OCEAN
EXPLORATION & RESEARCH

Coral Ecosystem Connectivity 2013:
From Pulley Ridge to the Florida Keys Expedition

Aliens on the Reef!

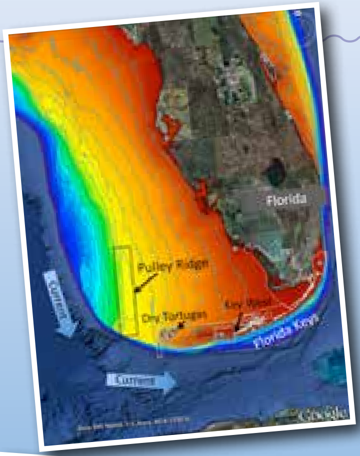

Image captions/credits on Page 2.

lesson plan

Focus

Impacts of invasive species on coral reefs (Life Science)

Grade Level

6-8

Focus Question

What are some interactions between native coral reef species and invasive lionfish?

Learning Objective

- Students will explain interactions between native coral reef species and invasive lionfish, and construct explanations that predict how these interactions may affect other ecosystems

Materials

- ☐ Access to resources listed in Step 1b.
- ☐ (Optional) Copies of Table 1. (This information maybe shared via interactive white board or other display).

Audio-Visual Materials

- ☐ (Optional) Interactive white board which may be used by teacher/ students to list ideas, responses to questions, or share information they create on iPads, or other devices, with the entire class

Teaching Time

Two 45-minute class periods, plus time for student reading and research

Seating Arrangement

Groups of two or three students

Maximum Number of Students

30

Key Words

Pulley Ridge
Marine protected area
Coral ecosystem
Fishery management
Conservation

Invasive species
Lionfish

Background Information

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

Coral reefs provide habitats for some of the most diverse biological communities on Earth. Most people have seen photographs and video images of shallow-water coral reefs, and many have visited these reefs in person. Around the world, shallow coral ecosystems are threatened by climate change, fishing, pollution, invasive species, and other human activities such as dredging and anchoring. These threats not only jeopardize coral reefs, but also endanger many benefits provided by these reefs such as supporting recreation and tourism industries, protecting shorelines from erosion and storm damage, supplying foods that are important to many coastal communities, and providing promising sources of powerful new antibiotic, anti-cancer and anti-inflammatory drugs.

In addition to shallow-water coral ecosystems, scientists have discovered two other types of coral reefs. In depths between 400 m and 700 m, ocean explorers have discovered extensive mounds of living coral. An important difference between deepwater coral species and those living in shallow waters is that shallow-water corals often have microscopic algae called zooxanthellae (pronounced “zoh-zan-THEL-ee”) living inside their soft tissues. Because they are capable of photosynthesis, these algae provide an important source of nutrition for many coral species and may also be involved with the corals’ growth. Deepwater corals do not contain zooxanthellae, and do not build the same type of reef that are produced by shallow-water corals; but the diversity of species in deep-water coral ecosystems may be comparable to that of coral reefs in shallow waters (for more information, activities, and lessons about coral reefs, visit the National Ocean Service Coral Reef Discovery Kit at http://oceanservice.noaa.gov/education/kits/corals/welcome.html).

Recently, ocean explorers have discovered a third type of coral ecosystem: light-dependent deep reefs living in what coral ecologists call the mesophotic zone (or “twilight zone”) in depths of 30 m to over 150 m, depending upon water clarity. Mesophotic coral ecosystems have not been studied as much as shallow- and deepwater coral reefs because of technological limitations. Shallow-water coral reefs have been intensively studied by scientists using self-contained underwater breathing (SCUBA) equipment, while deep coral systems are being

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Images from Page 1 top to bottom:
Map of project area showing Pulley Ridge, off the west coast of Florida at depths of 200-330 feet in relation to the downstream reefs of the Dry Tortugas and Florida Keys. Colors represent water depth, which ranges from 33 feet (red) to depths of 820 feet or greater (dark blue). Current arrows depict prevalent current direction. Background image is from Google Earth and the depth information is from the U.S. Geological Survey and NOAA. Image courtesy: Robert Cowen.

Example of corals and algae found on Pulley Ridge: The plate corals *Leptoseris cucullata* (foreground) and *Agaricia fragilis*; the finger coral *Madracis* sp.; the leafy green algae *Anadyomene menziesii*; and the branching algae *Dictyota* sp. Image courtesy: Mike Echevarria, Florida Aquarium.

The University of Miami’s technical dive team installed sensors on a mooring buoy to collect information on ocean currents. Image courtesy: Michael J. Echevarria, Florida Aquarium.

Understanding the value of the commercial fish species present at Pulley Ridge, such as the red grouper, *Ephinephelus morio*, is a key research objective for this project. Image courtesy: University of North Carolina at Wilmington.

The dominant communities providing structural habitat at Pulley Ridge are coralline algae (thin pink plates) and hard coral (brown plates are *Agaricia* sp.). Image courtesy: John Reed using the University of Connecticut's Kraken remotely operated vehicle.

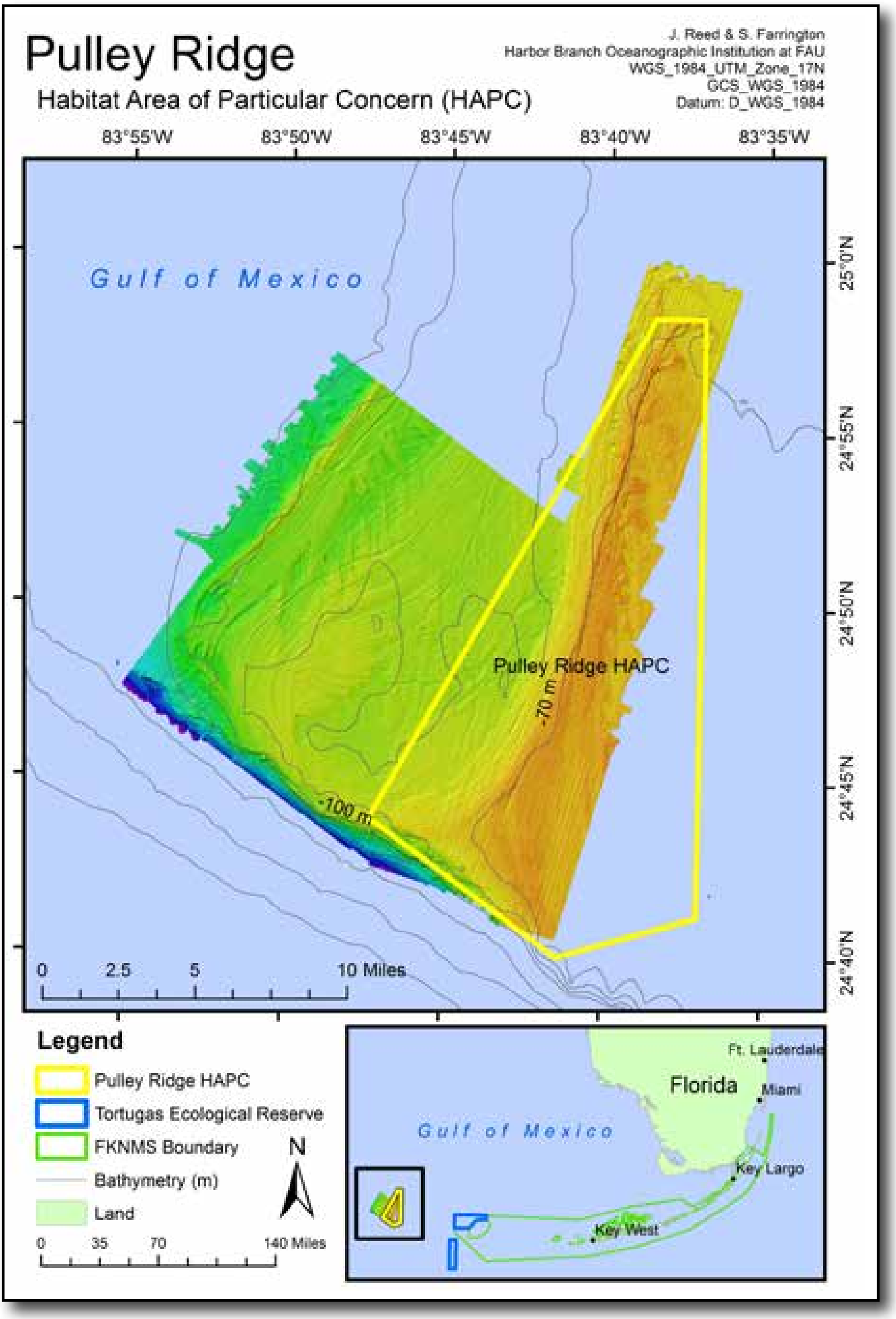
investigated with human-occupied submersibles and remotely operated underwater vehicles (ROVs). Mesophotic coral ecosystems, however, are beyond the safe range of conventional SCUBA equipment, yet are too shallow and close to shore to justify the use of expensive submersibles and ROVs. Over the past decade, advances in undersea technologies have begun to make it possible to study mesophotic coral ecosystems.

While only a few studies of mesophotic zone reefs have been done using these new capabilities, data from these studies suggest these ecosystems include coral, sponge, and algal species that provide important refuges and nursery habitats for corals and fishes found on shallower reefs. Because of the threats faced by shallow-water coral reefs, scientists believe it is urgent to understand the connections between mesophotic and shallow-water ecosystems. This sense of urgency also stems from the fact that mesophotic coral ecosystems are subject to many of the same threats faced by shallower coral ecosystems, but the extent of threats to mesophotic ecosystems is unknown and needs to be evaluated.

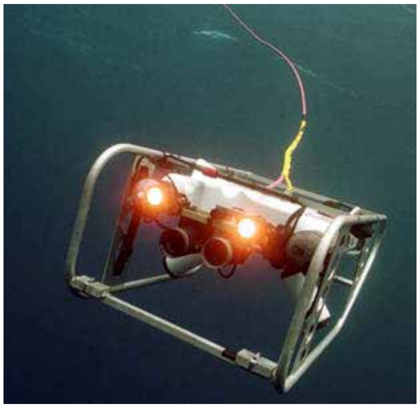
A larval squirrelfish of the Family Holocentridae. Larval fishes are sampled using plankton nets or light traps. Image courtesy: Cedric Guigand.

Since mesophotic corals are adapted to live in low-light conditions and require sunlight for survival, anything that limits light penetration (such as dredging or sediment runoff from the land) can be very harmful. Mesophotic coral ecosystems may also include species that are only found within this depth range or geographical location. These species are known as endemic species, and are especially vulnerable to disturbances from human activities and may face extinction if they are overexploited.

Pulley Ridge is a mesophotic coral ecosystem off the southwest coast of Florida in 60-80 meters depth, and is the deepest light-dependent coral reef that has been discovered off the United States.



Map of Pulley Ridge Habitat Area of Particular Concern (HAPC) showing multibeam sonar. Image courtesy: Harbor Branch Oceanographic Institute.



The University of North Carolina at Wilmington's *Phantom S2* remotely operated vehicle has the capability of maneuvering in shallow water to depths of 300 m, making it possible for scientists to study mesophotic reefs. Image courtesy: University of North Carolina at Wilmington.

Pulley Ridge was originally discovered in 1950, and was found again in 1999 by scientists from the U.S. Geological Survey (USGS) and graduate students from the University of South Florida. Since then, a series of expeditions have revealed that coral ecosystems at Pulley Ridge are considerably healthier compared to many in the Florida Keys, and are unusual because of the variety of life they support. Scientists hypothesize that Pulley Ridge may play an important role in replenishing key fish species, such as grouper and snapper, and other organisms in downstream reefs of the Florida Keys and Dry Tortugas. Since most of Florida's reefs have severely declined over the past 30 years, this potential role means it is important to protect, and manage, Pulley Ridge as a possible source of larvae that can help sustain Florida's reef ecosystems and the tourism economy that depends on them.

In 2011, NOAA's National Centers for Coastal Ocean Science's Center for Sponsored Coastal Ocean Research began a five-year project to investigate the role that reefs of Pulley Ridge and the northern Gulf of Mexico may play in replenishing key fish species and other organisms in the downstream reefs of the Florida Keys and Dry Tortugas. The Pulley Ridge Project is a collaboration of more than 30 scientists from ten different universities pooling their expertise through NOAA's Cooperative Institute for Marine and Atmospheric Studies (CIMAS) (http://cimas.rsmas.miami.edu/) in coordination with the Cooperative Institute for Ocean Exploration Research and Technology (CIOERT) (http://cioert.org/).

During the project's first year (2012), fieldwork began that included:

- Installing moored instruments at Pulley Ridge and the Dry Tortugas to measure temperature, salinity, and currents;
- Field-testing moored larval light traps to resolve any design issues and work out specific sampling procedures (for more about larval light traps, please see http://www.marine.usf.edu/user/djones/pubs/Jones_2006b.pdf);
- Conducting transect surveys with an ROV to quantify benthic habitats and organisms, and to identify suitable sites for technical divers to collect specimens;
- Collecting specimens with technical diving (for more about technical diving, please see Expedition Purpose for the Cayman Islands Twilight Zone 2007 Expedition, http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/purpose.html);
- Sampling plankton using the Multiple Opening/Closing Nets and Environmental Sampling System (MOCNESS), which is a system of nets that can be opened and closed at different depths, and also carries a number of sensors for measuring environmental parameters as it is towed (such as conductivity, temperature, pressure, fluorescence, optical transmission, dissolved oxygen,

and light levels). For more about MOCNESS, please see http://www.gulfofmaine-census.org/education/research-technology/sampling-tools-for-physical-capture/;
- Using a CTD to measure temperature, dissolved oxygen, salinity, fluorescence, turbidity, and depth (for more about CTDs, please see the "Where's the Oxygen" lesson, http://oceanexplorer.noaa.gov/explorations/10lophelia/background/edu/media/loph10_oxygen912.pdf);
- Deploying a drifter to measure surface currents (for more about drifters, please see http://oceanexplorer.noaa.gov/technology/tools/drifters/drifters.html); and
- Beginning to archive information about Pulley Ridge in a database at Harbor Branch Oceanographic Institute.

The Coral Ecosystem Connectivity 2013: From Pulley Ridge to the Florida Keys Expedition will continue this work.

During 2012 field investigations, explorers noticed a large increase in the number of lionfish compared to the first observations of lionfish on Pulley Ridge in 2010. In 2012, the total lionfish count during all ROV dives was 332 individuals. Lionfish are not a native species to Atlantic Ocean ecosystems, and like many exotic species, may have serious effects on ecosystems that they invade. In this lesson, students will investigate the Atlantic lionfish invasion, make inferences about possible interactions between lionfish and native coral reef species on Pulley Ridge, and construct explanations that predict how these interactions may affect other ecosystems.

Learning Procedure

1. To prepare for this lesson:
   a) Review the background essays for the Coral Ecosystem Connectivity 2013: From Pulley Ridge to the Florida Keys Expedition (http://oceanexplorer.noaa.gov/explorations/13pulleyridge/welcome.html).
   b) Review "The Lionfish Invasion" Web page [http://oceanservice.noaa.gov/education/stories/lionfish/] and the Lionfish Biology Fact Sheet [http://oceanservice.noaa.gov/education/stories/lionfish/factsheet.html]
   (c) Download an image of a parrotfish (see Step 3).

2. Briefly introduce the Coral Ecosystem Connectivity 2013: From Pulley Ridge to the Florida Keys Expedition, including the distinction between shallow-water coral reefs, mesophotic coral reefs, and deepwater coral reefs. Discuss the threats faced by coral reefs worldwide. Whenever possible, it is desirable to engage students in conversations, either in small groups or as an entire class, to elicit their ideas and perspectives; rather than rely primarily on a lecture-based approach.

3. Show students several images from the Coral Ecosystem Connectivity 2013: From Pulley Ridge to the Florida Keys Expedition Web site, and point out sponges, corals, algae, and fishes. Ask students why they think these groups are the focus of the Pulley Ridge project. A variety of reasons may be suggested, and should include the idea that these are the most abundant groups in the Pulley Ridge ecosystem, as well as the idea that these groups play important functional roles in this ecosystem.

   Discuss students' ideas about these possible roles. If students are unfamiliar with food webs, you may need to introduce the concepts of primary producers, herbivores, and carnivores. Ideas should also include the concept of habitats, since corals, sponges, and to some extent algae provide shelter for various species as well as a potential source of food.

4. Show students an image of a parrotfish. Discuss their feeding habits, which include grazing algae from reef surfaces as well as eating coral polyps. Show Table 1, and ask students to interpret the information provided. Students should realize that reef areas with high parrotfish grazing rates have much higher coral cover than reefs with low parrotfish grazing rates. Discuss students' ideas about reasons for this observation. One generally accepted explanation is that algae compete with corals for space on the reef, and grazing by parrotfish helps prevent algae from displacing corals. On some reefs, grazing parrotfish create conspicuous scars on living coral; but the relative impact of coral damage compared to benefits of algae removal has not been established.

5. Tell students that during fieldwork in 2012, Pulley Ridge explorers noticed lionfish on many of the sites visited by their underwater robot (remotely operated vehicle, ROV). Ask why this observation might be important. Some students may already be familiar with lionfish as an exotic species, and may have some ideas about the negative impacts that are associated with its presence in Atlantic marine habitats. Assign the following questions to student groups, and provide access to resources listed in Step 1b:
   Where are lionfish normally found?
   What is an invasive species?
   What do lionfish eat?
   Are lionfish dangerous to humans?
   What enemies do lionfish have on Florida coral reefs?
   Is it likely that lionfish can be removed from Atlantic Ocean habitats?
   What are some explanations for how lionfish may have arrived in Atlantic habitats?

6. Have student groups present and discuss answers to their assigned questions. Examples of some answers are provided in Table 2, but others may be acceptable as long as students are able to cite evidence for their ideas.

   Ask how lionfish might affect coral reef ecosystems in Florida. If necessary, remind students about the relationships discussed in Step 4. Students should infer that, since lionfish are carnivorous, they may include parrotfish and other herbivores in their diet. Further, since lionfish are not native to Florida waters, they may have few or no enemies. Reduced numbers of parrotfish could lead to a decline of reef corals and increase in algae. Since mesophotic coral reefs are believed to provide larvae to other reef systems, a reduction in live coral cover could have consequences for many other reef ecosystems. Emphasize that these types of interactions tend to be consistent among many different ecosystems, and introducing new predators can affect many species in addition to those that are actually consumed as food. Ask students what abiotic ecosystem components are involved in the lionfish-coral reef scenario. At a minimum, students should identify substrate type, which affects settlement and growth of corals and sponges; currents, which affect larval transport; and water temperature, which limits the distribution of many species (including lionfish, unless humans provide alternative means of dispersal!). You may also want to have students identify the various types of interactions involved with the lionfish-coral reef scenario, such as competitive, predatory, and mutually beneficial.

   Read or show the abstract provided in Appendix A, paraphrasing as needed. This paper documents the impacts of lionfish on a Bahamian coral reef, which include loss of fish species including herbivores, increase in algal cover, and decline in corals and sponges in mesophotic ecosystems. The authors are dubious about the ability of these communities to recover from lionfish impacts.

   Brainstorm what may be done about the lionfish invasion. At this point, there is no known solution to the problem; but students may be able to imagine a remedy that hasn't been considered yet!

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Ocean Science Topics" in the navigation menu to the left, then "Habitats," then "Coastal," then "Coral" for resources on corals and coral reefs. Scroll over "Ocean Science Topics," "Biology," and click on "Exotics" for resources about invasive species.

The "Me" Connection

Have students write a brief essay about how they might be personally affected by lionfish or some other invasive species.

Connections to Other Subjects

English Language Arts

Assessment

Student presentations and class discussions provide opportunities for assessment.

Extensions

Have students visit http://oceanexplorer.noaa.gov/explorations/13pulleyridge/welcome.html to find out more about the Coral Ecosystem Connectivity 2013: From Pulley Ridge to the Florida Keys Expedition.

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html Click on the links to Lessons 3 and 12 for interactive multimedia presentations and Learning Activities on deep-sea corals and biotechnology.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

A Piece of Cake

(from the 2007 Cayman Island Twilight Zone Expedition)

http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/cake.pdf

Focus: Spatial heterogeneity in deep-water coral communities (Life Science)

Students explain what a habitat is; describe at least three functions or benefits that habitats provide; describe some habitats that are typical of deep-water hard bottom communities; and explain how organisms, such as deep-water corals and sponges, add to the variety of habitats in areas such as the Charleston Bump.

Deep Gardens

(from the 2007 Cayman Island Twilight Zone Expedition)

http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/deepgardens.pdf

Focus: Comparison of deep-sea and shallow-water tropical coral communities (Life Science)

Students compare and contrast deep-sea coral communities with their shallow- water counterparts; describe three types of coral associated with deep-sea coral communities; explain three benefits associated with deep-sea coral communities; and explain why many scientists are concerned about the future of deep-sea coral communities.

Let's Go to the Video Tape!

(from the 2007 Cayman Island Twilight Zone Expedition)

http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/videotape.pdf

Focus: Characteristics of biological communities on deep-water coral habitats (Life Science)

Students recognize and identify some of the fauna groups found in deep-sea coral communities; infer possible reasons for observed distribution of groups of animals in deep-sea coral communities; discuss the meaning of "biological diversity;" compare and contrast the concepts of "variety" and "relative abundance" as they relate to biological diversity; and, given abundance and distribution data of species, will be able to calculate an appropriate numeric indicator that describes the biological diversity of a community.

Treasures in Jeopardy

(from the 2007 Cayman Island Twilight Zone Expedition)

http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/treasures.pdf

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

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

Easy as Pi

(from the 2003 Charleston Bump Expedition)

http://oceanexplorer.noaa.gov/explorations/03bump/background/education/media/03cb_pi.pdf

Focus: Structural complexity in benthic habitats (Life Science/Mathematics)

Students describe the importance of structural features that increase surface area in benthic habitats; quantify the relative impact of various structural modifications on surface area in model habitats; and give examples of organisms that increase the structural complexity of their communities.

Keep Away

(from the 2003 Gulf of Mexico Deep Sea Habitats Expedition)

http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_keepaway.pdf

Focus: Effects of pollution on diversity in benthic communities (Life Science)

Students discuss the meaning of biological diversity; compare and contrast the concepts of variety and relative abundance as they relate to biological diversity; and, given information on the number of individuals, number of species, and biological diversity at a series of sites, students will make inferences about the possible effects of oil drilling operations on benthic communities.

Big Fleas Have Little Fleas
(from the 2003 Mountains in the Sea Expedition)
http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_fleas.pdf
Focus: Physical structure in benthic habitats (Life Science)
Students recognize that natural structures and systems often display recurrent complexity over many scales of measurement; infer the importance of structural complexity to species diversity and abundance in benthic habitats; and discuss ways that octocorals may modify seamount habitats to make these habitats more suitable for other species.

Design a Reef!
(from the Gulf of Mexico Deep Sea Habitats 2003 Expedition)
http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_aquarium.pdf
Focus: Niches in coral reef ecosystems (Life Science)
Students compare and contrast coral communities in shallow water and deep water; describe the major functions that organisms must perform in a coral ecosystem; explain how these functions might be provided in a miniature coral ecosystem; explain the importance of three physical factors in coral reef ecosystems; and infer the fundamental source of energy in a deep-water coral community.

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/explorations/13pulleyridge/welcome.html – Web site for the Coral Ecosystem Connectivity 2013: From Pulley Ridge to the Florida Keys Expedition

http://mcbi.marine-conservation.org/publications/pub_pdfs/Deep-Sea%20Coral%20issue%20of%20Current.pdf – A special issue of Current: the Journal of Marine Education on deep-sea corals. (You might need to copy and paste the URL into your browser.)

Halpern B., S. Walbridge, K. Selkoe, C. Kappel1, F. Micheli, C. D'Agrosa, J. Bruno, K. Casey, C. Ebert, H. Fox, R. Fujita, D. Heinemann, H. Lenihan, E. Madin, M. Perry, E. Selig, M. Spalding, R. Steneck, and R. Watson. 2008. A global map of human impact on marine ecosystems. Science 319:948–952.

Jeffrey, C.F.G., V.R. Leeworthy, M.E. Monaco, G. Piniak, M. Fonseca (eds.). 2012. An Integrated Biogeo¬graphic Assessment of Reef Fish Populations and Fisheries in Dry Tortugas: Effects of No-take Reserves. NOAA Technical Memorandum NOS NCCOS 111. Prepared by the NCCOS Center for Coastal Monitoring and Assessment Biogeography Branch. Silver Spring, MD. 147 pp.

Mumby, P. 2006. The impact of exploiting grazers (Scaridae) on the dynamics of Caribbean coral reefs. Ecological Applications, 16(2):747–769

http://oceanservice.noaa.gov/education/stories/lionfish/factsheet.html – National Ocean Service, Lionfish Biology Fact Sheet

http://oceanservice.noaa.gov/education/stories/lionfish/ – National Ocean Service, "The Lionfish Invasion" Web page

Lesser, M. and M. Slattery. 2011. Phase shift to algal dominated communities at mesophotic depths associated with lionfish (*Pterois volitans*) invasion on a Bahamian coral reef. Biological Invasions 13(8):1855-1868

Alignment to the Next Generation Science Standards Performance Expectations

MS-LS2 Ecosystems: Interactions, Energy, and Dynamics

Performance Expectation:

MS-LS2-2. Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.

[Clarification Statement: Emphasis is on predicting consistent patterns of interactions in different ecosystems in terms of the relationships among and between organisms and abiotic components of ecosystems. Examples of types of interactions could include competitive, predatory, and mutually beneficial.]

Science and Engineering Practices:

Constructing Explanations and Designing Solutions

- Construct an explanation that includes qualitative or quantitative relationships between variables that predict phenomena.

Disciplinary Core Idea:

LS2.A: Interdependent Relationships in Ecosystems

- Predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared.

Crosscutting Concepts:

Patterns

- Patterns can be used to identify cause and effect relationships.

Connections to Common Core State Standards for Literacy in Science and Technical Subjects

ELA/Literacy –

- RST.6.8.1 Cite specific textual evidence to support analysis of science and technical texts.
- WHST.6-8.2 Write informative/explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content.
- WHST.6-8.9 Draw evidence from literary or informational texts to support analysis, reflection, and research.
- SL.8.1 Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 8 topics, texts, and issues, building on others' ideas and expressing their own clearly.
- SL.8.4 Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation.

Mathematics –

- 6.SP.B.5 Summarize numerical data sets in relation to their context.

Additional Science and Engineering Practices:

Obtaining, Evaluating, and Communicating Information

- Critically read scientific texts adapted for classroom use to determine the central ideas and/or obtain scientific and/or technical information to describe patterns in and/or evidence about the natural and designed world(s)

Additional Crosscutting Concepts:

Cause and Effect: Mechanism and Prediction

- Relationships can be classified as causal or correlational, and correlation does not necessarily imply causation.
- Cause and effect relationships may be used to predict phenomena in natural or designed systems.

Systems and System Models

- Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems.
- Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems.

Stability and Change

- Small changes in one part of a system might cause large changes in another part.
- Stability might be disturbed either by sudden events or gradual changes that accumulate over time.

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 c. Most of the major groups that exist on Earth are found exclusively in the ocean and the diversity of major groups of organisms is much greater in the ocean than on land.
Fundamental Concept d. Ocean biology provides many unique examples of life cycles, adaptations, and important relationships among organisms (symbiosis, predator-prey dynamics, and energy transfer) that do not occur on land.
Fundamental Concept e. The ocean provides a vast living space with diverse and unique ecosystems from the surface through the water column and down to, and below, the seafloor. Most of the living space on Earth is in the ocean.

Essential Principle 6.
The ocean and humans are inextricably interconnected.
Fundamental Concept b. The ocean provides food, medicines, and mineral and energy resources. It supports jobs and national economies, serves as a highway for transportation of goods and people, and plays a role in national security.
Fundamental Concept e. Changes in ocean temperature and pH due to human activities can affect the survival of some organisms and impact biological diversity (coral bleaching due to increased temperature and inhibition of shell formation due to ocean acidification).
Fundamental Concept g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Essential Principle 7.
The ocean is largely unexplored.

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

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

Fundamental Concept c. Over the last 50 years, use of ocean resources has increased significantly; the future sustainability of ocean resources depends on our understanding of those resources and their potential.

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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Acknowledgements

This lesson was developed and written for NOAA's Office of Ocean Exploration and Research (OER) by Dr. Mel Goodwin, PhD, Marine Biologist and Science Writer
Design/layout: Coastal Images Graphic Design, Mt. Pleasant, SC.

Credit

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Table 1
Percent Coral Cover on Reefs with High and Low Rates of Parrotfish Grazing

High Parrotfish Grazing Rates	Low Parrotfish Grazing Rates
65.8 %	7.0 %
64.4 %	7.0 %
66.9%	6.2 %
65.7%	7.3%
65.7%	7.1%
58.3%	9.3%
66.8%	6.9 %
65.0%	6.9 %
66.0%	7.1%
65.4%	7.3 %
65.9%	6.9%
65.0%	6.9%
62.9%	7.1%
42.5%	6.0 %

The *R/V F.G. Walton Smith*, owned and operated by the University of Miami, Rosenstiel School of Marine and Atmospheric Sciences (RSMAS), is one of two vessels to be used during the expedition. Image courtesy: University of Miami/RSMAS.

Table 2
Examples of Answers to Student Research Questions

Where are lionfish normally found?	Lionfish are normally found on coral reefs in the South Pacific and Indian Oceans.
What is an invasive species?	An invasive species is a species that is non-native to the ecosystem it occupies and whose introduction causes or is likely to cause economic or environmental harm, or harm to human health.
What do lionfish eat?	Lionfish are carnivores near the top of their food webs, and eat fishes, shrimps, and crabs.
Are lionfish dangerous to humans?	Lionfish have venomous spines that cause wounds that are painful but not deadly.
What enemies do lionfish have on Florida coral reefs?	Lionfish have few predators, but there have been a few reports of lionfish being eaten by sharks and large groupers.
Is it likely that lionfish can be removed from Atlantic Ocean habitats?	There are no proven methods for removing lionfish from Atlantic habitats, and many scientists are pessimistic about this possibility.
What are some explanations for how lionfish may have arrived in Atlantic habitats?	Because they are popular in the aquarium trade, it is widely assumed that lionfish were accidentally or deliberately released by one or more aquarium hobbyists. Other, less likely, possibilities are that larvae or juveniles were transported in ship ballast, or that they entered the Atlantic via the Panama Canal.

Appendix A

Phase shift to algal dominated communities at mesophotic depths associated with lionfish (*Pterois volitans*) invasion on a Bahamian coral reef

by
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ABSTRACT

Mesophotic coral reefs (30–150 m) have been assumed to be physically and biologically connected to their shallow-water counterparts, and thus may serve as refugia for important taxonomic groups such as corals, sponges, and fish. The recent invasion of the Indo–Pacific lionfish (*Pterois volitans*) onto shallow reefs of the Caribbean and Bahamas has had significant, negative, effects on shallow coral reef fish populations. In the Bahamas, lionfish have extended their habitat range into mesophotic depths down to 91 m where they have reduced the diversity of several important fish guilds, including herbivores. A phase shift to an algal dominated (>50% benthic cover) community occurred simultaneously with the loss of herbivores to a depth of 61 m and caused a significant decline in corals and sponges at mesophotic depths. The effects of this invasive lionfish on mesophotic coral reefs and the subsequent changes in benthic community structure could not be explained by coral bleaching, overfishing, hurricanes, or disease independently or in combination. The significant ecological effects of the lionfish invasion into mesophotic depths of coral reefs casts doubt on whether these communities have the resilience to recover themselves or contribute to the recovery of their shallow water counterparts as refugia for key coral reef taxa.

~ Published in Biological Invasions;
August 2011 Volume 13, Issue 8, pp 1855-1868

Lionfish and Butterfly fish at depth. Image courtesy of Jill Heinerth, Bermuda Deep Water Caves 2011 Exploration, NOAA-OER. http://oceanexplorer.noaa.gov/explorations/11bermuda/logs/hires/lionfish_hires.jpg