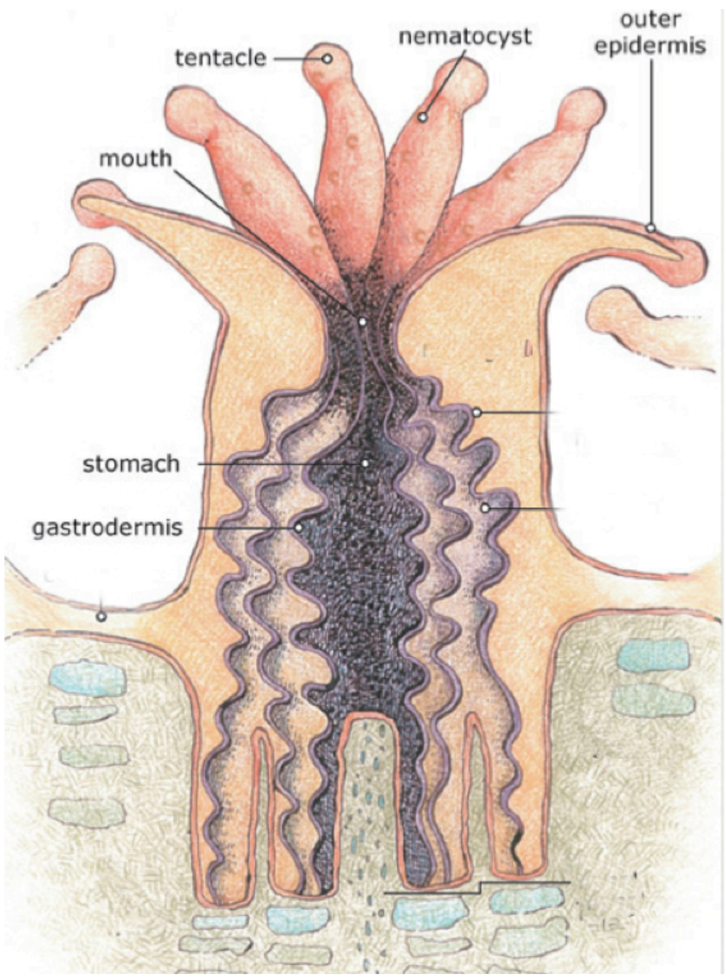
FINAL

Exchanging O_2 & CO_2:

Eliminating Waste:

Obtaining Water:

Reproduction:



Growth:

Consuming Nutrients for Energy:

Responding to Stimuli:

Other notes and interesting facts about coral:

Lesson 4 - Ocean Acidification and Its Effect on *Lophelia*

Focus
In this lesson, students learn about ocean chemistry and how addition of atmospheric CO_2 can lead to ocean acidification with associated effects on marine organisms.

Grade Level
9-12 (Biology/Earth Science)

Focus Question
How does a coral, like *Lophelia,* with soft, delicate polyps, build such a hard, skeletal structure?
How can climate change affect *Lophelia*?

Learning Objectives:
- Students will be able to explain how coral polyps build their skeletal structures, and will be able to identify the necessary building blocks of calcium and carbon-derived carbonate ions for *Lophelia* to produce a skeleton;
- Students will be able to demonstrate the effect of increased CO_2 on ocean chemistry using a simple model, and explain how sea water acts as a buffer reducing the effects of chemical changes on pH, to a point;
- Students will be able to explain that coral polyps compensate for lower pH (and aragonite saturation levels at depth) by changing internal pH in the calcifying fluid, including impact to corals over time;
- Students will be able to discuss implications of increasing amounts of anthropogenically-derived carbon dioxide in the atmosphere on *Lophelia* and other calcareous marine organisms.

Ocean Literacy Essential Principles and Fundamental Concepts
3 – The ocean is a major influence on weather and climate.
E. The ocean dominates the Earth's carbon cycle. Half of the primary productivity on Earth takes place in the sunlit layers of the ocean and the ocean absorbs roughly half of all carbon dioxide added to the atmosphere.
F. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing and moving heat, carbon and water.

Climate Literacy Essential Principles
7 – Climate change will have consequences for the Earth system and human lives.
D. The chemistry of ocean water is changed by absorption of carbon dioxide from the atmosphere. Increasing carbon dioxide levels in the atmosphere is causing ocean water to become more acidic, threatening the survival of shell-building marine species and the entire food web of which they are a part.

Materials
- Small 50 ml beakers or cups with petri dishes as lids
- Fresh or distilled water
- Bromothymol blue (BTB)
- Straws

- Stopwatches or timers
- Labeling tape and markers
- Distilled vinegar
- Calibrated cylinders
- Litmus paper (to test pH)
- Coral and/or seashell pieces
- Paper towels
- Balance with precision to 0.1 gram
- Tweezers
- Safety glasses
- Copies of "Ocean Acidification Experiment" handout; one per student

NOTE: Freshwater vs. Seawater
Due to the buffering capacity of aquarium products like "Instant Ocean" we recommend using fresh water in this lesson's experiment. If you wish to substitute "ocean water" to make the experiment more realistic, we recommend making a simple "seawater" of just sea salt (or Kosher salt) and freshwater.

Audio-Visual Materials
Computer and projector access

Teaching Time
Three to four 45-50 minute class periods

Seating Arrangement
Groups of 4

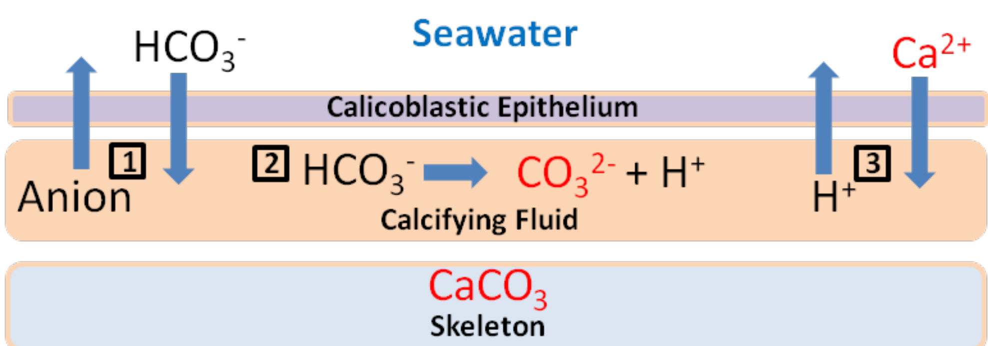
Key Words
Ocean Acidification
Ocean chemistry
CO_2 - carbon dioxide
Bicarbonate ion (HCO_3^-)
Ca^{2+} ion
pH
Alkalinity
Buffer
Ions - positively or negatively charged molecule
Calcium carbonate
Aragonite – one of two common, naturally occurring crystal form of calcium carbonate
Zooxanthellae
Tentacles
Oral tissue
Aboral tissue
Calicoblastic epithelium
Calcifying fluid

Background Information

As students have already learned, stony or hard corals, like *Lophelia*, need solid places to attach and grow. Stony corals are invertebrates and build their skeleton outside of their bodies. The coral polyp secretes calcium carbonate ($CaCO_3$) out of its base, forming a distinctive cup or calyx to sit in. This calyx also provides protection – i.e., when stressed, polyps will retract completely inside the cup.

To create the skeleton, corals use calcium (Ca^{2+}) and carbonate (CO_3^{2-}) ions from the seawater. The production of skeleton occurs at the outermost layer of the aboral tissue, called the calicoblastic epithelium. This layer is at the interface of the tissue and the skeleton and contains a "calcifying fluid." Corals are able to alter the chemistry within this internal fluid to make the concentration of aragonite (the crystal form of calcium carbonate that the corals use) higher than the surrounding seawater. This causes calcium carbonate to precipitate out of the fluid and be deposited onto the skeleton.

The most abundant form of inorganic carbon in seawater is bicarbonate (HCO_3^-). The polyp brings bicarbonate in to the tissue (through an unknown transporter) and it is subsequently traded for another negatively charged ion **(**see diagram below, step **1).** The hydrogen dissociates from the bicarbonate because of the high pH maintained inside the calcifying fluid **(**step **2).** The remaining ion is carbonate (CO_3^{2-}). Positively charged hydrogen ions removed from bicarbonate are then exchanged with calcium, and calcium carbonate is formed **(**step **3).** A PowerPoint presentation describing this calcification process is provided.



For an excellent reference article on this process, see "Why Corals Care About Ocean Acidification – Uncovering the Mechanism" by A.L. Cohen and M. Holcomb (2009), in *Oceanography* vol. 22, no. 4, pp 118-127. The article is available online at (http://tiny.cc/kwkjmw).

Another good reference on ocean acidification, "Ocean Acidification" by E.H. Buck and P. Folger (2009), Congressional Research Service, is available online at http://www.fas.org/sgp/crs/misc/R40143.pdf

Learning Procedure
A multi-part PowerPoint presentation and script is provided to guide this lesson and classroom investigation. The lesson and PowerPoint is organized into five parts: 1) an opening demonstration showing how dissolved CO_2 can change the pH of water along with introductory slides soliciting students' prior knowledge, 2) an in-class experiment where students explore how solutions of differing pH dissolve pieces of coral, 3) background slides on how corals produce skeleton (to be covered while experiment is in process) and reflection questions on the in-class experiment when complete, 4) another section in which students explore how ocean acidification may affect corals and 5) a final section in which students read and discuss an online essay about ongoing research exploring the effects of acidification on *Lophelia*.

Part I – What do you know about ocean acidification and its effects on marine organisms?
This section introduces the concept of CO_2 making water more acidic, and provides a review of *Lophelia's* requirements (substrate, food, cold temps, and minerals for skeleton production) as it prompts students for their initial thoughts on the effects of acidification on coral skeletons.

1) INTRODUCTION: Beginning with the PowerPoint, ask students what they know about ocean acidification, what causes it, and what effects it's having on the ocean and the organisms living there. Encourage them to say as much as possible, and that there are no right or wrong answers at this point. Use this discussion to introduce this lesson in which they will explore what causes the ocean to become more acidic and what happens to some organisms in such an altered environment.

2) DEMONSTRATION: Introduce where CO_2 in the atmosphere is coming from and discuss how this gets into the ocean. To demonstrate the concept of acidification of water from a gas, have students conduct the following demonstration showing how CO_2 from their own respiration blown into a beaker of water changes the pH, making it more acidic.
    a. Measure pH of fresh water: With students working in pairs, have each pair fill a small beaker halfway full with fresh water. Using litmus paper or BTB, have students record the pH of the fresh water.
    b. Add CO_2: Next, have one student in each pair gently blow through the straw into the water in the beaker, for one minute. Have the other student time their partner. After one minute, have students measure and record the pH. You may wish to play with the timing and have some students blow into the water for ½ a minute or another group blow into the water for 2 minutes, and then compare the resulting pH values.
    c. Have students report their results and note if there are differences in pH depending on how much time (a proxy for the amount of CO_2 added) they spent blowing into the water. Discuss why there may be differences (e.g., variation between students, different amounts of time) and how to handle this (e.g., average the results). Calculate a class average with standard deviation.

d. Have students explain how this exercise models ocean acidification, and how this model system is similar to and different from the actual ocean and actual ocean acidification. There will be plenty of ways in which it is different (fresh water vs. seawater; quantity of CO_2 entering the liquid, source of CO_2, etc).

3) Next, return to the PPT to review what the deep-sea coral *Lophelia* needs to survive (substrate, food, cold temperatures, and minerals for skeleton production). Students will draw upon what they learned in Lesson 3 as they consider effects of acidification on coral skeleton production.

Part II – Exploring the effects of acidified seawater on coral skeletons

1) This section introduces the experiment that students will follow to examine the impact of changing pH on coral skeleton. The essential question of the experiment is *"What is the effect of pH on the mass of a coral skeleton?"* A handout, *Ocean Acidification Experiment,* guiding students through the experiment is provided. Give each student a copy of the handout describing the experiment design and review with the class. The handout lists the materials each group will need along with step-by-step procedures.

2) Working in groups, students will set up the experiment exploring the effect of pH on the dissolution of coral skeletons, setting up three treatments: "neutral water", "mildly acidic water, "very acidic water", using distilled vinegar (5- 8% acetic acid in water) in place of CO_2. Students will measure the starting mass of their coral pieces and, after 1 week, the ending mass of the coral pieces and will calculate a proportion of mass loss. **Note**: be sure your balance measures to at least 0.1 grams to be able to detect the mass loss of the coral pieces.

3) When students have completed setting up their experiment and made their predictions, return to the PPT.

Part III – Background on how corals make their skeleton and how ocean acidification is changing ocean chemistry.

1) This section provides detailed information on how corals produce their skeleton from raw materials in the environment, and detailed information on how CO_2 pollution is affecting ocean pH. Present the PowerPoint slides to students, allowing them time to take notes. Two reflections questions (#1 and #2) in the student handout refer to information presented in this part of the PowerPoint.

2) At the end of this section, have students return to their experiments to determine ending mass and proportion of mass loss, and examine how the experiment is similar to and different from real life.

3) Allow students time to complete the reflection questions (#3 - #6) of their student handout. They will complete the last page of the handout after the next section.

Part IV – What are the effect of Ocean Acidification on corals*?*

1) After summarizing their experiment results, this section explores two consequences of ocean acidification to corals, and challenges students to predict what they think will be the effects on *Lophelia*. Present the PowerPoint slide for this section. The important point for students to understand is that *live* corals are surviving even in more acidic waters and are doing so by having to work harder to compensate for a changing external environment. The experimental system in the classroom uses just the coral skeleton pieces without the living organism continually building skeleton.

2) Ask students to consider how marine organisms may accommodate the effects of lower pH on their shells and skeletons, and give students time to record their thoughts in the student handout (question #7).

3) At this point, you may wish to have a class discussion and record students' ideas. Ultimately, emphasize that the animal must work to maintain an internal environment and that this effort is affected by the external environment, requiring more or less energy expenditure by the coral.

Part V – Deep-sea coral research

1) In this final section, students will read an online essay by one of the researchers of the Lophelia II research program – Jay Lunden. The essay is title "Exploring the "C's": Climate Change and Cold-Water Corals" and is available on the NOAA Ocean Explorer website : http://oceanexplorer.noaa.gov/explorations/09lophelia/background/climatechange/climatechange.html The essay introduces the idea that at least two climate-change related variables, rising temperature and changing ocean chemistry, may have a direct effect on corals. Allow students time to read the essay and complete the final two questions of the student handout (#8 and #9). When students have completed their handouts, have a class discussion about the essay and the students thoughts.

2) Time-permitting, you may also wish to have students explore other essays and log entries that were a part of the expedition.

The "Me" Connection

Have students explore how they personally add CO_2 to the environment (e.g., driving in cars, flying on planes, etc.). Students could explore various "carbon footprint" calculators available online to better understand how their lifestyle and personal choices add to the carbon balance.

Assessment

Use the student handouts to assess students' understanding of the material.

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html?url=http://www.learningdemo.com/noaa/#lesson3 Click on the links to Lessons 3 for an interactive multimedia presentation on Deep-Sea Corals.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program
http://oceanexplorer.noaa.gov/explorations/09lophelia/background/edu/lessonplans.html See lesson titled "Off Base"

Lophelia pertusa and Ocean Acidification, PowerPoint Script

Slide 1
In this lesson, we are going to explore the issue of Ocean Acidification, what causes it, and what effects it may have on marine organisms like *Lophelia.*

Note: *This first section of the PowerPoint will ask the students to recall what they have learned thus far about Lophelia and apply this knowledge in the context of ocean acidification. Ocean acidification is not addressed in detail in this portion of the PowerPoint, rather, the students are asked what they think ocean acidification is and what it's effects may be on marine organisms, particularly the deep-sea coral Lophelia.*

Slide 2 – Part I: What do you know about ocean acidification?
What do you know about ocean acidification? What causes it? What affect can it have on marine organisms?

Note: *Begin with a general class discussion; encourage the students to share what they think ocean acidification is and why it is of particular concern in marine environments. Use the questions on the slide to guide and stimulate discussion. There are no wrong answers, this is simply meant to get the students thinking about the causes and effects of ocean acidification. These questions will be addressed in detail later in the lesson*.

Slide 3
What do you think happens to the pH of water when CO_2 is added? What is your prediction?

Note: *at this point, have students conduct the demonstration of blowing exhaled air (with* CO_2 *from respiration) into a small beaker of water, and record pH changes.*

Slide 4
If ocean water is changing, that is if the pH of the water is getting more acidic, what do you think happens to organisms living in that water? *Get students' ideas.*

To make better predictions, let's think about what Lophelia needs to survive, and see if any of that may be affected by a changing environment, specifically by more acidic ocean water.

Slide 5
Let's review what *Lophelia* needs to survive. What do you recall from previous lessons? Let's make a list.

Have students brainstorm a list of "needs" before displaying the four criteria listed on the slide

Slide 6
Now let's go through each of these individually. First … Hard Substrate to settle on.

Why are hard substrates important for Lophelia? When you imagine the deep-sea, what do you think the seafloor looks like? A large majority of the ocean floor is composed of soft sediments and mud. However, most sessile organisms (non-mobile) require a hard, stable surface on which to settle. What do you think would happen if corals tried to settle on soft sediments? If corals need a hard substrate to settle, where do you think such substrates can be found?

Hard substrates come in many different forms. Dead corals and carbonate rock are the most common hard substrates in the Gulf of Mexico. However, anthropogenic objects can also provide important substrates for corals and other sessile organisms, such as oil platform piles and shipwrecks.

Slide 7
Next, of course, these organisms need food. But recall, deep-sea corals are below the photic zone and do not have symbiotic zooxanthellae to produce their own food. These corals need to catch what food they can floating by in the deep ocean currents or falling down from above. They use their tentacles with stinging cells called nematocysts to capture their prey.

Slide 8
Lophelia is adapted to cold-temperatures. Here is a graph showing how ocean water cools with depth. The red line represents the temperature of the ocean at depths from 0 to 4500 meters. Notice that the ocean is warmer (~22 degrees C) at the surface, and that it cools rapidly through the thermocline (i.e., 500-1000 m depth), and then stays cold (~3-4 degrees C) at depths below 2000 m. The brown portion, between 4-12 degrees C or *Lophelia's* preferred temperature range, occurs at depths between 500-2500 m. So *Lophelia* prefers deep water. And cold too!

Slide 9
By the way, here's a map showing where *Lophelia* has been found world-wide.

Slide 10
Lastly, corals need minerals to build their skeleton. This skeleton provides a place for the polyp to live.

Slide 11
It also provides protection, as we've seen in previous lessons and videos. When bothered, the coral polyp retracts into the cup of the skeleton.

Slide 12
After a section dies, the bare coral skeleton also provides substrate for other corals and sessile organisms to settle on. They can't settle on the muddy seafloor. Coral skeletons represent one of the more common substrates for settlement.

Slide 13
And they provide important habitat for a whole community of organisms.

Slide 14

Coral skeleton is made of calcium carbonate, the same mineral found in egg shells, chalk, even antacid tablets like Tums.

Slide 15
The big question is will the acidification of ocean waters affect these hard skeletons? What do you think??

Facilitate a discussion during which the students synthesize their knowledge about Lophelia's requirements and hypothesize different ways that ocean acidification may affect Lophelia. Direct the discussion to focus specifically on how ocean acidification may affect Lophelia's ability to build a hard skeleton.

Slide 16 – Part II: Let's do an experiment!
Ok, let's do an experiment to explore this.

The next few slides will introduce the experiment.

Slide 17
The basic idea of the experiment is to test the effect of pH on coral skeleton pieces. We've already seen how CO_2 changes the pH of water. To simulate the addition of CO_2, we substitute distilled vinegar, a weak acid, as the additive to water to achieve the different pHs. Using vinegar instead of exhaling CO_2 through a straw gives us more control over the resultant pH. We'll set up three different solutions with three different pHs. What do you predict will happen to the coral pieces soaking in the different solutions?

IMPORTANT NOTE: in this experiment, we are trying to create solutions of "ocean water" with different pHs using vinegar to acidify the water. Keep in mind that ocean water will never really become 'acid' (i.e., with a pH below 7) but it will be acidified (i.e., lowered) from its current pH of 8.2 or so. An ocean pH of 7.5, while technically not acidic, IS a result of ocean acidification. We are using the vinegar solutions with their low pHs to show the effects on calcium skeletons but speeded up for classroom observation.

After a class discussion in which students share their predictions, distribute the handout "Ocean Acidification Experiment" and give students time to set up their experiments. Once each group's setup is complete, return to the presentation, giving students background information on how Lophelia creates its skeleton, and also on how CO_2 additions can make the ocean more acidic. At the end of Part III, allow students to review/revise their predictions.

Slide 18 – Part III: Background on *Lophelia* and how it makes its skeleton
Now, while the coral pieces are soaking in the different treatments, let's get back to how corals produce skeleton, and how CO_2 pollution is affecting the ocean.

Slide 19
Let's explore how a soft coral polyp can produce a hard skeleton.

Note: *This portion of the presentation is intended to introduce students to the biological process that mediates coral skeleton production. Once the students understand* ***how*** *Lophelia makes its hard skeleton, the process of ocean acidification is introduced. The students should* *notice commonalities between the chemical process of ocean acidification and the chemical process of skeleton creation. As the PowerPoint progresses, ask the students to keep Lophelia's basic needs in mind, as the coral's biology plays an important role in how ocean acidification will affect Lophelia in the future.*

Slide 20
Let's zoom-in to an individual polyp and investigate the calcification process at a microscopic scale.

Slide 21
Coral polyp tissue can be broadly classified into two categories: the oral and aboral tissue. The oral tissue is in direct contact with the surrounding seawater, while the aboral tissue lies at the interface of the polyp and its skeleton. The gray area in between these two tissue layers is the coelenteron, or the gastric cavity, where food is digested.

Slide 22
Now, let's zoom in a little closer, so that we can focus on the two layers.

Slide 23
At the base of the aboral tissue is a layer known as the calicoblastic epithelium. This is the site of calcification and is where we will focus next to study how corals build such a hard skeleton.

Slide 24
The site of "skeletogenesis" is within the "calcifying fluid" that is present between the calicoblastic epithelium and the skeleton.
Let's zoom in a little closer to look at this layer and the 'calcifying fluid.'

Slide 25
In this graphic, we will see the exchange of ions and anions from the seawater through the two layers of the coral polyp to the calcifying fluid in the calicoblastic epithelium.

First, bicarbonate (HCO_3^-) is brought in to the tissue (through an unknown transporter) and traded for another negatively charged ion. Bicarbonate is the most abundant form of inorganic carbon in seawater.

Slide 26
Next, hydrogen dissociates from the bicarbonate because of the high pH maintained inside the calcifying fluid.

Slide 27
Hydrogen ions (proton) are pumped out, exchanging calcium ions and changing the pH (raising it) of the calcifying fluid.

Slide 28
Finally, calcium combines with carbonate to form calcium carbonate which precipitates to form the skeleton.

Precipitation of the skeleton is dependent on the coral's ability to internally maintain concentrations of carbonate and calcium *above* that found in the seawater.

Slide 29
It is important to keep in mind that the coral polyp controls this whole process by regulating the internal chemistry of the calcifying fluid.

It can change the pH of the fluid, as well as the concentration of various chemical components relative to the surrounding environment.

Slide 30
But all of this comes with a cost. It takes **energy** to regulate this internal environment. And depending on the external conditions, this regulation process may be more or less difficult, requiring more or less energy.

Changes in the external environment therefore affect how Lophelia regulates its internal environment.

Slide 31
So…Now let's turn to the external environment, the surrounding ocean environment.

The next five slides describe the reactions involved in ocean acidification in detail. Keep in mind that the reactants necessary for the coral to make its hard skeleton are **carbonate and calcium**. Keep an eye out for these molecules, especially carbonate, during this examination of ocean acidification.

Ok first, the ocean acts as a "sink" for atmospheric CO_2, regardless of whether it is from natural sources or from pollution.

Slide 32
As we saw in the beginning demonstration when we exhaled respired CO_2 into beakers of water changing the pH of the water in those beakers, CO_2 mixed with water forms carbonic acid.

Slide 33
This carbonic acid splits (dissociates) into hydrogen ions and bicarbonate.

Wait - Do you recognize any of these chemicals? Do you recall how corals use bicarbonate?

Slide 34
And some of this bicarbonate splits again, into more hydrogen and carbonate ions.

Recognize any of these chemicals? How is this process linked to the process of calcification?

Slide 35
Notice how the concentration of protons in seawater increases - resulting in a lower pH.

But that's not all….

Slide 36
As hydrogen ion concentration increases (and pH decreases), this whole carbonate equilibrium is shifted back to the left. Le Chatelier's Principle

In other words, it is energetically favorable for carbonate (CO_3^{2-}) to recombine with H^+, decreasing the concentration of carbonate in seawater.

Lophelia will need to **exert energy** to increase its internal pH & maintain an environment, relative to the external environment, where carbonate remains unbound

Slide 37
Fortunately, seawater is highly buffered. This buffering slows the change in pH.

Anions in seawater bind to positive hydrogen ions, effectively removing these protons from solution.

Slide 38
But even though the ocean has great buffering capacity, the pH of seawater is still changing. CO_2 pollution is causing the ocean to become more acidic.

Slide 39
Ok, let's check on the experiment, and see what has happened to our coral pieces sitting in solutions of varying pH. What do you think has happened?

At this point, return to the experiment. Students will now determine how much mass loss each piece experienced. When they have completed collecting their data and calculating the proportion of mass loss, have students complete the reflection questions regarding what is similar and different between this simple experiment and real life. For example, the experiment is similar to real life in that coral is exposed to acidic water causing the skeleton piece to dissolve. It is different in that this is not seawater, with its buffering capacity; it does not include the live coral polyp; it is not the same temperature; and it is likely not the same pH levels – among many other differences. At this point, have students predict what they think will be the impact of ocean acidification on Lophelia. Once they have made their predictions, continue to the next part – which covers some of the expected consequences on Lophelia.

Slide 40 – Part IV: what does ocean acidification do to live corals?
Let's look at what may happen to live corals in this type of altered environment.

Slide 41
In the actual ocean, the first consequence of additional sources of CO_2 is the decrease in pH of the ocean (acidification).

The impact of this is that this can dissolve existing coral skeletons and shells of other marine animals.

Did we see this in our in-class experiments?

Slide 42
The second consequence of a more acidic ocean environment is that there is now a greater difference between Lophelia's internal environment (i.e., the calcifying fluid) and its external environment (i.e., seawater), making all of the processes of calcification more difficult.

For example, to exchange H^+ for calcium cations, *Lophelia* must pump protons against a steeper concentration gradient – **a process that requires lots of energy**

Lophelia will need to **exert more energy** to increase its internal pH (maintaining an internal environment relative to the external environment) where carbonate remains unbound.

Slide 43
So ocean acidification makes it *harder* to form skeleton and shells, requiring these organisms to exert *more energy* to do so.

How will they get more energy?

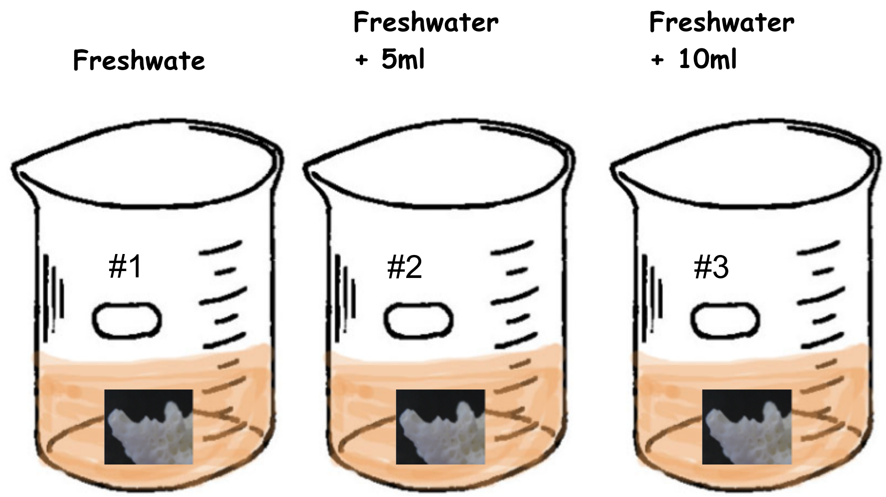
Slide 44
Here are some thoughts to consider…
How will *Lophelia* generate more energy?
What if acidification also affects the availability of *Lophelia's* food sources?

Slide 45 – Part V: Deep-Sea Research on *Lophelia*
Ocean acidification is an issue of concern and a great deal of research is currently underway to understand its causes and impacts. Researchers are currently examining the impact of acidification on deep-sea coral communities. As a final step of this lesson, read the following essay on climate change and its potential effect on cold-water coral and answer the last two questions in your handout.
"*Exploring the C's: Climate Change and Cold-water Corals*" by deep-sea scientist, Jay Lunden from Temple University, found on the NOAA Ocean Explorer website:
http://oceanexplorer.noaa.gov/explorations/09lophelia/background/climatechange/climatechange.html

Ocean Acidification Experiment **Name: ____________**

Materials List (per group):

- 3 Beakers
- 3 petri dishes as lids
- Labeling tape & marker
- Fresh Water
- Distilled Vinegar
- Calibrated cylinder
- pH paper
- 3 coral pieces
- Paper towel
- Balance
- Tweezer (to handle coral pieces)
- Safety glasses (1 per student)



Procedure – Experiment setup and making predictions

1. Label each of your beakers with your group's name. Label beaker #!: "Freshwater" and beaker #2: "Freshwater + 5 ml Vinegar" and beaker #3: "Freshwater + 10ml Vinegar
2. Fill each beaker with 50 ml water. Add 5 ml distilled vinegar to beaker #2. Add 10ml distilled vinegar to beaker #3.
3. Measure the initial pH for each solution and record in the table below.
4. Measure the starting mass of each piece of coral, record on the table below, and then place one piece in each of the beakers.
5. Cover each beaker with a petri dish to minimize evaporation and set aside undisturbed for one week.
6. Write down your prediction of what will happen to each piece of coral after one week.

I predict the coral piece in Beaker #1 will____________________

I predict the coral piece in Beaker #2 will____________________

I predict the coral piece in Beaker #3 will____________________

Understanding what acidic solutions can do to coral skeleton

7. **While your coral pieces are in solution for the week, you will learn how corals make their skeleton and how CO_2 pollution is causing the pH of the ocean to change. At the end of the presentation, take a moment to re-evaluate your predictions and make any necessary changes.**
8. **At the end of the week, carefully remove the coral from solution and let it dry for 1 day. Be careful to keep track of which solution each coral piece came from. Working with one beaker at a time, carefully remove the coral piece from solution and place on a paper towel, discard the liquid and dry the beaker, and then place the coral piece back inside the beaker to dry for a day.**
9. **When coral pieces are completely dry, measure the ending mass of each piece of coral and record on the table below.**
10. **Calculate the difference between starting mass and ending mass and record in the table below.**
11. **You should also calculate the proportion of mass loss. This is equal to the difference between starting and ending mass divided by starting mass.**

	Beaker #1	Beaker #2	Beaker #3
Amount of water	50 ml	50 ml	50 ml
Amount of Vinegar	0 ml	5 ml	10 m
Initial pH of solution			
Initial mass of coral piece (gm)			
Ending mass of coral piece (gm)			
Difference in mass (final – initial) (gm)			
Proportion of mass loss (difference / initial mass)			

Reflection Questions:

1. Write down the chemical equation for calcification (from the PowerPoint presentation). Include names for each chemical formula.

2. Where does this calcification take place? (from ppt)

3. How close were your predictions to what actually happened to each coral piece? Be specific.

4. How is this experiment similar to the real world?

5. How is this experiment different from the real world? List as many differences as you can think of. Hint: are these pHs realistic for ocean water?

6. Pick one of the items listed as a "difference" and design an experiment to test the effect of that variable on coral. Describe your experiment here. Be certain to label the independent and dependent variables.

Understanding what acidification can do to polyps:

7. One of the key differences between this classroom experiment and the real world is that only the coral skeleton is exposed to the acidic solution. In other words, the living polyp is not part of the experiment. What do you predict would be the effect of acidification on the coral polyp? Would it still make its skeleton?

Understanding what acidification may do to *Lophelia*:

Read the essay titled "*Exploring the C's: Climate Change and Cold-water Corals*" by deep-sea scientist, Jay Lunden from Temple University, found on the NOAA Ocean Explorer website:
http://oceanexplorer.noaa.gov/explorations/09lophelia/background/climatechange/climatechange.html

8. What two factors does Jay identify as potentially changing the environment in which *Lophelia* is found?

9. Pick one of these factors and describe how it may directly affect the deep-sea coral, *Lophelia pertusa*

Lesson 5 - Movement and Currents in the Gulf of Mexico

Focus
In this lesson, students learn about deep ocean currents, bottom bathymetry of Gulf of Mexico, and larval and plankton drift,

Grade Level
9-12 (Biology/Earth Science)

Focus Question
How can ocean currents influence the spread and survival of *Lophelia*?

Learning Objectives:
- Students will be able to demonstrate effects of ocean currents on water, and larval and plankton movement using a simple model.
- Students will be able to identify advantages and limitations of the model as compared to real currents.
- Students will be able to use the results of their model to predict possible currents in an area of concern from the Challenge Scenario.
- Students will be able to infer impacts of currents on the spread and survival of *Lophelia.*

Ocean Literacy Essential Principles and Fundamental Concepts
1- The Earth has one big ocean with many features.
   B. Throughout the ocean, there is one interconnected circulation system powered by wind, tides, the force of the Earth's rotation (Coriolis effect), the Sun, and water density differences. The shape of ocean basins and adjacent land masses influence the path of circulation.
2 – The ocean and life in the ocean shape the features of the Earth.
   C. Erosion – the wearing away of rock, soil and other biotic and abiotic earth materials – occurs in coastal areas as wind, waves, and currents in rivers and the ocean move sediment.

Materials
- Small plastic tanks (~12 quart size or larger); 1 per group of 4 students
- 1/4" diameter tubing, 24" lengths; 1 per group of 4 students
- 3/8" diameter tubing, 24" lengths; 1 per group of 4 students
- 1-liter containers or 1000mL beakers; 1 per group of 4 students
- Flakes of fish food (at least 2oz. for 5 classes)
- Rocks, small Petri dishes, or small saucers to form landforms; 2 per group of 4 students
- Modeling clay to wrap around base of rocks or Petri dishes so they slope out and form a flat base
- Bathymetry with amplitude map for Challenge Scenario (electronic version to project)
- Rulers (Optional for water speed investigation); 1 per group of 4 students
- Wax pen or marker; 1 per group of 4 students

- Handout - “Deep Ocean Current Experiment”; 1 per student
- Stopwatch or clock with second hand

Audio-Visual Materials

Computer and projector with Internet access

Teaching Time

Two to three 50-minute class periods

Seating Arrangement

Groups of 4

Key Words

Ocean Currents
Deep Ocean Currents
Density
Salinity
Gulf Loop
Bathymetry
Plankton
Larvae

Background Information

Currents are important to deep-sea corals – they bring plankton (food particles) to the corals and also disperse larvae. This lesson provides an opportunity for students to experiment with creating currents and observe the effects of the current on particles floating in the water. Students will model possible currents in the Gulf of Mexico and infer the effects of currents on larval dispersal and drifting plankton. Ocean currents are a very complex topic, and while much is known about general movements in the Gulf of Mexico, the currents in a specific location on the bottom are not well understood and are quite difficult to study.

Scientists do know that ocean currents influence the distribution of *Lophelia* corals. Here are a few examples: 1) When *Lophelia* reproduce, the sperm and egg cells are released into the water. Without favorable currents, fertilization might never occur. 2) Larvae drift in the currents until they settle on the bottom. To continue developing, they need to settle on something hard, like carbonate rock, metal from platform legs, pipelines, or shipwrecks, or wood from shipwrecks. Without currents on the bottom of the Gulf of Mexico, these hard surfaces could become buried in sediment. 3) *Lophelia* polyps use their tentacles to capture food as it floats by. Being in an area with a current brings more water past their tentacles and the possibility of more food.

Use the following websites to find additional information. If you choose to show any of the video clips to your students, have them do the activity first. This way, they have a concrete experience to connect the animated current models and information.

Ocean Currents:

http://www.youtube.com/watch?v=3niR_-Kv4SM&feature=related - This animation, without sound, shows the major ocean currents associated with the ocean conveyor belt. Scientists estimate that it takes about 1000 years for a water molecule to complete one entire cycle.

http://www.youtube.com/watch?v=SdgUyLTUYkg&NR=1&feature=fvwp - The 1 minute clip shows the ocean conveyor belt and emphasizes the current's role in getting oxygen to the deepest parts of the ocean. Without the conveyor belt, driven by temperature differences between the poles and equatorial regions, only water near the surface would carry oxygen. This change would have huge consequences to life in the oceans.

http://www.youtube.com/watch?v=QsEbP5zarCQ&feature=related - This animation, without sound, shows the full extent of major ocean currents and how they are connected.

Gulf of Mexico Loop Current:
http://oceancurrents.rsmas.miami.edu/atlantic/img_rl/currents_carib.mpg - Animation of average **surface** currents and temperatures in the Gulf of Mexico from January to December; This goes quickly so you'll want to watch it a few times. After the first time, locate Florida and the Gulf Coast to help you understand what's happening. Colors indicate surface water temperatures, from 20 – 30 degrees C. Arrows indicate direction and speed of surface current. Dates are shown at the top of the map.

http://oceancurrents.rsmas.miami.edu/caribbean/img_topo2/loop-current2.jpg - Relief map of the Gulf of Mexico basin; The deepest areas are dark blue. The shelf region along the coast is where most of the oil drilling and fishing have occurred in the past. More exploration, drilling, and fishing are occurring in deeper water areas due to shrinking resources on the shelf.

http://oceancurrents.rsmas.miami.edu/caribbean/loop-current.html - Loop current description; The loop current flows north into the Gulf of Mexico from the Caribbean and then into the Atlantic around the southern tip of Florida. This current is visible in the animation listed above.

http://oceancurrents.rsmas.miami.edu/caribbean/img_mgsva/loop-current-YYY.gif - Map of loop current. This map is not animated so it allows a longer look at the surface loop current.

http://oceanexplorer.noaa.gov/explorations/02mexico/background/currents/currents.html - "Currents in a Cul-de-sac" describes the surface currents and deep-water currents in the Gulf of Mexico

http://oceanexplorer.noaa.gov/explorations/02mexico/background/geology/geology.html - "Geological Setting" describes the geology of the Gulf of Mexico

Research Techniques on the ocean bottom:

http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/sept2/sept2.html - This essay describes the larval traps used to study the distribution, both geographic and seasonal, of larvae and other suspended particles as they fall to the bottom of the ocean.

Learning Procedure

1) Ask students to think about what causes currents in the deep parts of the ocean (as opposed to the surface of the ocean). Have them brainstorm a list of factors with their table partner. Ask partners to share their ideas with partners in a nearby group. Walk around and listen in to the discussion, noting some of the ideas. You can write on the board some of the factors mentioned by more than one group.

2) Show the following YouTube videos: http://www.youtube.com/watch?v=w_8mw-1HYFg In this first video, Bill Nye demonstrates how saltier water has a higher density and sinks to the bottom of the ocean. http://www.youtube.com/watch?v=RXTc-kHQN2U The demonstration in this video shows how two liquids with different densities separate. Ask your students what they think the liquids are and why the blue liquid behaves differently from the red liquid. It could be differences in salinity (like in the Bill Nye clip) or it could be differences in temperature. Both temperature and salinity are factors that affect deep ocean currents. Because the temperature and salinity of ocean water is different in different places, the water moves, including water in the Gulf of Mexico. Show either or both of the animations of the ocean conveyor belt: http://www.youtube.com/watch?v=3niR_-Kv4SM&feature=related and http://www.youtube.com/watch?v=SdgUyLTUYkg&NR=1&feature=fvwp to demonstrate how temperature differences from the equator to the poles creates a convection current. Differences in salinity also contribute to these global currents. Point out that ocean currents are like winds. We understand a lot about the global patterns, but that doesn't mean we know what the currents will be like in any specific location, especially on the bottom of the ocean. (Note: Review with students heat transfer by convection and convection currents if necessary.)

3) Ask students how they think different landforms (underwater hills, mountains, valleys, cliffs, etc.) affect ocean currents. Ask students how they might figure this out using the small plastic tubs available for this lesson. Have them share their ideas with their partner and then ask a few pairs to share their idea with the class.

4) Distribute the *Deep Ocean Currents Experiment* handout and explain that they will create a current using a siphon to get water to flow from a 1000 ml beaker (or equivalent size container) through a small plastic tube into the plastic tub. Fish food flakes will drop from the surface of the water to the bottom of the plastic tub to show the effects of the current. The students will make observations of the distribution of fish food flakes and they will also measure the velocity of a particle to understand how currents affect particles in the water column.

5) Demonstrate the experiment with just a flat bottom. Fill one tub half way with water and the 1000 ml beaker half way with water. Place one end of a piece of tubing in the beaker. The other end of tubing will be placed in the tub, lying along the bottom. Sprinkle a few flakes of fish in the tub. Next, you will need to start the siphon by gently sucking on the tubing (tub end) to get the flow from the beaker going. Once it's going, gently place the tubing into the tub. Note that some types of fish flakes float on the surface for a long time. After they have floated for about 30 seconds,

start poking them so they are submerged and start to sink. Start the current (siphon) when the fish flakes start to sink. You'll probably need a couple students to assist.

6) Ask students to think about the *Lophelia* communities in the Gulf of Mexico and how the experimental set-up models conditions where *Lophelia* communities are found. Remind students that *Lophelia* relies on currents to bring plankton to them. Food particles that settle are of little use to the corals. Have students complete the boxes in the table on the worksheet. Model the first line if necessary. [For ELL or students with difficulty writing, ask them to draw a picture of what the experimental set-up represents. They can use lines or arrows to connect their drawing with the diagram of the experimental set-up to show the relationships. Encourage them to include labels.]

7) Ask students how their model is different from the real world. You should get lots of answers, including that the bottom of the ocean isn't perfectly flat. Ask students how they could make their model more realistic. They may suggest using rocks or clay to make landforms on the bottom of the tub. Project for the students the bathymetry map for the Challenge Scenario. Explain that this map shows an area approximately 72 square miles on the bottom of the Gulf of Mexico. Point out the major landform features and how to find depth. [*Remember, the higher "hilltops" have lower numbers because they represent distance from the surface of the ocean. This is different from reading topographic maps that measure land above sea level. This map measures the distance from sea level down to the bottom.]* Show students the materials available to create model landforms on the bottom of their tub (small saucers, rocks, modeling clay, or petri dishes). Demonstrate how they can use the clay around the base of a rock or a petri dish to make a slope from the top to the base, rather than having overhanging areas (on a rock) or steep cliffs (around a petri dish). Ask them to work in groups of four to design a landform to test using any of the materials provided. Remind them not to make their landform too complex.

8) Once students have designed their landforms, review the procedures for the experiment and let them get started. You may want to decide as a class where in the tub you want the current to originate (i.e., where the tube is placed). This will make the results more comparable across groups. Rotate through the class to encourage students to move quickly through their experiment and to make detailed drawings of their results. Groups that finish early can try to measure the speed of the water in the tub with and without the landform. To do this, they'll have to time a small fish food flake as it travels from one part of the tank to the back. They will need to measure the distance the flake traveled and the time.

9) Once the students have completed the experiment and cleaned up, have them respond to the reflection questions. This can also be a homework assignment.

10) Begin the class discussion by asking students to list strengths and weaknesses of their model as compared to real deep-ocean currents. List these so everyone can see them. Refer to this list as needed during the remaining discussion. Ask the class if they can formulate some generalizations about the effects of deep ocean currents.

Push students to give reasons or evidence from their experiment for their generalizations. The following statements are examples of some generalizations.

- Currents tend to speed up around landforms.
- More particles settle where there is no current.
- Very little settles where there is a current.
- Things that settle on the top of a landform tend to stay there.
- Particles do not settle in a valley with a current going through it.
- A current will form through a valley as it goes around some type of mound or hill.

11) Project the Challenge Scenario bathymetry map. Ask students where they expect to find higher currents and why. Have them discuss this in their small groups first. You may want to provide maps for each group and have them use arrows to show current directions on the map. Ask the class for ideas. Encourage them to support their ideas with reasons based on their observations. Allow different groups a chance to rebut a different group's ideas when they vary. Encourage discourse and evidence-based argument. Then **show them there is a fairly strong current flowing from the bottom, right-hand corner of the map across and up through the valley to the upper left-hand side of the map.** Discuss how the currents could influence the habitat on the bottom of this section of the Gulf. Where might hard surfaces be exposed? Where would food carried in the water be more available? Where would the conditions be best for *Lophelia* colonies to survive? Have students support their ideas with reasoning.

12) To pull all the ideas from this lesson together, ask students to draw a comic or story board depicting the effects of deep ocean currents on *Lophelia*. Encourage them to be creative, yet accurate in their portrayal of the biology of coral polyps (from lesson 3) and the influence of currents on the reproduction and survival of the polyps. A rubric is included to give to the students. Post the comics in the classroom once students have handed them in. If possible, assign this as homework rather than using class time to complete the assignment.

The "Me" Connection

Life above sea level is impacted by air currents, rather than water currents. We call air currents "wind." Describe how winds affect several different terrestrial organisms. Students could choose to describe the effects of wind on certain trees or plants, migrating birds, and them and their family. Have they ever experienced a power outage because winds blew down power lines or trees fell on power lines?

Assessment

Use the comic strip to assess student understanding of the effects of ocean currents on *Lophelia* distribution and survival. The rubric will help assess how strong of an understanding students have of the relationship.

Extensions

Read the essay "Currents in a Cul-de-sac" that describes surface currents and deep-water currents in the Gulf of Mexico, http://oceanexplorer.noaa.gov/explorations/02mexico/background/currents/currents.html What are some of the obstacles to scientists wishing to learn more about deep currents in the Gulf of Mexico? Which types of currents in the Gulf, deep or surface currents, appeared to have the greatest impact on the spread of oil after the Deep Water Horizon oil spill?

Multimedia Discovery Missions
http://oceanexplorer.noaa.gov/edu/learning/welcome.html
Click on the links to Lessons 3, 5, and 6 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program
http://oceanexplorer.noaa.gov/edu/curriculum/section3.pdf and http://oceanexplorer.noaa.gov/explorations/02arctic/background/education/media/arctic_c_events.pdf - These are alternative lessons on ocean currents. The first one is a general lesson on currents. It uses an experimental set-up that is more elaborate than the one described in this lesson. The second one is focused on currents caused by differences in water density in the Arctic Ocean.

Deep Ocean Currents Experiment   Name:____________

Experimental Set-up
(Draw a diagram of your experimental set-up with tub, siphon, 1000mL beaker, etc)

Model	Real World	...because
The **tub of water** is like		because they both have large volumes of water.
The **fish food flakes** are like		
	deep ocean currents	

List the type of landforms you can test in your model ocean. Circle the one you will test.

In the space below, draw the type of ocean bottom landform you will test as it will look in your model ocean.
Side View: Top View:

Investigative Question: What is the effect of different landforms on the distribution of particles (fish food flakes) that fall through the water from the surface when there is a current on the bottom?

Hypothesis:

Procedures:

1. Fill your tub half full of water. Mark the water level on the outside of the tub using a wax pen or marker. Fill your beaker (or other container) with 1000mL of water.
2. Practice creating a current in the tub without the landform. Sprinkle half a teaspoon of fish flakes across the surface so they are distributed as evenly as possible. Let them float for 30 seconds. Then, practice poking them so they fall to the bottom.
3. Conduct the experiment. Try to do everything exactly the same way each time (sprinkling the fish flakes evenly across the surface, poking the fish flakes so they sink, holding the tube in the same place to create a current).
4. Complete the table below using words and pictures to show where the fish flakes land on the bottom under each condition.
5. Clean up your materials when you are finished. Answer the reflection questions below.

Distribution of Fish Food Flakes (use words and pictures to show their location)

Landform	No Current	Current
Flat Bottom		

Reflection Questions:

1. Describe the distribution of the fish food flakes when there is **no current** in the tub.

2. Describe the distribution of the fish food flakes when there **is a current** in the tub.

3. Imagine that your model ocean has *Lophelia* corals somewhere on the bottom. How might <u>deep ocean currents</u> affect:

   a. availability of food

   b. sexual reproduction

   c. formation of new colonies

3. How well do you think you understand deep ocean currents after completing this activity?

4.What questions do you have about deep ocean currents?

Assignment: Create a comic strip or storyboard that illustrates possible effects of currents on *Lophelia.*

Rubric for Comic Strip

	4	3	2	1
Content	Includes everything in Level 3 plus: __ Describes the biology of *Lophelia* in relationship to the effects of currents (for example, feeding, sexual reproduction, exchange of Oxygen and Carbon Dioxide)	__ Shows effects of currents on the dispersal of larvae __ Shows effects of currents on availability of food __ Shows effects of currents on the presence of hard surfaces __ Content is accurate	Omits 1 or more of the criteria in Level 3	Omits 2 or more of the criteria in Level 3
Presentation	__ Includes color __ Neatly done __ Easy to read	__ Easy to read	Not neatly done	Not easy to read
Due Date	__ Turned in on time	__ Turned in on time	__ Turned in on time	Turned in late

(Optional)

Investigative Question: What is the effect of different landforms on the speed of water flowing around them?

Hypothesis:

Procedures:

1. Measure a distance from just in front of the tube creating the current to almost at the back of the tub. Mark this distance on the side of the container or on a piece of paper that you put under the tub.
2. Use the stop watch to measure the length of time it takes a small particle of fish food to travel the distance.
3. Calculate the speed of the particle by dividing the distance by the time.

Speed=distance (cm)/ time (sec)

Speed of Water

Landform	No Current	Current
Flat Bottom		

Reflection:

1. Where is the speed of a particle the fastest around the landform you created?

2.Where is the speed of a particle the slowest around the landform you created?

Lesson 6 - Living in *Lophelia's* Neighborhood

Focus
In this final lesson, students explore ways to study food webs in the *Lophelia* community, and learn how stable isotope data are used to infer trophic relationships.

Grade Level
9-12 (Biology/Earth Science)

Focus Question
How does the community of organisms living near and within *Lophelia* reefs obtain energy? Does a deep-sea *Lophelia* community obtain energy from the surface (photosynthetic primary productivity) or because it co-occurs with seep communities, is the energy from chemosynthetic primary production?

Learning Objectives:
- Students will understand that *Lophelia* is known as a foundational species because it creates a habitat for many other species;
- Students will be able to create a preliminary food web of a *Lophelia* community based on prior observations from *Lophelia* reefs;
- Students will understand how stable isotope analysis can be used to infer trophic relationships for key organisms;
- Students will make corrections to their preliminary food webs based on conclusions from the stable isotope data;
- Students will be able to identify the source of energy for the food web as the sun and clarify the connection between producers in the photic zone and *Lophelia* communities (drift as well as organisms that move between the surface and the bottom on a regular basis).

Ocean Literacy Essential Principles and Fundamental Concepts
5 – The ocean supports a great diversity of life and ecosystems.
A. Ocean life ranges in size from the smallest virus to the largest animal that has lived on Earth, the blue whale.
D. Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.
G. There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, methane cold seeps, and whale falls rely only on chemical energy and chemosynthetic organisms to support life.
7 - The Ocean is Largely Unexplored
B. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.

Materials
- *Living in Lophelia's Neighborhood* PowerPoint

- Copies of “Living in *Lophelia’s* Neighborhood” Student Handout; one per student
- Paper for drawing food webs

Audio-Visual Materials

- Computer and projector with internet access

Teaching Time

One to two 45-50 minute class periods

Seating Arrangement

Groups of 3-4 students

Key Words

Lophelia
Habitat
Community
Foundation species
Food web
Trophic level
Stable Isotope

Background Information

So far in this unit, students have been focusing on *Lophelia* as an organism. In this lesson, students are introduced to the idea that *Lophelia* provides habitat for other deep-sea organisms, and in fact is considered a **foundation species.** A foundation species as defined by Dayton (1972) is “a single species that defines much of the structure of a community by creating locally stable conditions for other species, and by modulating and stabilizing fundamental ecosystem processes.” In this lesson, students consider that organisms form communities for a number of reasons including access to food, and then they explore the food web associated with a community around *Lophelia pertusa.* They are introduced to various ways scientists determine what organisms eat, keeping in mind the challenges of studying a seafloor ecosystem. They are introduced to the relatively new approach of using stable isotope analysis to determine food web relationships. Two examples are provided that illustrate carbon and nitrogen isotope data interpretation. Students participate in an interactive PowerPoint presentation and analyze a dataset showing three species’ stable isotope values. At the conclusion of the lesson, students are asked to revisit their initial assessment of *Lophelia* communities food webs, and learn that while we have determined some things about these deep-sea communities (e.g., that primary production is photosynthetic-based, and that corals feed at multiple trophic levels), we still have a great deal to learn about these communities. Students will also discuss how these deep sea communities are connected with the rest of the marine ecosystem.

Reference:

Dayton, P. K. 1972. Toward an understanding of community resilience and the potential effects of enrichments to the benthos at McMurdo Sound, Antarctica. In: Proceedings of the Colloquium on Conservation Problems in Antarctica. Allen Press, pp. 81-95.

Learning Procedure

1) A narrated PowerPoint (PPT) and 4-part Student Handout are provided to structure this lesson. Give each student a copy of the PPT, giving students time to work on each part of the handout as you proceed through the PPT. Notes from the PPT are included on the slides and also below; however because some of the slides are self-explanatory, not *all* slides have narration. A warm-up exercise is also provided on the Student Handout. It asks students to recall and draw what they understand about atoms and isotopes. Pick one of the atoms to have students draw.

2) **Part 1: Tools to Study a Community's Food Web (slides 1-8).** The PPT opens by introducing the idea that students will now be considering *Lophelia* communities, rather than focusing on *Lophelia* as a single organism. Begin be explaining the concept of a foundation species, and ask students to consider ways in which other organisms rely on *Lophelia*. Slide 2 introduces reasons why organisms form communities. We will focus the trophic structure/relationships within a community.

3) On slide 3, students are asked to focus specifically on the food web of *Lophelia* communities. Using their handout, have students work in groups to create a food web of the organisms shown in the PPT. They are not expected to *know* who eats whom but to use their prior experience and best guesses to create the food web. If they flounder, suggest that they look at the organism's morphology as a way to infer what it eats

4) Have each group briefly report their food web. As students are reporting their ideas, ask students to explain how they could actually determine who eats what, using examples from their food webs. For example, if they said "crab eats fish," ask them how they could determine this or what evidence would they look for to support this assertion. Have them record these ideas in their handout, in question 2. Also ask them what they think is at the base of the food web. Brainstorm a list of possibilities. Remind students that these are communities located on the seafloor, hundreds of meters below the photic zone.

5) Next, using the PowerPoint slides 4-8, explain the various methods scientists have used to determine what an organism eats, allowing students time to take notes on their handout.

6) **Part 2: Carbon Isotope Analysis (slides 9-24).** At this point, introduce the concept of using stable isotopes as a way to infer trophic level. An example is provided to illustrate how carbon isotope analysis was used to infer primary food source for different populations of cattle, one in Britain that foraged on grass and another in Brazil that was fed corn. Give students a few minutes to discuss with their groups what they think caused the difference in carbon isotope ratios.

7) **Part 3: Nitrogen Isotopes & Trophic Levels (slides 25-27)** The second example illustrates how nitrogen isotope analysis is used to determine trophic levels. Hair samples taken from vegans and from meat-eaters show different N isotope values reflecting the fact that the meat-eaters are consuming organisms from higher trophic levels than vegans who eat only plants. Again, give students a few minutes to

discuss with their groups what they think accounts for the difference before revealing answers in the following slides. *(20 minutes)*

8) **Part 4: Sorting out *Lophelia's* Food Web (slides 28-35).** In this part, students are asked to consider how all of this relates to understanding the food web in a *Lophelia* community, and are introduced to a dataset provided by Dr. Erin Becker who studies food webs in deep-sea ecosystems. After presenting the three organisms, give students time to interpret the dataset provided (slide 29). Note, you may have to help students read the graph, noting that now we see both C isotope AND N isotope data on the same graph, ^{13}C on the x-axis and ^{15}N on the y-axis. You should also remind students that each point represents one individual, either a crab, hydroid or coral polyp. You may also want to point out that the sample size is small because of the challenges of collecting organisms from this environment. Give students 10 minutes to come up with several interpretations of the data.

9) Use slides 30-33 to lead a class discussion of the results.

10) The final part of this lesson asks students to apply this new understanding of trophic relationships between *Lophelia*, hydroids and *Munidopsis* to the larger *Lophelia* community. Slide 34 shows the original set of organisms. Give students another 5-10 minutes to re-arrange these organisms in a food web organized by trophic level, given what they now know. Ask students to include notes justifying why they placed each organism where they did, including stating when they do not know.

11) Have student groups present their revised food webs and lead a class discussion with the following questions:

    a. Which organisms are at the lowest trophic level? Are these primary producers, and if not, where is the primary production coming from in this ecosystem. *The lowest trophic level represented in the assemblage of organisms is primary consumer represented by sponges, hydroids and corals. The primary producers are not visible within this ecosystem, but are likely phytoplankton coming from surface waters, along with zooplankton and detritus (e.g., marine snow).*
    b. Which organisms are at the highest trophic level? *Munidopsis and fish*
    c. Are all organisms resident or endemic to the *Lophelia* community? *It is likely that the fish are NOT resident but come and go from the community and have a much larger range. The other species shown here are either sessile or, in the case of the crab, do not range far and may be considered endemic to Lophelia communities.*
    d. How does this community interact/interface with the larger marine ecosystem? *Fish are visitors, possibly using this habitat for feeding or protection. Most importantly, the primary base of the food web comes from surface waters, or other detritus in the water column.*
    e. How important do you feel these deep-sea coral communities are? *Answers will vary.*

The "Me" Connection

Students could develop a food web for their class, exploring where most of the food eaten falls within this web (trophic level), and where it comes from (distance, country, etc). Students could also explore the concept of "eating locally" and discuss the pros and cons for doing so.

Assessment

Students will reveal their understanding through class discussions. You may choose to have students turn in their answers to the discussion questions to assess what they have learned.

Extensions

Students could investigate why scientists are establishing Marine Protected Areas for coral habitats, and they could explore whether they feel these MPAs should also apply to deep sea coral communities.

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html
Click on the links to Lessons 3, 5, and 6 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals.

Living in *Lophelia's* Neighborhood, PowerPoint Script

Slide 1
So far in this unit, we've been focusing on *Lophelia* as an organism. But this organism is particularly important because of the habitat is provides *other* organisms and because of the community that forms around *Lophelia* colonies. We refer to *Lophelia* as a **foundation species** because without it, the other organisms would not be there or form the community there. This lesson focuses on the COMMUNITY living among *Lophelia* and on how we determine the trophic relationships.

The definition of a foundation species, according to Dayton, is "a single species that defines much of the structure of a community by creating locally stable conditions for other species, and by modulating and stabilizing fundamental ecosystem processes."
Dayton, P. K. 1972. Toward an understanding of community resilience and the potential effects of enrichments to the benthos at McMurdo Sound, Antarctica. In: Proceedings of the Colloquium on Conservation Problems in Antarctica -Allen Press, pp. 81-95.

Slide 2
As you probably recall from looking at the photomosaics in the first lesson, there are quite a few organisms living among *Lophelia*, more than we may at first have noticed. In addition to the hard coral, *Lophelia pertusa*, we saw a few different types of soft corals, 2 different crab species, lots of hydroids, crinoids, sponges, anemones, bacteria, tubeworms, and even fish.

When thinking about communities, it's useful to start by thinking about **why organisms live together**. Sometimes organisms live around another for shelter, sometimes to find others of its own kind for mating, and sometimes because other organisms provide food. Let's look at this last reason in some detail.

What do each of the organisms in the *Lophelia* community eat?

Slide 3
Here are typical organisms found in and among a *Lophelia* colony. Can you put these six organisms together in some sort of food web? Take about 5 minutes to discuss with your group.

Note to teacher: it is not expected that students will be able to construct a food web based on what they know so far. Even scientists don't know how all of these organisms fit together in a food web.

Slide 4
Ok, but HOW do we know who eats whom?

Look at this crab. How could you tell what this crab eats? One of the first ways to determine this is to OBSERVE the crab in its natural environment. You could do this in person by swimming down there (well, in shallow water at least) and watching, or perhaps photographing. But you have to be careful not to disturb the crab or you may not catch it actually eating something. You could leave a camera down there and hope that the crab eats something within the field of view of the camera.

But actually, observing the crab in action is tough to do. What other ways can you think of?

Slide 5
Well, another way is to collect the crab and dissect it to see what's in its stomach. But this too has its problems, particularly if the crab had already digested its meal, or chewed it up beyond recognition. And you have to sacrifice the animal to determine its meal.

Slide 6
A third way is to look at the animal's shape or morphology and infer what it might eat based on its shape. For example, look at this crab's claws. It looks like the pinchers would be good for catching prey or picking out food from substrates. But this approach does not tell you what the crab *actually* eats.

Slide 7
And then what about really small organisms like the hydroids in this community. A careful examination of its morphology (using a microscope) reveals that hydroids, a cnidarian, have stinging cells that it uses to capture prey. But again, it is difficult to determine whether the hydroid is catching and eating things like bacteria or perhaps larger plankton.

Slide 8
So scientists tend to use all of these methods together, and still it can be difficult to determine what an organism eats. This is especially challenging in the deep-sea because it's difficult to easily observe organisms down there, and even if you sample them, they often die on the way to the surface. And the morphology only narrows down the possibilities to TYPE of food, not to the particular species.

So we need another tool!!

Slide 9
So, what do you think this other tool might be. Here's a hint: "You are what you eat!"
Think about that. What does it mean?

Well, all animals eat to obtain energy, in the form of basic building blocks called amino acids, made up of elements carbon, nitrogen, oxygen and hydrogen among others. So for example, the very carbon that is in the grass get eaten by the cow and metabolized into the cow's muscle, and this is then eaten as hamburgers by us! Wow.
Ok, you probably knew that already.

Slide 10
But what you may not know is that each of these elements (carbon, nitrogen, oxygen, etc) have a particular chemical signature that show the proportion of stable isotopes in each element.

Slide 11
Isotopes.

Ok, let's back up and recall some basic chemistry. As you will recall, atoms are made up of protons, neutrons and electrons. Each element has a unique number of protons, but the number of neutrons may vary. Isotopes are atoms of the same element (that is, with the same number of protons in their atomic nucleus), but having *different* numbers of neutrons. Here's Carbon, in two different forms. It has 6 protons but it can have 6 or 7 or 8 neutrons, making the atomic mass number of carbon 12, or 13, or 14 respectively depending on the number of neutrons. This diagram shows only ^{12}C and ^{13}C, the two stable forms of carbon.

Almost 99% of the carbon in the earth's atmosphere is ^{12}C. The remaining percent is made up of ^{13}C and ^{14}C, - this last isotope is radioactive.
Note to teachers: Good sites with additional information:
http://archaeology.about.com/od/stableisotopes/qt/dummies.htm

Slide 12
And as you may guess, some isotopes are heavier than others because of the differing number of neutrons in the nucleus.

Which is heavier, ^{12}C or ^{13}C??

Slide 13
That not all isotopes are treated equally is a key concept. In fact, many metabolic processes that require energy prefer to use the lighter isotope.

Slide 14
So, in food webs, there tends to be more ^{12}C incorporated into the animal's tissue than in the plant tissue that it ate.

Slide 15
So let's look at an example.

The proportion of ^{13}C in air is 1.11%, not a lot since most of it is ^{12}C. But when plants take up carbon in the form of CO_2 to use in photosynthesis, plants tend to use the lighter isotope – ^{12}C – resulting in a different proportion of ^{13}C in their tissues than what is in air. What's more, different plants use isotopes differently. Wheat uses even less ^{13}C than corn.

Note to teacher: Two points on this slide are:
1) The proportion of isotope changes slightly from the original (CO_2 in air **1.11%**) to the product (in corn **1.10%** or wheat **1.09%**) and
2) Different plant types (C3 vs C4 plants) tend to use the stable isotopes differently (see extra notes below).

These known differences leave a chemical signature that we can use to infer "food source".

EXTRA NOTES: Wheat is a C3 plant and uses the Calvin-Benson process. Corn is a C4 plant and uses the Hatch-Slack process to convert CO_2 to organic compounds.

From http://www.uga.edu/sisbl/stable.html : "C3 plants convert atmospheric CO_2 to a phosphoglycerate compound with three C atoms while C4 plants convert CO_2 to dicarboxylic acid, a four-C compound. Carbon isotopes are strongly fractionated by photosynthesis and the C3 and C4 processes involve different isotopic fractionation, with the result that C4 plants have higher delta13C values ranging from -17‰ to -9‰ with a mean of -13‰ relative to PDB, while C3 plants show delta values ranging from -32‰ to -20‰ with an average value of -27‰. Most terrestrial plants are C3, all forest communities and most temperate zone plant communities of all kinds being dominated by C3 plants. The native plant populations of North America and Europe are almost exclusively C3. Over 80% of crop plants are C3. C4 plants are characteristically found in hot, arid environments: a selective advantage of C4 photosynthesis is more efficient use of water. Some crops of immense importance are C4 plants: maize, sorghum, millet, and sugar cane."

Slide 16
Although these are small differences, they do provide us with a chemical signature.

To see this difference more easily, we typically convert the proportion to magnify the difference. The symbol **δ ^{13}C** is pronounced "delta c 13**."**

Notice that as the proportion of the heavier isotope goes down, the conversion results in a more negative number (e.g., wheat has the lowest proportion of ^{13}C, or the least amount of the heavier isotope, and it has the most negative number).

Slide 17
OPTIONAL SLIDE
Note to teacher: The conversion is provided just for completeness but is not necessary for students to understand.

Slide 18
So, δ c13 of air is -7, δ c13 of corn is -12, and δ c13 of wheat is -25.

Notice that as the proportion of the heavier isotope goes down, the conversion results in a more negative number (e.g., wheat has the lowest proportion of ^{13}C, or the least amount of the heavier isotope, and it has the most negative number).

Slide 19
Here are actual data showing stable carbon isotope analysis of muscle tissue from cattle from Brazil (in ORANGE) and from Britain (in GREEN). Each dot represents the isotope analysis of one cow - 9 cows from Britain and 9 cows from Brazil total. Notice the distinct difference between the values of carbon isotopes of cows from Britain vs. cows from Brazil. Notice too which cows have a higher proportion of the heavier isotope (the cows from Brazil have more of the heavier ^{13}C isotope).

What accounts for these differences?

Note: these data are taken from:
Heaton K, Kelly SD, Hoogewerff J, and Woolfe M. 2008. Verifying the geographical origin of

beef: The application of multi-element isotope and trace element analysis. *Food Chemistry 107*, 506-515.

Slide 20
Remember it has to do with the expression "You are what you eat!"
Cows in Brazil feed on corn primarily. Cows in Britain graze on grass and fodder, similar to wheat. So the carbon isotope signature of corn shows up in the cows from Brazil because that's what they eat. And the carbon isotope signature of wheat shows up in the grass-fed cows.

Slide 21
In general, carbon isotope analysis can tell us what the primary producer was, in this case either corn or grass.

Slide 22
Our simple carbon isotope analysis of beef cattle illustrates that the primary producers in this simple food chain are photosynthesis based, and are either corn or grass primary producers.

But the next important point is that after primary production, the carbon isotope values do not change from one organism to the next in the food web. It's really only the metabolic processes of fixing carbon that uses the heavier or lighter isotopes differently. After that, the proportion stays the same (of CARBON ISOTOPES, but not other isotopes, as we'll see).

So, this is where the expression, "You are what you eat!" comes in.
And it can tell us what your primary producer was.

Slide 23
Of course the same thing applies in ocean food chains.

Slide 24
Cartoon courtesy of Dr. Brian Fry

Slide 25
Not all isotopes act the same. So an isotope analysis of Nitrogen, for example, can tell us other things about the food web. Nitrogen isotopes actually help us figure out trophic relations. This isotope is affected by metabolic processes involved in digestion and excretion. In this case, the lighter isotope is digested and then excreted (in urine) so the remaining tissue actually builds up more of the heavier isotope.

So the higher you go on the food web, the higher your proportion of the heavier isotope, ^{15}N.

Slide 26
Here is another example, this one showing a stable isotope analysis of hair samples taken from two different populations of people – one that eats strictly plant material, and another that eats anything, meat and vegetables. We'll call these meat-eaters. The meat-eaters have a higher ^{15}N isotope value than the vegans. They have more of the heavier nitrogen isotope.

In technical terms, the biochemical processes of the consumer that breakdown protein use the lighter isotope (^{14}N) which are then excreted at a higher rate than the heavier isotope (^{15}N). This leaves the consumer's tissue enriched in the heavier isotope. So the consumer has a higher ^{15}N ratio than that of what it consumed.

Note to teacher: Notice that the Nitrogen isotope values are now on the y-axis. This is done only because of convention – as we get further in our analysis and combine the N and C analysis, we'll keep C on the x-axis and N on the y-axis.

Slide 27
AND THIS CONTINUES UP THE FOOD CHAIN.
The nitrogen isotopic ratio increases by a consistent amount with each trophic level (e.g., +2 ‰ to +5 ‰). The next consumer has a higher ratio than what it consumed, etc..
The cool thing is that this can be used to indicate trophic level, such as primary producer, consumer, secondary consumer, top predator.

The general rule for N is "You are what you eat +3"

In other words, a consumer has a Nitrogen isotope value that is 3 units higher than the organism it eats.

Slide 28
So how does this apply to our study of the *Lophelia* community?

Let's look at just a simple subset of data from Dr. Erin Becker, from Pennsylvania State University, who studies the food web dynamics of deep sea ecosystems like these coral communities and the tubeworm and mussel communities of the Gulf of Mexico, and hydrothermal vent ecosystems.

In the following slides, we will look at carbon and nitrogen isotope data from three species in the *Lophelia* community: a crab, hydroids, and the coral itself and see if we can discern any patterns of who ate whom.

Slide 29
Here are the data. Each point on the graph represents data from one individual. Notice that we've combined the carbon and nitrogen data on one graph. So for example, one red square (one crab) has a carbon isotope ratio and a nitrogen ratio. As expected there is variation in these values for each individual since they are each eating different things.

What can you see?

Note to teacher: be sure to help students read the graph. For example, there are three Lophelia individuals, with an average ^{13}C value of around -22, and an average ^{15}N value of 11. The Hydroids have a range of ^{13}C values from -17 to -21, but a very consistent ^{15}N value of around 8. And the crabs have the greatest variation, most likely because they eat all kinds of things. Give students time to discuss what they see.

Slide 30

Here are the results you can see in this dataset:

Hydroids are feeding at the same trophic level whereas *Munidopsis* crabs are feeding at a higher trophic level.
Lophelia are feeding at two different trophic levels, one similar to Hydroids and the other similar to *Munidopsis*

Hydroids are likely feeding on small organic particulate matter, possibly plankton and detritus raining down from the surface or being stirred up from the sediment by bottom currents.
Lophelia is probably eating both organic particulate matter (like the hydroids) AND larger organisms like copepods swimming around and feeding on smaller particulate matter.
Munidopsis are eating other critters.

This slide shows the range of delta c13 values, all in the range of photosynthesis-based Carbon isotope signatures. This *Lophelia* community is based on the SUN!

Extra Note: Some seafloor communities are based on chemosynthesis rather than photosynthesis. Chemosynthesis-based primary production comes from the use of hydrocarbons seeping up from under the seafloor. *In the case of deep sea ecosystems (e.g., tubeworm communities) which are known to rely on microbes fixing carbon through chemosynthesis and using methane and other hydrocarbons from the seeps as the carbon source, the C isotope signature is very different than one from photosynthetic processes, typically much more negative. There is an optional slide at the end of this presentation showing typical* ^{13}C *values.*

Slide 31
This slide shows the delta N15 values for hydroids. Since they are all so similar, it appears that hydroids are feeding at the same trophic level. Hydroids are likely feeding on small organic particulate matter, possibly plankton and detritus raining down from the surface or being stirred up from the sediment by bottom currents.

Slide 32
Munidopsis (crabs) have a higher delta N 15 than hydroids, indicating that they are likely consumers feeding at a higher trophic level. In other words, *Munidopsis* are eating other critters.

Slide 33
Here we see *Lophelia* N values at two different levels.

Lophelia is probably eating both organic particulate matter (like the hydroids) AND larger organisms like copepods swimming around and feeding on smaller particulate matter. One individual probably ate the organic particulate matter only, and the other two individuals at things like copepods.

Slide 34
So NOW what can we say about our food web? Can you place these common *Lophelia* community organisms in different trophic levels?

Slide 35
Note to teacher: this slide is animated, bringing in one species at a time and placing it according to trophic level. Notice the food web does not start with producers.
This is an important point. The base of this food web is likely coming from primary production taking place at the surface and then "raining" down through the water column. Unlike shallow water corals that have symbiotic algae that produce food for them, these deep-sea corals feed by eating particles in the water column. And all of that originated at the surface.

So, we know that the deep-water coral communities rely on sunshine and photosynthetic processes. And we know approximate trophic level for many organisms. But exactly who eats what is still unknown!

There are still many many unknowns.

Slide 36
Acknowledgements: Much of the content in this presentation was prepared by Liz Podowski, formerly of Dr. Chuck Fisher's Lab at PSU, and was drawn from work by Dr. Erin Becker. Erin also provided assistance reviewing the accuracy of the overall presentation. Both have been invaluable in the development of this lesson.

Slide 37
OPTIONAL SLIDE on CHEMOSYNTHESIS
Note to teacher: although this is a complicated slide, it points out an important difference for seafloor ecosystems that get their energy from sources other than the sun. Many seafloor ecosystems use CHEMOSYNTHESIS as the basis of the food web, and this results in a very different carbon isotope signature, one with a much lower ^{13}C number than photosynthesis based ecosystems. ***In the case of deep sea ecosystems (e.g., tubeworm communities) which are known to rely on microbes fixing carbon through chemosynthesis and using methane and other hydrocarbons from the seeps as the carbon source, the C isotope signature is very different than one from photosynthetic processes.***

The carbon isotope composition of a primary producer depends largely on **the carbon input** (i.e.: the source of inorganic carbon such as carbon dioxide or hydrocarbons) and **the pathway the organism uses to fix inorganic carbon** into organic carbon. Carbon fixed through a photosynthetic pathway can range in stable isotope composition from about -12 to -25. This variation is partly a result of the diversity of photosynthesis - not all plants perform photosynthesis exactly the same. C3 photosynthesis fractionates carbon differently than C4 photosynthesis. Because carbon is fractionated differently in each of these forms of photosynthesis, stable isotope analysis helps us to differentiate between the types of photosynthesis that may be supporting a food web.

Living in Lophelia's Neighborhood

Name: ___________

Warm-up:

Draw a diagram of one atom of either ^{12}C, ^{13}C, ^{14}N, or ^{15}N:
(your teacher will tell you which one to draw.)

$^{12}_{6}C$	$^{13}_{6}C$	$^{14}_{7}N$	$^{15}_{7}N$

Part 1: Tools to Study a Community's Food Web (Slides 1-8)

1. Using your prior knowledge of cold-water coral communities, construct a food web of the *Lophelia* community. Use these organisms: *Lophelia* coral, sponge, crab, hydroids, fish, and brittle stars. *(Let the pictures in the third slide help you.)*

2. As an ecologist, how could you determine who eats whom? What could you do?

My Ideas	**Techniques Used by Ecologists** *(from slides)*

Part 2: Carbon Isotope Analysis (Slides 9- 24)

3. Predict whether the following statements are True or False. Then, as you go through the slides with your teacher, give your final answers and then reword any false statements so they are true.

Prediction (T or F)	**Statement**	**Final Answer**
	A) Scientists have tools that can measure the amount of Carbon 12 (^{12}C) and of Carbon 13 (^{13}C) in different organisms.	
	B) Plants use equal amounts of ^{12}C and of ^{13}C during photosynthesis.	
	C) Plants are known as consumers and animals as primary producers.	
	D) Scientists can analyze a steak to determine if the cow the steak is from ate more corn or grasses (like wheat).	
	E) Carbon 13 (^{13}C) values give us information on the source of carbon for different organisms.	

4. Listed below are different living and non-living objects that contain Carbon and its average converted value of ^{13}C, called $\boldsymbol{\delta}^{13}C$. Put the objects in order from highest proportion of ^{13}C to lowest proportion of ^{3}C. *(Note – use after slide 15 but before looking at slide #19)*

   Air: $\boldsymbol{\delta}^{13}C = -7$
   Carbon stored in the soil: $\boldsymbol{\delta}^{13}C = -23$
   Corn: $\boldsymbol{\delta}^{13}C = -12$
   Cow in Brazil: $\boldsymbol{\delta}^{13}C = -11.6$
   Cow in Britain: $\boldsymbol{\delta}^{13}C = -25.5$
   Lophelia: $\boldsymbol{\delta}^{13}C = -22$
   Wheat: $\boldsymbol{\delta}^{13}C = -25$

   Explain how you decided which item had the smallest proportion of ^{13}C .

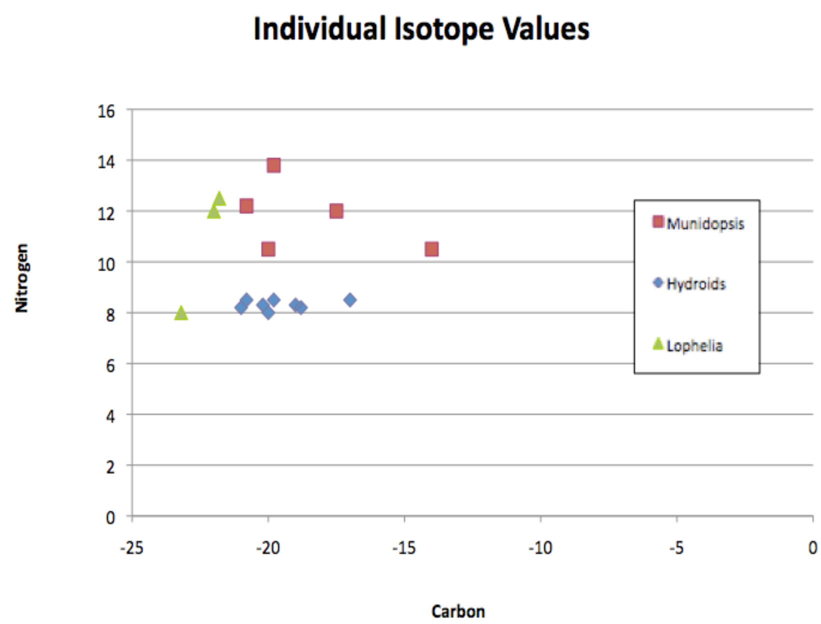
5. Explain what the phrase **"You are what you eat"** means using Carbon as an example.

Part 3: Nitrogen Isotopes & Trophic Levels (Slides 25-27)

6. In your own words, explain why it's necessary to use BOTH Carbon and Nitrogen isotope values to figure out "who eats what" in a food web. Think about what Carbon isotope values tell us, and then what Nitrogen isotope values tell us.

Part 4: Sorting out *Lophelia's* Food web (Slides 28-35)

1. Using this graph, write down at least three trophic relationship patterns you see in this dataset.



2. After reviewing the slides and class discussion, record any new or revised patterns you now see in this dataset.

3. In the *Lophelia* community food web, …

a. which organisms shown in the slides are at the lowest trophic level?

b. who are the primary producers and where are they in the marine environment? How do they get to the *Lophelia* community?

c. which organisms are at the highest trophic level?

d. which organisms are full-time residents vs. those that are visitors?

e. how does this community interact with the larger marine ecosystem?

f. how important do you feel these deep coral communities are?