www.oceanexplorer.noaa.gov

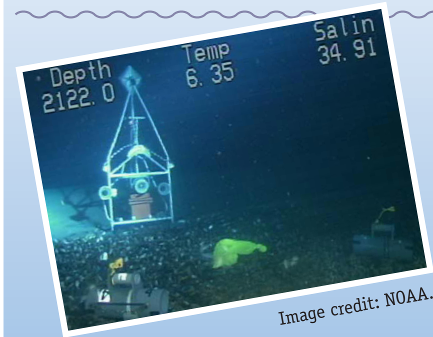


Image credit: NOAA.

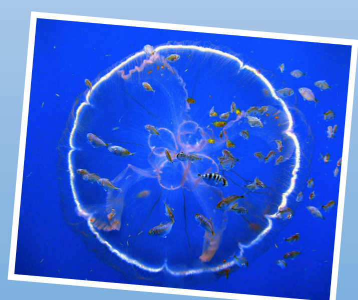


Image credit: NOAA.


Image credit: NOAA.

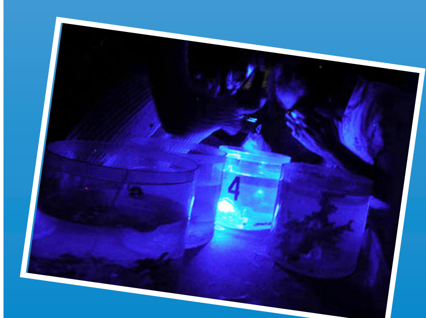


Image credit: NOAA.

Image captions on Page 2.

lesson plan

Bioluminescence 2009:
Living Light on the Deep Sea Floor Expedition

To See or Not to See

Focus
Bioluminescence, color, and camouflage in deep ocean organisms

Grade Level
9-12 (Life Science)

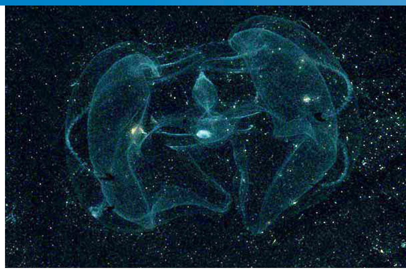
Focus Question
How are light and color important to organisms in deep ocean environments?

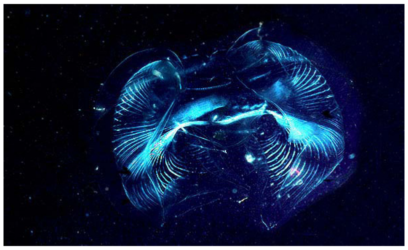
Learning Objectives
- Students will be able to identify and discuss key factors that determine the effectiveness of color camouflage in pelagic and benthic habitats.
- Students will be able to describe how ambient light changes with increasing depth in the ocean.
- Students will be able to explain how the wavelength of light that illuminates an organism may determine the most effective camouflage coloration.
- Students will be able to explain how an organism that has effective camouflage coloration under ambient illumination may not be effectively camouflaged when it is illuminated by bioluminescence.

Materials
- Copies of “Bioluminescence and Color Camouflage Inquiry Guide,” one copy for each student group
- Flashlights; one for each student group
- Blue filters (see Learning Procedure Step 1c)

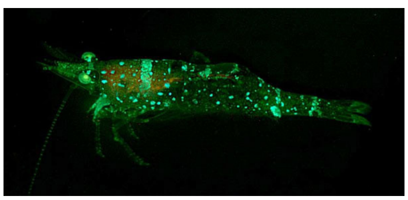
Audio/Visual Materials
- (Optional) Images showing light and color in deep-sea environments and organisms (see Learning Procedure, Step 1d)

Teaching Time
Two 45-minute class periods, plus time for student research





The lobate ctenophore *Ocyropsis maculata* as viewed under unpolarized light (top) and polarized light (bottom). Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/05deepscope/logs/aug27/media/ocyropsis_unpolarized_600.jpg
http://oceanexplorer.noaa.gov/explorations/05deepscope/logs/aug27/media/ocyropsis_polarized_600.jpg



Unidentified *Sargassum* shrimp bearing two colors of fluorescent patches. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/05deepscope/logs/aug22/media/fluorescent_shrimp_600.jpg

Images from Page 1 top to bottom:

The Eye-In-The-Sea camera system deployed on the edge of a brine pool, over 2,100 ft deep in the Gulf of Mexico. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/04deepscope/logs/aug8/media/eye_600.jpg

A flotilla of fish follow a transparent drifting jellyfish, *Aurelia aurita*. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/05deepscope/logs/sep3/media/aurelia3_rs_600.jpg

The pontellid copepod *Pontella securifer*. Various parts glow fluorescent green when viewed under blue light. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/05deepscope/logs/aug26/media/horned_copepod_mf_600.jpg

Deep Scope 2005 science crew examines recently collected specimens. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/05deepscope/logs/sep4/media/examining_specimens_600.jpg

Seating Arrangement

Groups of 2-4 students

Maximum Number of Students

30

Key Words

Light
Vision
Bioluminescence
Electromagnetic spectrum
Color
Wavelength
Camouflage

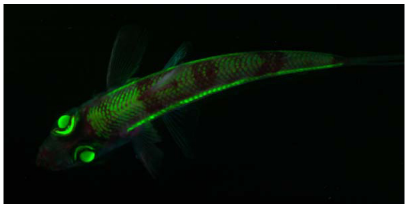
Background Information

[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 usually will need to adapt the language and instructional approach to styles that are best suited to specific student groups.*]

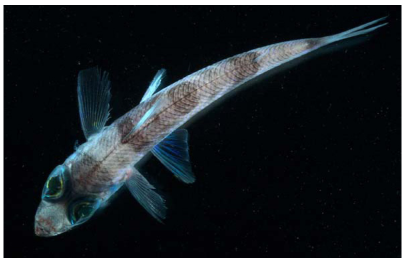
Deep ocean environments are almost completely dark; yet light is still important in these environments. Many marine species are able to produce "living light" through a process known as bioluminescence, but very little is known about specific ways that deep-sea organisms use this ability. Part of the problem is that these organisms are difficult to observe: turning on bright lights can cause mobile animals to move away, and may permanently blind light-sensitive sight organs. In addition, transparent and camouflaged organisms may be virtually invisible even with strong lights, and many types of bioluminescence can't be seen under ordinary visible light. Overcoming these obstacles is a primary objective of the Bioluminescence 2009: Living Light on the Deep Sea Floor Expedition.

Like the 2004 and 2005 Ocean Exploration Deep Scope Expeditions (http://oceanexplorer.noaa.gov/explorations/04deepscope/welcome.html and http://oceanexplorer.noaa.gov/explorations/05deepscope/welcome.html), Bioluminescence 2009 will use advanced optical techniques to observe animals under extremely dim light that may reveal organisms and behaviors that have never been seen before. In addition, these techniques will allow scientists to study animals whose vision is based on processes that are very different from human vision.

These techniques are based on a number of basic concepts related to the production of light by chemical reactions, a process known as



The shortnose greeneye fish gets its name from fluorescent eyes. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/04deepscope/logs/aug16/media/greeneye_fluor_600.jpg



Under white light, the greeneye fish looks very different, but its green lenses are still apparent. Image credit: NOAA.
http://oceanexplorer.noaa.gov/explorations/04deepscope/logs/aug16/media/greeneye_600.jpg

chemiluminescence. When these reactions occur in living organisms, the process is called bioluminescence. A familiar example is the bioluminescence of fireflies; another is "foxfire," which is caused by bioluminescence in fungi growing on wood. Bioluminescence is relatively rare in terrestrial ecosystems, but is much more common in the marine organisms including bacteria, algae, cnidarians, annelids, crustaceans, and fishes.

Investigating the role of bioluminescence in the deep-sea benthic ecosystems involves the basic properties of light in seawater, as well as different ways in which certain forms of light may be perceived by living organisms. "Light" is usually defined as the portion of the electromagnetic spectrum that is visible to the normal human eye, but since the Bioluminescence 2009 Expedition is concerned with eyes other than human ones, we need a broader definition. It is helpful to think of light as a series of waves that consist of energy in the form of electric and magnetic fields that together are known as electromagnetic radiation. These waves can have many different wavelengths (the distance between any two corresponding points on successive waves, such as peak-to-peak or trough-to-trough), so they form a spectrum of wavelengths. The full range of wavelengths in the electromagnetic spectrum extends from gamma rays that have wavelengths on the order of one billionth of a meter, to radio waves whose wavelengths may be several hundred meters. The wavelength of light visible to humans ranges from 400 billionths of a meter (violet light) to 700 billionths of a meter (red light), but we know that some organisms are able to detect light wavelengths outside these limits.

The amount of energy in a light wave is related to its wavelength: shorter wavelengths have higher energy than longer wavelengths. In the portion of the electromagnetic spectrum visible to humans, violet has the most energy and red the least. In seawater, light waves with more energy travel farther than those with less energy. Warm colors such as red and orange are absorbed fairly near the surface, so red objects appear black at depths greater than 10 meters. In clear ocean water, visible light decreases by about 90% with every 75 m increase in depth (so at 150 m depth, there is only 1% of the visible light present at the surface). Deep-sea environments below 1,000 m appear almost completely dark to humans; yet vision and "light" are still important to many of the organisms that live in these environments.

This lesson guides student inquiry into an investigation of bioluminescence and color in deep-sea ecosystems, and provides direct experience with interpreting scientific literature.

Learning Procedure

1. To prepare for this lesson:
   a. Read:
   – Introductory essays for the Bioluminescence 2009 Expedition (http://oceanexplorer.noaa.gov/explorations/09deepscope/welcome.html);
   b. Review questions and procedures on the "Bioluminescence and Color Camouflage Inquiry Guide." Make a copy of the Inquiry Guide for each student group. Note that color copies are needed for Figure 1.
   c. Assemble materials required for student inquiries. Blue filters may be obtained from theatrical supply houses, music stores, or via the Internet (e.g., http://sldlighting.com/). Try to obtain filters having 20% transmittance or less.
   d. Optional: Download or copy several images showing light and color in deep-sea environments and organisms from one or more of the following Web sites:
   http://oceanexplorer.noaa.gov/gallery/livingocean/livingocean_coral.html
   http://www.pbs.org/wgbh/nova/abyss/life/bestiary.html
   http://www.lifesci.ucsb.edu/~biolum/

2. Briefly discuss the mission plan and activities of the Bioluminescence 2009 Expedition. You may want to show images of various deep-sea environments and organisms, and briefly review background information on bioluminescence from the introductory essays.

3. Tell students that their assignment is to conduct an inquiry into an investigation of bioluminescence and color in deep-sea ecosystems, and provide each group with a copy of the "Bioluminescence and Color Camouflage Inquiry Guide." You may also want to provide copies of the technical article cited in the Inquiry Guide, or leave this to students to download on their own.

4. Lead a discussion of the results of students' inquiries. These should include:

   A. Web Inquiry

   (1) Crypsis is a technique used by animals to hide from other animals.
   (2) Mesopelagic species are species that live in the mesopelagic zone (also known as the twilight zone) of the ocean, from 200 m to about 1,000 m.
   (3) Benthic species are species that live on the bottom.
   (4) Ambient light is the light that naturally surrounds an object.
   (5) According to the introductory paragraphs, the ideal camouflage coloration for a mesopelagic organism viewed under ambient

light is determined by the spectrum of the background light and the light hitting the animal.

(6) According to the introductory paragraphs, the ideal camouflage coloration for a mesopelagic organism viewed under bioluminescence is a color that reflects no light over the wavelength range of the bioluminescence.

(7) According to the introductory paragraphs, the ideal camouflage coloration for a benthic organism is a color that matches the background.

(8) Approximate wavelengths:
Red – 780-622 nm
Orange – 622-597 nm
Yellow – 597-577 nm
Green – 577-492 nm
Blue – 455-492 nm

(9) Most marine bioluminescence is in the blue to green portions of the visible spectrum (455-577 nm).

(10) As ocean depth increases, ambient light includes increasing proportions of shorter wavelengths. Most red light is absorbed within 10 m of the surface; yellow light penetrates to around 30 m; green light reaches depths around 60 m; blue light penetrates to about 75 m.

(11) Reflectance is the fraction of incident radiation that is reflected from a surface.

B. Experiment

Under ordinary room light or daylight, Figure 1 does not look like good camouflage coloration, since the red-spotted crab is clearly visible against the gray-spotted background. Under blue and green light, however, the red spots seem to lose their color, because the blue and green filters remove any red light that could be reflected to the observer's eyes. The point here is that the effectiveness of color as camouflage depends a great deal on the color of light illuminating an organism and its surroundings, and the ability of observers (including predators) to perceive differences between the organism's color and that of its surroundings. So, an ideal camouflage coloration for a benthic organism would be colors that reflect the same wavelengths as the organism's surroundings. If the color of the illuminating light changes, then the ideal camouflage color may also change.

C. Analyze and Interpret

(1) The measured reflectance from three mesopelagic shrimp is much less than the predicted ideal reflectance. Assuming that reflectance is important to the survival of the shrimp, the predicted reflectance is far too high.

(2) This suggests that camouflage when the shrimps are illuminated by ambient light may not be as important as camouflage when they are illuminated by bioluminescence. Under bioluminescence the best camouflage would be not to reflect any of the wavelengths making up the light from bioluminescence.

(3) According to the introductory paragraphs, most mesopelagic species are either red or black. Since most marine bioluminescence is in the blue to green portions of the visible spectrum, red-colored objects would appear nearly black under bioluminescent illumination. So red and black-colored organisms would reflect little or no light when they are illuminated by bioluminescence.

(4) The crab legs strongly reflected light wavelengths above 600 nm. Since most marine bioluminescence is in the 455-577 nm range, the crab legs would appear nearly black under bioluminescent illumination. Similarly, because red light is absorbed within 10 meters of the ocean surface, ambient light in the deep sea contains no red light, so the crab legs would also appear black under ambient illumination.

The BRIDGE Connection

http://www.vims.edu/bridge/ – Type "bioluminescence" in the Search box on the welcome page for links to information and activities related to light producing organisms in the ocean.

The "Me" Connection

Have students write a short essay on, or discuss as a group, how color camouflage plays a role in the lives of students, either as a means of crypsis, or as a means of attracting attention ("reverse camouflage").

Connections to Other Subjects

English/Language Arts, Physical Science, Earth Science

Assessment

Answers to Inquiry Guide questions and group discussions provide opportunities for assessment.

Extensions

1. Have students visit http://oceanexplorer.noaa.gov/explorations/09deepscope/welcome.html to keep up to date with the latest discoveries by the Bioluminescence 2009 Expedition.

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html
Click on the link to Lesson 6 for interactive multimedia presentations and Learning Activities on Deep-Sea Benthos.

Other Relevant Lessons from NOAA's Ocean Exploration and Research Program

Where Is That Light Coming From?
http://oceanexplorer.noaa.gov/explorations/04deepscope/background/edu/media/WhereisLight.pdf
(6 pages, 208Kb) (from the Operation Deep Scope 2004 Expedition)
Focus: Bioluminescence

In this activity, students explain the role of luciferins, luciferases, and co-factors in bioluminescence and the general sequence of the light-emitting process. Additionally, students discuss the major types of luciferins found in marine organisms, define the "lux operon" and discuss at least three ways that bioluminescence may benefit deep-sea organisms. Students give an example of at least one organism that actually receives each of the benefits discussed.

Light at the Bottom of the Deep, Dark Ocean???
http://oceanexplorer.noaa.gov/explorations/02sab/background/edu/media/sab_light.pdf
(8 pages, 476k) (from the 2002 Islands in the Stream Expedition)

Focus: Biology - Adaptations of deepwater organisms

In this activity, students will participate in an inquiry activity; relate the structure of an appendage to its function; and describe how a deepwater organism responds to its environment without bright light.

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.09deepscope/welcome.html – The Bioluminescence 2009 Expedition Web site

Johnsen, S. 2005. The Red and the Black: Bioluminescence and the Color of Animals in the Deep Sea. Integr. Comp. Biol. 45:234–246; http://www.biology.duke.edu/johnsenlab/pdfs/pubs/blcolor.pdf

http://www.lifesci.ucsb.edu/~biolum/ —The Bioluminescence Web Page

http://www.bioscience-explained.org/ENvol1_1/pdf/BiolumEN.pdf – Marine bioluminescence by Edith A. Widder; Bioscience Explained; Vol 1:1.

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

http://www.bioscience-explained.org/ENvol1_1/pdf/PhotoEN.pdf – Bacterial illumination, by Madden, D. and B.-M. Lidesten; Bioscience Explained; Vol 1, No. 1; Procedures for Culturing Bioluminescent Bacteria

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

National Science Education Standards

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Structure of atoms
- Structure and properties of matter
- Chemical reactions

Content Standard C: Life Science

- Interdependence of organisms
- Matter, energy, and organization in living systems
- Behavior of organisms

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Natural resources

Ocean Literacy Essential Principles and Fundamental Concepts

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.

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 d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.
Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

Send Us Your Feedback

We value your feedback on this lesson, including how you are using it in your formal/informal education setting.
Please send your comments to:
oceanexeducation@noaa.gov

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To See or Not to See

Bioluminescence and Color Camouflage Inquiry Guide

You will need:
- A flashlight
- Blue and green filters to cover the flashlight
- A darkened space

A. Web Inquiry

Johnsen (2005) investigated how color may be related to camouflage in deep-sea organisms. Read the first three introductory paragraphs in the paper (http://www.biology.duke.edu/johnsenlab/pdfs/pubs/blcolor.pdf), and answer the following questions:

1. What is crypsis?

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2. What are mesopelagic species?

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3. What are benthic species?

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4. What is ambient light?

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5. According to the introductory paragraphs, what is the ideal camouflage coloration for a mesopelagic organism viewed under ambient light?

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6. According to the introductory paragraphs, what is the ideal camouflage coloration for a mesopelagic organism viewed under bioluminescence?

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To See or Not to See

Bioluminescence and Color Camouflage Inquiry Guide - continued

7. According to the introductory paragraphs, what is the ideal camouflage coloration for a benthic organism?

8. What is the approximate wavelength of the following colors:
   - Red
   - Orange
   - Yellow
   - Green
   - Blue

9. What is the approximate wavelength of most marine bioluminescence?

10. How does the wavelength of ambient light change as depth increases in the ocean?

11. What is reflectance?

B. Experiment

1. Look at Figure 1. Is this an example of good camouflage coloration?

2. Put a blue filter over the flashlight, and use the filtered flashlight to look at Figure 1 again in a darkened space. Repeat this procedure with a green filter. What do you observe?

To See or Not to See

Bioluminescence and Color Camouflage Inquiry Guide - continued

3. From these observations, what do you conclude about the ideal camouflage coloration for a benthic organism?

C. Analyze and Interpret

1. Johnsen used information about light in the deep ocean to predict what the background illumination would be at various depths, and used this information to predict the ideal reflectance for an organism in order to be least visible under these light conditions. The predicted reflectance is shown in Figure 2, along with the actual reflectance measured from three mesopelagic shrimp. What do these measurements suggest about the predicted reflectance?

2. What do these results suggest about the relative importance of bioluminescence and ambient light to camouflage in mesopelagic organisms?

3. According to the introductory paragraphs, what colors are most mesopelagic species? How does this observation relate to your analysis in the previous question?

To See or Not to See

Bioluminescence and Color Camouflage Inquiry Guide - continued

4. Figure 3 shows reflectance spectra measured from the legs of five deep-sea benthic crab species. How would you expect these legs to appear under ambient light and bioluminescence?

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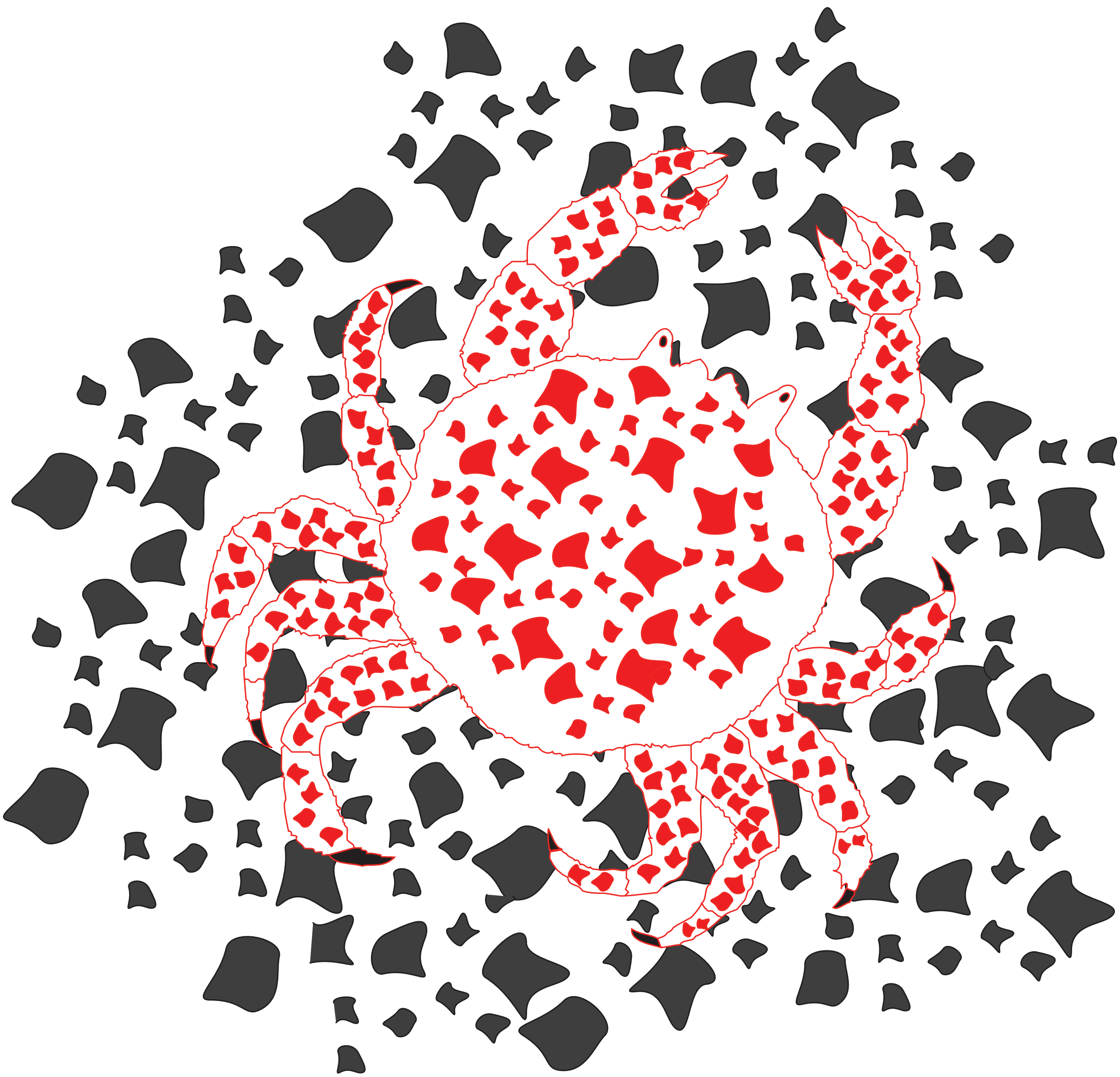
Figure 1



To See or Not to See

Bioluminescence and Color Camouflage Inquiry Guide - continued

Figure 2:

Predicted ideal reflectance for camouflage of mesopelagic species (dotted line) and measured reflectance (solid lines) of three mesopelagic shrimp species (*Systellaspis debilis*, *Acanthephyra purpurea*, and *Meningodora* sp.)

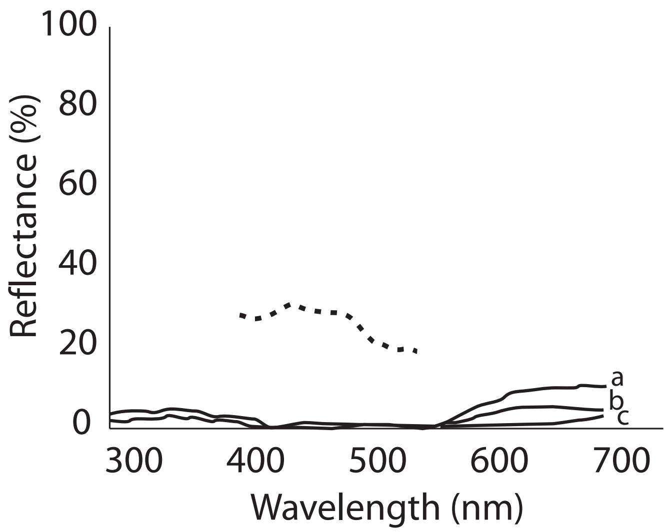


Figure 3:

Measured reflectances for legs of five benthic crab species