Lessons from the Deep:
Exploring the Gulf of Mexico's Deep-Sea Ecosystems
Education Materials Collection

Through Robot Eyes

Focus
Imagery of deep-sea organisms and habitats

Grade Level
9-12 (Physical Science/Technology)

Focus Question
How can images obtained by underwater robots be used to assist scientific explorations?

Learning Objectives
❍ Students will describe typical applications and limitations of imagery obtained with remotely operated vehicles (ROVs).

❍ Students will use ROV imagery to make inferences about deep ocean habitats in the Gulf of Mexico.

Materials
❍ Copies of *Robot Imagery Inquiry Guide*, one for each student group
❍ Copies of *ImageJ Basics,* one for each student group; see Learning Procedure, Step 1b
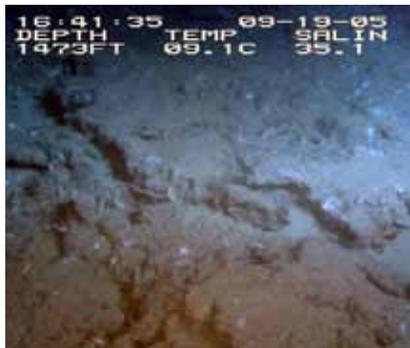
Audio/Visual Materials
❍ (Optional) Video projector or other equipment to display downloaded images (see Learning Procedure, Step 1c)

Teaching Time
One or two 45-minute class periods, plus time for students to complete the *Inquiry Guide*

Image captions/credits on Page 2.

lesson plan

Seating Arrangement
Groups of 2-4 students

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Areas of active, if subdued, hydrocarbon seeps are notably devoid of large sessile invertebrates. A fluffy gray biofilm coats the underlying rock, dotted with small white patches of the cold-seep-associated bacteria *Beggatoia*. Image courtesy Ken Sulak USGS 2004-2006 *Lophelia* program Chief Scientist.
http://fl.biology.usgs.gov/images/pictures/CHEMO_SEEP_BIOTOPE.jpg

This group of very old tubeworms (*Lamellibrachia luymesi* and *Seepiophila jonesi*) live on the same piece of carbonate rock as large colonies of the gorgonian *Callogorgia Americana*. Note the brittle stars and a galatheid crab crawling on the gorgonians. Image courtesy Derk Bergquist.
http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/signature_600.html

Images from Page 1 top to bottom:
A close-up mussel aggregation with *Chirodota heheva* sea cucumbers. Image courtesy of Expedition to the Deep Slope 2007.
http://oceanexplorer.noaa.gov/explorations/07mexico/logs/july3/media/cuke_600.html

A CTD rosette being recovered at the end of a cast. Note that the stoppers on the sample bottles are all closed. Image courtesy of INSPIRE: Chile Margin 2010.
http://oceanexplorer.noaa.gov/explorations/10chile/logs/summary/media/2summary.html

A methane hydrate mound on the seafloor; bubbles show that methane is continuously leaking out of features like this. If bottom waters warmed, this entire feature may be destabilized and leak methane at a higher rate.
http://oceanexplorer.noaa.gov/explorations/10chile/background/methane/media/methane4.html

Lophelia pertusa create habitat for a number of other species at a site in Green Canyon. Image courtesy of Chuck Fisher.
http://oceanexplorer.noaa.gov/explorations/08lophelia/logs/sept24/media/green_canyon_lophelia.html

Maximum Number of Students
32

Key Words
Robot
Imagery
Video
Photomosaic
ImageJ

Background Information

Following the Deepwater Horizon blowout, responders worked around the clock to control the flow of oil from the damaged wellhead. Many of these efforts depended upon remotely operated vehicles (ROVs), which are underwater robots that allowed responders to work on the mile-deep wellhead without the expense and risk involved in using manned submersibles. ROVs are linked by a group of cables to an operator who is usually aboard a surface ship. Most of these robots are equipped with one or more video cameras and lights, and may also carry other equipment such as collecting devices, cutters, water samplers, and measuring instruments to expand the vehicle's capabilities.

Many questions have arisen concerning the impact of the Deepwater Horizon blowout on deep-sea ecosystems in the Gulf of Mexico. Efforts to answer these questions depend heavily upon the ability of underwater robots to obtain images that can be used to identify living organisms, as well as to estimate the abundance and distribution of these organisms. Particularly important is the ability to compare images obtained before the blowout with images obtained after this event. The following activities are designed to acquaint students with some techniques for analyzing images obtained with underwater robots. Once they are familiar with these techniques, they will be able to use them for a wide variety of inquiries related to the Deepwater Horizon blowout, as well as other investigations about ocean organisms and ecosystems.

Learning Procedure

1. To prepare for this lesson:
   a. Review the essay on photomosaics at: http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug30/aug30.html. You may want to provide copies of this essay to students as a reading assignment.
   b. Review procedures on the *Robot Imagery Inquiry Guide*. If students will be using classroom computers, download ImageJ and the *ImageJ Basics* handout from http://rsbweb.nih.gov/ij/download.html and http://rsbweb.nih.gov/ij/docs/pdfs/ImageJ.

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Viosca Knoll is an elevated salt dome with dormant and active cold seeps. Where hydrocarbons are actively escaping from the substrate, dense clusters of tightly entwined vestimentiferan tubeworms grow. As the submersible approaches, it disturbs a blackbelly rosefish (*Helicolenus dactylopterus*), and a conger eel (*Conger oceanicus*). Image courtesy Ken Sulak USGS 2004-2006 *Lophelia* program Chief Scientist.
http://fl.biology.usgs.gov/images/pictures/CHEMO_TUBE-WORM_BUSH.jpg

Hela, an ROV carrying a High Definition TV camera (foreground) and Isis, a towed sled with auxiliary lighting, sit on the stern of the RV Connecticut.
http://oceanexplorer.noaa.gov/explorations/03portland/logs/sept15/media/helaisis.html

Lophelia pertusa coral, with opened polyps, attached to an authigenic carbonate rock. Seep-dependent tubeworms are visible behind the coral. Image courtesy of, *Lophelia* II 2009: Deepwater Coral Expedition: Reefs, Rigs and Wrecks.
http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug25/media/lophelia_insitu_.html

pdf respectively. Also, download the photomosaic image from http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/hires/madrepora_mosaic_hires.jpg. If students will not be using classroom computers, ensure that they will have access to these files.

c. You may also want to download examples of imagery from underwater robots from http://oceanexplorer.noaa.gov/okeanos/media/slideshow/flash_slideshow.html and http://oceanexplorer.noaa.gov/okeanos/media/slideshow/video_playlist.html.

2. Briefly discuss the Deepwater Horizon blowout, highlighting the potential importance of deep-sea biological communities that may have been adversely affected by this event. Point out that many questions remain to be answered about such impacts, and ask students how scientists can investigate ecosystems that are thousands of meters deep. Human-occupied submersible vehicles are likely to be mentioned, as well as robotic vehicles. Highlight some of the advantages of unoccupied vehicles, which include greatly reduced costs and risks to human life. You may want to show some of the imagery referenced in Step 1c at this point, and provide the essay on photomosaics if this is to be a reading assignment.

3. Tell students that their assignment is to learn about some of the ways scientists use imagery from underwater robots to investigate deep-sea ecosystems. Provide each student group with a copy of the *Robot Imagery Inquiry Guide* and the *ImageJ Basics* handout, as well as any instructions about operating the ImageJ software on classroom computer systems. Point out that the primary purpose of the *Inquiry Guide* exercises is to become familiar with techniques that can be used for a wide variety of investigations and projects that use digital imagery.

4. When students have answered all questions on the *Inquiry Guide*, lead a discussion of their results. The following points should be included:

• The approximate length of the lobster's carapace in Figure 1 is 8.44 cm.

• The approximate length of the right cheliped in Figure 1 is 18.75 cm; elongated chelipeds are a distinctive feature of squat lobsters, as well as the fact that the fifth pair of legs is often hidden so that the squat lobster appears to have only eight legs.

• The fish in Figure 3 is 6 meters from the robot, since the beam from the third laser converges with the beam from the parallel

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laser on the right, giving the appearance of only two dots on the fish.

• The total length of the fish in Figure 3 is approximately 30 cm.

• The fish in Figure 4 is 3 meters from the robot, since the beam from the third laser forms a dot that is 2.5 cm from the dot formed by the parallel laser on the right. The hint in Figure 5 is that that the angle θ is constant, so the tangent of θ is constant and equal to d / D, and b and B will have the same value.

• The total length of the fish in Figure 4 is approximately 30 cm.

• Errors involved with video fish surveys include avoidance of the robot by some fish species, attraction to the robot by other species which may also circle the robot and be counted more than once, and the exclusion of cryptic species that hide in crevices that are out of the camera's view.

• The width (W) of a video transect made with a camera whose horizontal angle of view (A) is 90 degrees and with an effective distance (D) of 5 m is:
$$W = 2 \cdot (\tan(0.5 \cdot A)) \cdot D = 2 \cdot (\tan 45) \cdot 5 = 2 \cdot 1 \cdot 5 = 10 \text{ m}$$

• The length of a transect that begins at 28.123456° North latitude, -87.369212° West longitude, and ends at 28.125255° North latitude, -87.369146° West longitude is 0.200144 km.

• Using values from questions 8 and 9, the area of the transect is:
$$10 \text{ m} \cdot 200.144 \text{ m} = 2001.44 \text{ square meters}$$

To correct for the space that is outside the camera's field of view, it is necessary to subtract:
$$0.5 \cdot (W \cdot D) = 25 \text{ square meters}$$
which is the shaded area shown in Figure 6.

• The approximate carapace widths of the four decapod crustaceans in the mosaic are:
    upper left = 9 cm
    lower right = 10 cm
    upper right = 8 cm
    upper center = 11 cm

• The approximate area occupied by the white *Lophelia* coral in the mosaic is 0.2 square meters; students' results will vary depending upon how precisely they outline the coral branches.

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• The approximate area occupied by the purple gorgonians and their attached brittle stars is 0.22 square meters; again, students' results will vary depending upon the precision with which they outline.

The BRIDGE Connection

www.vims.edu/bridge/ – In the "Site Navigation" menu on the left, click "Ocean Science Topics," then "Human Activities," then "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 how robotic imagery might be of personal benefit.

Connections to Other Subjects

English/Language Arts, Life Science, Mathematics, Physics

Assessment

Students' answers to *Inquiry Guide* questions and class discussions provide opportunities for assessment.

Extensions

1. Try ImageJ on more photomosaics from the *Lophelia* II 2010 Expedition http://oceanexplorer.noaa.gov/ explorations/10lophelia/logs/photolog/photolog.html

2. See the "Resources" section of *Lessons from the Deep: Exploring the Gulf of Mexico's Deep-Sea Ecosystem Education Materials Collection Educator's Guide* for additional information, activities, and media resources about deepwater ecosystems in the Gulf of Mexico.

3. Build your own underwater robot! See *ROV's in a Bucket* and books by Harry Bohm under Resources.

Multimedia Discovery Missions

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

Other Links and 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.

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http://oceanexplorer.noaa.gov/ – Ocean Explorer Web site

Christopher C. Koenig, C. 2001. Oculina Banks: Habitat, Fish Populations, Restoration, and Enforcement. Report to the South Atlantic Fishery Management Council; http://www.safmc.net/Portals/0/Oculina/oculinareport.pdf

Bohm, H. and V. Jensen. 1998. Build Your Own Programmable Lego Submersible: Project: Sea Angel AUV (Autonomous Underwater Vehicle). Westcoast Words. 39 pages.

Bohm, H. 1997. Build your own underwater robot and other wet projects. Westcoast Words. 148 pages.

http://www.marinetech.org/ – Web site for the Marine Advanced Technology Education (MATE) Center, with information on making ROVs and ROV competitions

http://monitor.noaa.gov/publications/education/rov_manual.pdf – ROV's in a Bucket: Directions for a simple underwater ROV that can be built by grade-school children using off-the-shelf and off-the-Internet parts; by Doug Levin, Krista Trono, and Christine Arrasate, NOAA Chesapeake Bay Office

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/OFR_2008-1148_MMS_2008-015/index.html

Fisher, C., H. Roberts, E. Cordes, and B. Bernard. 2007. Cold seeps and associated communities of the Gulf of Mexico. Oceanography 20:118-129; available online at http://www.tos.org/oceanography/issues/issue_archive/20_4.html

http://www.piersystem.com/go/site/2931/ – Main Unified Command Deepwater Horizon response site

http://response.restoration.noaa.gov/deepwaterhorizon – NOAA Web site on Deepwater Horizon Oil Spill Response

http://docs.lib.noaa.gov/noaa_documents/NESDIS/NODC/LISD/Central_Library/current_references/current_references_2010_2.pdf – Resources on Oil Spills, Response, and Restoration: a Selected Bibliography; document from NOAA Central Library to

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aid those seeking information concerning the Deepwater Horizon oil spill disaster in the Gulf of Mexico and information on previous spills and associated remedial actions; includes media products (Web, video, printed and online documents) selected from resources available via the online NOAA Library and Information Network Catalog (NOAALINC)

http://www.gulfallianceeducation.org/ – Extensive list of publications and other resources from the Gulf of Mexico Alliance; click "Gulf States Information & Contacts for BP Oil Spill" to download the Word document

http://rucool.marine.rutgers.edu/deepwater/ – Deepwater Horizon Oil Spill Portal from the Integrated Ocean Observing System at Rutgers University

http://www.darrp.noaa.gov/southeast/deepwater_horizon/index.html – Information about damage assessments being conducted by NOAA's Damage Assessment Remediation and Restoration Program

http://response.restoration.noaa.gov/ – Click "Students and Teachers" in the column on the left for information, fact sheets, and activities about oil emergencies, habitats, and other ocean issues

http://www.noaa.gov/sciencemissions/bpoilspill.html – Web page with links to NOAA Science Missions & Data relevant to the Deepwater Horizon/BP Oil Spill

http://ecowatch.ncddc.noaa.gov/jag/data.html – Data Links page on the Deepwater Horizon Oil Spill Joint Analysis Group Web site

http://ecowatch.ncddc.noaa.gov/jag/reports.html – Reports page on the Deepwater Horizon Oil Spill Joint Analysis Group Web site

http://www.education.noaa.gov/Ocean_and_Coasts/Oil_Spill.html - "Gulf Oil Spill" Web page from NOAA Office of Education with links to multimedia resources, lessons & activities, data, and background information

http://www.geoplatform.gov/gulfresponse/ - Web page for GeoPlatform.gov/gulfresponse—an online map-based tool developed by NOAA with the EPA, U.S. Coast Guard, and the Department of Interior to provide a "one-stop shop" for spill response information; includes oil spill trajectory, fishery area closures, wildlife data, locations of oiled shoreline and positions of deployed research ships

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National Science Education Standards

Content Standard A: Science As Inquiry
- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard E: Science and Technology
- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives
- Science and technology in society

Content Standard G: History and Nature of Science
- Nature of science

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 3.
The ocean is a major influence on weather and climate.
Fundamental Concept f. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon and water.

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.
Fundamental Concept c. Some major groups are found exclusively in the ocean. 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 (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.
Fundamental Concept g. There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, and methane cold seeps rely only on chemical energy and chemosynthetic organisms to support life.

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

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goods and people, and plays a role in national security.

Fundamental Concept g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustainthe 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 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.
Please e-mail your comments to: oceanexeducation@noaa.gov

For More Information

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

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Robot Imagery Inquiry Guide

Underwater robots are our eyes into Earth's deep ocean. As digital imaging technology continues to improve, views through these robot eyes are beautiful and fascinating (see, for example, http://oceanexplorer.noaa.gov/okeanos/media/slideshow/flash_slideshow.html and http://oceanexplorer.noaa.gov/okeanos/media/slideshow/video_playlist.html). Following the Deepwater Horizon blowout, many questions have arisen concerning the impact of the blowout on deep-sea ecosystems in the Gulf of Mexico. Efforts to answer these questions depend heavily upon the ability of underwater robots to obtain images that can be used to identify living organisms, as well as to estimate the abundance and distribution of these organisms. Particularly important is the ability to compare images obtained before the blowout with images obtained after this event. The following activities are designed to acquaint you with some techniques for analyzing images obtained with underwater robots. Once you are familiar with these techniques, you will be able to use them for a wide variety of inquiries related to the Deepwater Horizon blowout, as well as other investigations about ocean organisms and ecosystems.

Many underwater robots used for ecological surveys carry digital cameras that can look ahead of the robot as well as directly below it. Often, the forward-looking camera records video while the downward-looking camera may record still or video imagery depending upon specific mission needs. For some surveys, a series of overlapping still images is obtained from the downward-looking camera. These images are spliced together to produce a mosaic image that can provide complete coverage of a large area. The essay by Liz Podowski (http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug30/aug30.html) provides more details about this technique.

One problem with most images from underwater robots is that they are two dimensional, so it can be very difficult to accurately judge the size of organisms and ecosystem features. To overcome this problem, underwater photography systems use a system of lasers. Downward-looking cameras typically have two lasers whose beams are parallel and are a known distance apart. This places two bright dots on each image that establish the scale of the image. In Figure 1, the dots on the squat lobster's legs are 7.5 cm apart. Using this information, estimate:

Figure 1

http://oceanexplorer.noaa.gov/explorations/08lophelia/logs/sept27/media/galatheoid1_600.jpg

1. The length (front to back) of the squat lobster's carapace : _____

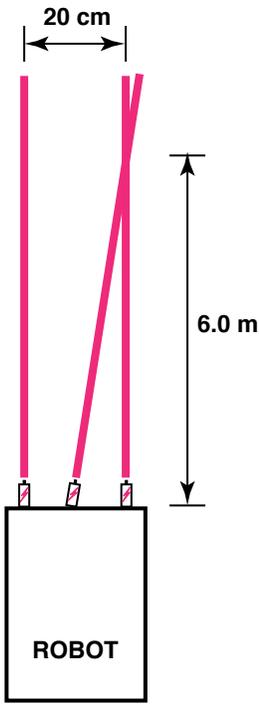2. The total length of the right cheliped (a cheliped is a leg equipped with a claw): _____

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Robot Imagery Inquiry Guide - 2

Figure 2:

20 cm

6.0 m

ROBOT
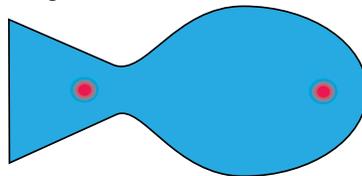
A similar system can be used in forward-looking video, but it is often important to be able to estimate distance as well. To provide this capability, a third laser is added to the system, in between the two parallel lasers. This additional laser is angled so that it converges with one of the parallel laser beams at a known distance in front of the robot (see Figure 2).

Suppose a video system using the lasers diagrammed in Figure 2 shows this image:

Figure 3:

3. How far away is the fish? _____

4. What is the total length of the fish? _____

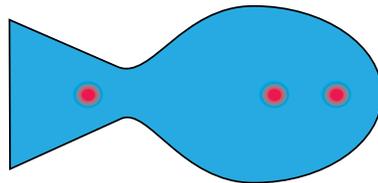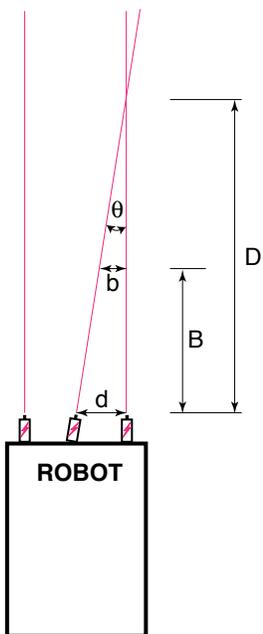Now suppose the same video system shows this image:

Figure 4:

Figure 5:

5. How far away is the fish? _____

6. What is the total length of the fish? _____

θ

b

D

B

d

ROBOT

Fishes are a conspicuous part of many marine ecosystems, and ocean explorers often have questions about what kinds of fish inhabit certain areas, and how many fishes are there. Koenig (2001) describes a way to obtain this information that involves navigating an underwater robot along a series of transects (a transect is a path along which data are collected) while recording video from a forward-looking camera. When the transects are completed, the video recording is reviewed and imaged fishes are identified and counted. The total counts for each species are divided by the total area of the transect to obtain an estimate of the density of each species. For example, if 50 fish belonging to a single species were

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Robot Imagery Inquiry Guide - 3

counted in a video transect that covered 100 square meters, the density of that species would be

50 fish / 100 square meters = 0.5 fish/square meter.

7. What might be some errors involved with surveying fishes in this way?
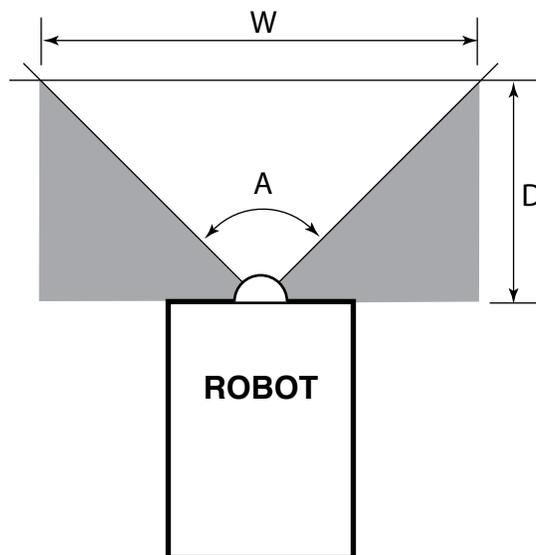
_____

_____

_____

_____

To find the area of a transect, we need to know the width (W) and length (L) of the transect. The width of the transect can be calculated from:
• The effective distance for identifying fish species (D); and
• The video camera's horizontal angle of view (A)

The effective distance for identifying fish species (D) is the limit at which the fish can be identified with a high degree of certainty. Koenig used a distance of 5 m. The horizontal angle of view (A) depends on the camera used and the zoom position of the lens.

8. Suppose we have a camera whose horizontal angle of view is 90 degrees. Using 5 m as the effective distance, what is the width (W) of a video transect?

_____

Hint:

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Robot Imagery Inquiry Guide - 3

The length of a transect (L) can be calculated from the geographic coordinates of the robot at the beginning and end points of the transect. The distance between two points whose latitude and longitude are known can be calculated using the spherical law of cosines formula:

$$d = acos \ (sin(lat1) \cdot sin(lat2) + cos(lat1) \cdot cos(lat2) \cdot cos(long2 - long1)) \cdot R$$

where lat1, long1, lat2, and long2 are the latitude and longitude of points 1 and 2 respectively in radians, d is the distance between the point in km, and R is Earth's mean radius (6,371 km); latitude and longitude measurements in degrees may be converted to radians by dividing by 180.

9. If our transect began at 28.123456° North latitude, -87.369212° West longitude, and ended at 28.125255° North latitude, -87.369146° West longitude, what was the length (L) of the transect (Hints: 1. Negative longitude values are used to distinguish between East and West longitude, but it doesn't matter whether you use negative or positive numbers in the spherical law of cosines formula; just don't mix negative and positive numbers! 2. Be sure to use a calculator or spreadsheet program accurate to at least six decimal places.

10. Now that you know the width (W) and length (L) of the transect, how much area did the transect include (Hint: be sure to allow for the space that is outside the camera's horizontal field of view)?

Basic analyses of photomosaics and single-frame images from downward-looking cameras can be done by identifying and counting individual organisms, and by using laser scale dots to estimate the area covered by the image. Much more sophisticated analyses can be done using image analysis software. ImageJ is a very powerful image analysis program developed by the National Institutes of Health, and is free to the public. Links for downloading, tutorials, and full documentation are available at: http://rsbweb.nih.gov/ij/index.html.

Launch the ImageJ program, and open the photomosaic file provided by your teacher. Review the I*mageJ Basics* handout, then try the following:

Draw a horizontal line across the center of the image. Assume that this line represents a length of 5 m on the actual seafloor, and set the measurement scale as described in the handout.

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Robot Imagery Inquiry Guide - 4

11. Four decapod crustaceans are clearly visible in the mosaic: one near the upper left side, one near the lower right corner, one in the upper right below the purple gorgonians, and a fourth near the upper center near the white *Lophelia* corals (this one is brown, and doesn't stand out as much as the others). Measure the maximum distance across the carapace for each of these crustaceans, and record your results (Hint: Use the magnifying glass to enlarge the image for greater accuracy):

12. What is the approximate area occupied by the white *Lophelia* coral?

13. Notice the purple gorgonian soft corals (with attached brittle stars) in the upper right corner. What is the approximate area occupied by these organisms?