


Image captions/credits on Page 2.

lesson plan

Lophelia II 2012:
Deepwater Platform Corals Expedition

Not Quite Macro, Not Quite Micro

Focus
Meiofauna associated with *Lophelia* coral reefs

Grade Level
7-8 (Life Science)

Focus Question
How are abundance and biodiversity of meiofauna affected by associations with *Lophelia* coral reefs?

Learning Objectives
- Students will analyze and interpret data on the abundance and density of meiofauna to identify patterns that may be associated with interactions between these animals and nonliving components of *Lophelia* coral reefs.
- Students will construct explanations that describe how changes resulting from the growth of *Lophelia* corals affect the biodiversity of meiofauna in *Lophelia* coral ecosystems.

Materials
- Copies of *Student Handout: Table 1*, one copy for each student group
- (Optional) Copies of *Appendix A*, one copy for each student group

Audio-Visual Materials
- Interactive white board

Teaching Time
One or two 45-minute class periods

Seating Arrangement
Groups of two to three students

Maximum Number of Students
30

Key Words
Lophelia
Meiofauna
Biodiversity

Background Information

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

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

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

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

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

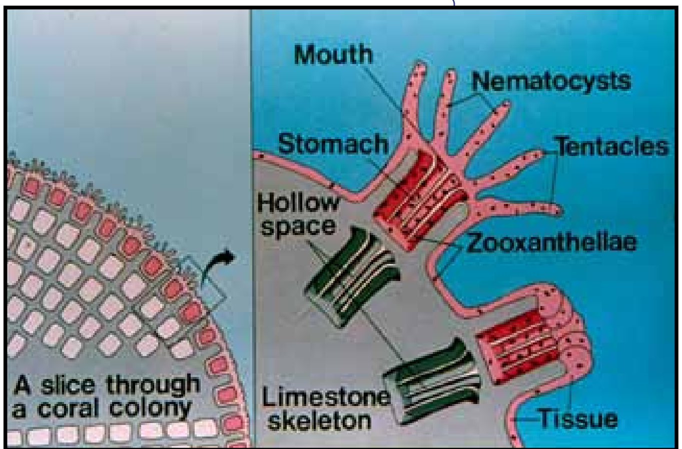
Images from Page 1 top to bottom:
Colonies of *Lophelia* coral with outstretched feeding polyps were discovered on the eastern scarp of the West Florida Escarpment at approximately 400 meters. These corals and Cretaceous rocks hosted crabs and tubeworms (at right). Image courtesy of NOAA *Okeanos Explorer*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

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

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

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

food within the reach of their tentacles. *L. pertusa* feeds on a variety of phytoplankton and zooplankton species, as well as dead materials.



Coral polyp diagram. Courtesy Mel Goodwin.

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

Because *L. pertusa* ecosystems occur in deep water, exploration of these ecosystems is usually done with remotely operated vehicles. These vehicles typically have video imaging capabilities, and sometimes are also able to collect specimens for laboratory study. Most investigations of *L. pertusa* ecosystems have focused on organisms that are visible in video imagery, but these ecosystems also include many other species. Meiofauna are animals that are smaller than 0.3 mm


A microscopic image of various meiofauna. The red dots are copepods, and the long worms are nematodes. The pink worm (along the left edge) is a juvenile polychaete worm. Image courtesy of Julia Zekely, University of Vienna.
http://oceanexplorer.noaa.gov/explorations/07mexico/logs/june27/media/meio_600.html

(the exact range of sizes that correspond to microfauna, meiofauna, and macrofauna often varies from one scientist to another). The accumulation of rubble and sediments in *L. pertusa* reefs provides many different habitats for meiofauna species, and these species make a significant contribution to the biodiversity of these ecosystems.

In this lesson, students will analyze data from an investigation of meiofauna associated with *Lophelia* coral reefs, and make inferences about how interaction with reef structures affects meiofaunal biodiversity.

Learning Procedure

1. To prepare for this lesson:
   Review the introductory essay for the *Lophelia* II 2012: Deepwater Platform Corals Expedition, and the background essay on measuring growth rates in *L. pertusa* (http://oceanexplorer.noaa.gov/explorations/12*Lophelia*/welcome.html). Download one or more images of a *Lophelia* coral colony from this Web site, or from the Photo and Video Log for the *Lophelia* II 2010: Oil Seeps and Deep Reefs expedition (http://oceanexplorer.noaa.gov/explorations/10*Lophelia*/logs/photolog/photolog.html). Be sure to select an image that includes several species in addition to *L. pertusa*, and that shows the branched growth form of this coral (e.g., http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/hires/lophelia_community_hires.jpg).

2. Introduce the *Lophelia* II 2012: Deepwater Platform Corals expedition and describe deepwater coral communities. Be sure to mention the connection to hardgrounds and hydrocarbon seeps, and say that the presence of deepwater coral communities is often an indication that petroleum deposits may be nearby. Emphasize that a central purpose of this expedition is to provide information needed to protect these deepwater coral ecosystems. Tell students that while deepwater coral reefs were discovered in the Gulf of Mexico nearly 50 years ago, very little is known about the ecology of these communities or the basic biology of the corals that produce them.

   Briefly describe the process of reef development, which begins with the settlement of one or more coral larvae that reproduce asexually to eventually form large colonies that provide habitats for many other species. When portions of the colony die, they are reduced to rubble that forms additional habitats at the base of the colony and adds stability to the reef structure.

3. If necessary, review the concept of biodiversity. Be sure students understand that biodiversity describes the variety of species found in Earth's ecosystems, and that numeric measures of an ecosystem's biodiversity are often used as a measure of its health. The concept of diversity includes the abundance of species in a given area as

These small oil droplets have seeped through the sediment and adhered to the top of methane hydrate. This image was taken at a depth of less than 1,000 m in the Gulf of Mexico. Image courtesy of Ian MacDonald, Texas A&M-Corpus Christi. http://oceanexplorer.noaa.gov/explorations/06mexico/logs/may08/media/oil_on_methane_600.html well as how evenly individuals within the area are divided among these species. A community that has more or less equal numbers of individuals within the species present is usually thought of as more diverse than a community that is dominated by one species. For example, samples from two separate communities might each contain the same seven species, with distribution of individuals as shown in Table A:

Table A

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

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

So, biodiversity includes two concepts:
- Species Diversity – the number of species in the environment; and
- Species Evenness – a measure of how evenly individuals are distributed among these species.

Appendix A describes a numerical index that combines these concepts into a single number. Depending upon students' mathematics skills, you may wish to discuss this index.

Show students an image of a *L. pertusa* colony, and ask how many different habitats are included in the image. Students should recognize that the exact number of habitats is difficult to estimate, but is very large because many different-sized spaces are created by the corals' branched growth form as well as by the accumulated rubble and sediments visible at the base of the coral colony and in the foreground. Ask how many species are included in the image. Again, the number is probably quite large, since there are almost certainly numerous microscopic species present in addition to the larger animals visible in the image. Introduce the term meiofauna, and briefly discuss the importance of small animals in ecosystems.

4. Tell students that their assignment is to analyze data from an investigation of meiofauna associated with *Lophelia* coral reef. This investigation (Rees and Vanreusel, 2005) is based on three core samples taken from the Belgica Mound in the Porcupine Seabight, which is an embayment off the southwest coast of Ireland. This mound was constructed by *L. pertusa* and other organisms (such as sponges) that are associated with *L. pertusa* reefs. The core samples were taken from an area of the mound composed of dead coral skeletons that have been degraded by other organisms. Dead skeletons are first colonized by bacteria and fungi, followed by sponges and octocorals that break down the skeleton structure and also fill the gaps between skeletons and branches with sediment. This process of biodegradation produces four distinct habitats within the overall degraded coral community: coral fragments, sponge skeletons, a mixture of particles, and underlying sediment.

   Provide each student group with a copy of *Student Handout: Table 1*, and assign one of the four habitats to each group. If students are not familiar with the invertebrate groups included in the Table, you may want to have each student group make a brief report on one or more of these organisms before proceeding with the rest of the lesson.

   Ask how data in Table 1 could be analyzed to compare the meiofauna biodiversity in the four habitats, and in the overall degraded coral community. At a minimum, students should identify total number of individuals, total number of species, and the relative abundance of individuals (number of individuals of each species divided by the total number of individuals among all species) in each habitat as appropriate measures. If you included a discussion of the Shannon-Weaver information function in Step 3, this measure should be identified as well.

   Have each group make the necessary calculations for their assigned habitat, then post their calculations on a whiteboard or interactive whiteboard. Each group should also prepare a short report in which they construct explanations that describe how the growth of *Lophelia* corals affects the biodiversity of meiofauna.

   Lead a discussion of the pooled results. Refer to Table 2 for calculated values. This should include the following observations:
   - Overall, nematodes, copepods, and nauplius larvae were most abundant, followed by polychaetes, tardigrades, and gastrotrichs.
   - Compared to other species, nematodes were most abundant in sediment habitats; probably because nematodes are long and slender organisms that are morphologically more adapted to moving between sand grains than to crawling over larger surfaces.
   - Coral fragments were the most densely populated habitat, and also had the highest number of taxa.

- The data indicate strong habitat preferences among the meiofauna, since only 12 of the 31 taxa were found in all four habitats. At the same time, few taxa were confined to a single habitat.
- Biodiversity was highest in the coral fragment habitat, and lowest in the sediment habitat.

Have each group present their explanations concerning the effect of *Lophelia* corals on the biodiversity of meiofauna. These may include:

- The growth and biodegradation of *Lophelia* corals produces a very complex structure that provides a wide range of habitats that may be suitable for a similarly wide range of organisms.
- Reef structures resulting from the growth of *Lophelia* corals provide shelter from strong currents and predators.
- *Lophelia* reef structures can trap organic particles that provide abundant food for meiofauna.

The emphasis should be on well-reasoned explanations based on students' analyses of meiofauna data and their overall knowledge about *Lophelia* reefs.

The BRIDGE Connection

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

The "Me" Connection

Have students write a brief essay about why biodiversity of deep coral ecosystems might be personally important.

Connections to Other Subjects

English/Language Arts, Mathematics

Assessment

Student presentations, answers to worksheet questions, and class discussions provide opportunities for assessment.

Extensions

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

Multimedia Discovery Missions

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

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Let's Hit the Slopes!
(from the *Lophelia* II 2010 Expedition)

Focus: Benthic communities on continental slopes in the Gulf of Mexico (Life Science)

Students will describe benthic communities found at selected sites on continental slopes in the Gulf of Mexico, and explain the possible ecological role of at least three species that are characteristic of these communities.

What's So Special?
(from the *Lophelia* II 2010 Expedition)

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

Students will describe the general biology and morphology of Lophelia corals, explain how these corals contribute to the development of complex communities, identify ways in which these corals are threatened by human activities, and discuss ways in which *Lophelia* communities are important to humans.

Corrosion to Corals
(from the *Lophelia* II 2009 Expedition)

Focus: Galvanic exchange and carbonate precipitation (Physical Science/Life Science)

In this activity, students will be able to describe galvanic exchange and explain how this process produces electric currents. Given two dissimilar metals and information on their position in an Electromotive Series, students will be able to predict which of the metals will deteriorate if they are placed in a salt solution. Students will also be able to describe the effect of electric currents on the availability of metal ions, and how this might contribute to the growth of corals on shipwrecks.

Treasures in Jeopardy
(from the Cayman Islands Twilight Zone 2007 Expedition)

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

In this activity, students will compare and contrast deep-sea coral communities with their shallow-water counterparts and explain at least three benefits associated with deep-sea coral communities.

Students will also describe human activities that threaten deep-sea coral communities and describe actions that should be taken to protect resources of deep-sea coral communities.

Other Resources

The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.

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

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

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

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

Rees, M. and A. Vanreusel. 2005. The metazoan meiofauna associated with a cold-water coral degradation zone in the Porcupine Seabight (NE Atlantic). In: A. Freiwald and J.M. Roberts (eds). Cold-water Corals and Ecosystems. Springer-Verlag Berlin Heidelberg. pp 821-847.

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

Standards Correlations

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

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

Objective: Students will analyze and interpret data on the abundance and density of meiofauna to identify patterns that may be associated with interactions between these animals and nonliving components of *Lophelia* coral reefs.

Practices:

4. Analyzing and interpreting data
5. Using mathematics and computational thinking

Crosscutting Concepts:

1. Patterns

Core Ideas:

LS2.A Interdependent Relationships in Ecosystems

Objective: Students will construct explanations that explain how changes resulting from the growth of *Lophelia* corals affect the biodiversity of meiofauna in *Lophelia* coral ecosystems.

Practices:

7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Crosscutting Concepts:

2. Cause and effect: Mechanism and explanation
7. Stability and change

Core Ideas:

LS2.C Ecosystems Dynamics, Functioning and Resilience
LS4.D Biodiversity and Humans

Objective: Students will analyze and interpret data from photographic images and use concepts of proportion and scale to estimate the growth rate of *Lophelia* coral colonies.

Practices:

4. Analyzing and interpreting data
5. Using mathematics and computational thinking

Crosscutting Concepts:

3. Scale, proportion, and quantity

Core Ideas:

LS1.B: Growth and Development of Organisms

Correlations to Common Core State Standards for Mathematics

7.EE – Solve real-life and mathematical problems using numerical and algebraic expressions and equations.

Correlations to Common Core State Standards for English Language Arts

RI.4 – Determine the meaning of words and phrases as they are used in a text, including figurative, connotative, and technical meanings.

W.1 – Write arguments to support claims with clear reasons and relevant evidence.

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

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.
The Earth has one big ocean with many features.
Fundamental Concept h. Although the ocean is large, it is finite and resources are limited.

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.
Fundamental Concept d. Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.
Fundamental Concept e. The ocean is three-dimensional, offering vast living space and diverse habitats from the surface through the water column to the seafloor. Most of the living space on Earth is in the ocean.
Fundamental Concept f. Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is "patchy". Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.

Essential Principle 6.
The ocean and humans are inextricably interconnected.
Fundamental Concept b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.
Fundamental Concept e. Humans affect the ocean in a variety of ways. Laws, regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise

pollution) and physical modifications (such as changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.

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

Essential Principle 7.
The ocean is largely unexplored.

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

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

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

Send Us Your Feedback

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

For More Information

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Credit

Student Handout

Table 1. Numbers of Individual Meiofauna Associated With Degraded Coral Habitats in a Lophelia Reef Complex (based on Rees and Vanreusel, 2005)

	Coral Fragments Number of Individuals	**Sponge Skeletons** Number of Individuals	**Mixed Substrate** Number of Individuals	**Sediment** Number of Individuals
Nematoda	4089	3624	1432	2280
Harpacticoida	1290	497	151	146
Nauplii	630	75	25	67
Polychaeta	585	285	88	79
Tardigrada	178	108	45	19
Gastrotricha	145	25	9	16
Ostracoda	72	18	10	16
Turbellaria	48	5	22	5
Aplacophora	52	0	4	8
Trochophora-larvae	46	0	0	2
Acari	48	15	10	6
Isopoda	18	8	3	1
Oligochaeta	5	5	3	2
Sipuncula	5	3	2	0
Bivalvia	4	0	1	0
Unknown juvenile arthropod	0	0	5	0
Cumacea	1	0	0	2
Kinorhyncha	0	0	0	4
Loricifera	0	0	3	1
Pycnogonida	0	1	3	0
Tantulocarida	3	0	1	0
Chaetognatha	1	0	0	0
Priapulida	1	0	1	0
Tanaidacea	0	0	0	0
Amphipoda	1	0	0	0
Cladocera	0	0	1	0
Echiura	1	0	0	0
Holothuroidea	1	0	0	0
Metazoea	0	0	0	1
Rotifera	0	0	0	1
Zoea	0	0	0	1

Table 2. Calculated Values for Relative Abundance, Number of Individuals, Number of Species, and Shannon-Weaver Diverity Index for Meiofauna Associated With Degraded Coral Habitats in a *Lophelia* Reef Complex

(based on Rees and Vanreusel, 2005)

	Coral		Sponge		Mixed		Sediment	
	Number Individuals	Relative Abundance	Number Individuals	Relative Abundance	Number Individuals	Relative Abundance	Number Individuals	Relative Abundance
Nematoda	4089	0.566	3624	0.7762	1432	0.7872	2280	0.8581
Harpacticoida	1290	0.1786	497	0.1064	151	0.083	146	0.0549
Nauplii	630	0.0872	75	0.0161	25	0.0137	67	0.0252
Polychaeta	585	0.081	285	0.061	88	0.0484	79	0.0297
Tardigrada	178	0.0246	108	0.0231	45	0.0247	19	0.0072
Gastrotricha	145	0.0201	25	0.0054	9	0.0049	16	0.006
Ostracoda	72	0.01	18	0.0039	10	0.0055	16	0.006
Turbellaria	48	0.0066	5	0.0011	22	0.0121	5	0.0019
Aplacophora	52	0.0072	0	0	4	0.0022	8	0.003
Trochophora-larvae	46	0.0064	0	0	0	0	2	0.0008
Acari	48	0.0066	15	0.0032	10	0.0055	6	0.0023
Isopoda	18	0.0025	8	0.0017	3	0.0016	1	0.0004
Oligochaeta	5	0.0007	5	0.0011	3	0.0016	2	0.0008
Sipuncula	5	0.0007	3	0.0006	2	0.0011	0	0
Bivalvia	4	0.0006	0	0	1	0.0005	0	0
Unknown arthropod	0	0	0	0	5	0.0027	0	0
Cumacea	1	0.0001	0	0	0	0	2	0.0008
Kinorhyncha	0	0	0	0	0	0	4	0.0015
Loricifera	0	0	0	0	3	0.0016	1	0.0004
Pycnogonida	0	0	1	0.0002	3	0.0016	0	0
Tantulocarida	3	0.0004	0	0	1	0.0005	0	0
Chaetognatha	1	0.0001	0	0	0	0	0	0
Priapulida	1	0.0001	0	0	1	0.0005	0	0
Tanaidacea	0	0	0	0	0	0	0	0
Amphipoda	1	0.0001	0	0	0	0	0	0
Cladocera	0	0	0	0	1	0.0005	0	0
Echiura	1	0.0001	0	0	0	0	0	0
Holothuroidea	1	0.0001	0	0	0	0	0	0
Metazoea	0	0	0	0	0	0	1	0.0004
Rotifera	0	0	0	0	0	0	1	0.0004
Zoea	0	0	0	0	0	0	1	0.0004
# of individuals	7224		4669	1	1819	1	2657	
# of species	22		13		20		19	
Shannon-Weaver Index	1.43		0.86		0.92		0.67	

Appendix A: Quantifying Diversity

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

- Species Diversity (S) - the number of species in the environment; and
- Species Evenness (or equitability) - a measure of how evenly individuals are distributed among these species.

Evenness is greatest when species are equally abundant. The simplest measure of species diversity is the number of species present in an environment. This is called species richness. But there is more to diversity than just the number of species in an environment. A community that has more or less equal numbers of individuals within the species present is usually thought of as more diverse than a community that is dominated by one species. For example, samples from two separate communities might each contain the same seven species, with distribution of individuals as shown in Table 1:

Table 1

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

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

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

$$\mathbf{H = -\Sigma p_i \ln p_i}$$

Where:
H is the diversity index
ln is the natural logarithm
$_i$ is an index number for each species present in a sample
$\mathbf{p_i}$ is the number of individuals within a species (n_i) divided by the total number of individuals (N) present in the entire sample

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

Table 2 illustrates the calculation:

Table 2

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

So, the diversity index H = 1.761.

When comparing communities, a higher diversity index means higher diversity.