2007: Exploring the Inner Space of the Celebes Sea

Let's Get Specific

Focus
Speciation

Grade Level
9-12 (Biology)

Focus Question
Why do some geographic areas have more species than others?

Learning Objectives
Students will be able to explain two definitions of "species."

Students will be able to describe at least two factors that favor increased speciation.

Students will be able to compare and contrast sympatric and allopatric speciation.

Students will be able to locate and define Wallacea and Wallace's Line, and offer at least two possible explanations for the high degree of endemism in Wallacea.

Materials
- ❒ Copies of "Celebes Sea Biodiversity Worksheet," one copy for each student or student group
- ❒ Internet access, downloaded articles, or library resources for student research

Audio/Visual Materials
None

Teaching Time
One or two 45-minute class periods plus time for student research

Seating Arrangement
Classroom style or groups of 3-4 students

Maximum Number of Students
30

Key Words
Speciation
Biogeography
Wallace's Line
Celebes Sea
Endemism
Biodiversity
Wallacea
Worksheet

Background Information
Indonesia is well-known as one of Earth's major centers of biodiversity. Although Indonesia covers only 1.3 percent of Earth's land surface, it includes:
- 10 percent of the world's flowering plant species;
- 12 percent of the world's mammal species;
- 16 percent of all reptile and amphibian species; and
- 17 percent of the world's bird species.

In addition, together with the Philippines and Great Barrier Reef, this region has more species of fishes, corals, mollusks, and crustaceans than any other location on Earth.

What, exactly, is meant by biodiversity, and why is it important? The term "biodiversity" is usually understood to include variety at several levels:
- variety of ecosystems: high biodiversity suggests many different ecosystems in a given area;
- variety of species: high biodiversity suggests many different species in a given area;
- variety of interactions between species; and
- variety within species (genetic diversity): high biodiversity suggests a relatively high level of genetic variety among individuals of the same species.

A simple definition of biodiversity could be "The variety of all forms of life, ranging in scale from genes to species to ecosystems."

Biodiversity is important to humans because our survival depends upon many other species and ecosystems. Some examples of our dependence on biodiversity include:
- fresh air containing oxygen;
- clean water;
- productive soils;
- food, medicines and natural products;
- natural resources that provide the basis for human economies; and
- natural beauty that improves our quality of life.

(adapted from the Biodiversity Project, http://www.biodiversityproject.org/bdimportant.htm)

Quite a lot is known about Indonesia's terrestrial and shallow-water ecosystems. But scientific knowledge and understanding of midwater ocean communities is generally sketchy, and many midwater animals have not been studied at all—even though the midwater ocean environment is our planet's largest ecosystem. Midwater animals range from microscopic zooplankton to the largest animals on Earth, provide a major source of nutrition for benthic (bottom) communities, and are an important link in the transfer of energy and materials from the top to the bottom of the ocean. Note that the term "midwater" as used here includes the entire water column, but the same term has also been used to refer to only part of the water column. Scientists often divide the ocean water column into three zones: the "epipelagic zone" (also called the "sunlit" or "euphotic" zone) from the surface to a depth of about 200 m; the "mesopelagic zone" between 200 m and 1100 m; and the "bathypelagic zone," which is deeper than 1100 m.

The seas of Indonesia and the Philippines (including the Sulu, Banda, Celebes, Java, Molucca, and Halmahera Seas) are the only deep-water gap between the continental shelves of Australia and Southeast Asia. Water flowing from the Western Pacific Ocean into the Indian Ocean is channeled by numerous island chains to form a series of ocean currents known as the Indonesian Throughflow. The dominant Throughflow current passes off the southern Philippines into the Celebes Sea (which is partially enclosed by Borneo (Kalimantan) and the island of Celebes (Sulawesi), then flows through the Makassar Strait, around Java and the Lesser Sunda Islands, and eventually becomes part of the west-flowing South Equatorial Current.

The path of the Indonesian Throughflow through the Celebes Sea coincides with an imaginary boundary known as "Wallace's Line." Alfred Russell Wallace was an English naturalist who spent eight years in Indonesia during the mid-1800's studying wildlife and collecting specimens for museums. During his travels, Wallace noticed that animals on the island of Bali seemed to be related to similar species found in Asia, while animals on the Island of Lombok (only 20 miles away to the southeast) were very different and more closely resembled species in Australia. The boundary between these two "zoogeographic regions" became known as "Wallace's Line," and extends from the middle of the Celebes Sea, through the Makassar Strait between Borneo and Celebes, and through the strait between Bali and Lombok.

This junction of two great zoogeographic regions is sometimes referred to as "Wallacea," and is an area of particularly high biological diversity and endemism. Endemic species are species that are found nowhere else. The high number of endemic species in Wallacea is probably due to several factors:

- High temperatures associated with the tropical climate are thought to increase rates of mutation, which in turn increase the opportunity for new species to arise;
- The presence of many islands creates habitats that are more or less isolated from each other, and such isolation favors the evolution of new species that are uniquely adapted to local conditions; and
- During past ice-ages, lower sea levels created land bridges between the islands of Java, Borneo, Sumatra and Bali and allowed species to spread among these islands, but deep ocean trenches prevented migrations to islands to the east.

These factors help explain the diversity of terrestrial organisms on either side of Wallace's Line; but what about marine organisms? Does Wallace's Line also exist in the ocean environment? Recent research on the genetics of some marine species suggests that populations in the seas of Indonesia may also be biologically isolated from each other, even though strong currents would be expected to spread larvae around the region and prevent this kind of isolation.

Why is this important? Because Earth's marine habitats are in serious trouble. In particular, coral reefs are in decline: 10% of reef environments have already been permanently lost, and this figure may increase to as much as 70% by the year 2020 (Wilkinson, 1992). Protected areas known as marine reserves are one way to deal with this problem; studies have shown that marine reserves can help restore biomass and diversity in over-exploited communities. To be effective, though, marine reserves must have a supply of new organisms to re-populate such communities, and for many marine species this means a supply of larval organisms.

So, decisions about the size and location of marine reserves require information on how much interaction or "connectivity" exists between populations in a given region. One way to predict connectivity is to examine the currents that flow between populations, and couple these data with information about the larval cycle of organisms of interest (organisms with long larval cycles would be expected to travel farther than those with shorter cycles). But this approach may not give an accurate picture if there are other factors that tend to keep populations isolated from each other.

The 2007: Exploring the Inner Space of the Celebes Sea Expedition is focused on exploring the variety of midwater organisms in the most biologically-diverse region on Earth. Key expedition questions include:

- What animals are found in Indonesian midwater communities?
- How does the biodiversity of Indonesian midwater communities compare with other marine communities in this region, and with other midwater communities in other regions?
- What proportion of animal species in Indonesian midwater communities is endemic to this region (found nowhere else on Earth), and how does this degree of endemism compare with that of other regions?

In this lesson, students will explore the concept of species and some of the factors that affect speciation.

Learning Procedure

1. To prepare for this lesson, review the introductory essays for the 2007: Exploring the Inner Space of the Celebes Sea Expedition at http://oceanexplorer.noaa.gov/explorations/07philippines/. You can view many images of planktonic organisms at http://www.imagequest3d.com/catalogue/larvalforms/, but be aware of copyright restrictions posted on the Web site.

   If students do not have Internet access for research, verify that available library resources have adequate information to answer questions on the "Celebes Sea Biodiversity Worksheet." Alternatively, suitable reference materials may be downloaded for student use. Keyword searches on worksheet topics will yield many sites that have sufficient information to answer the questions.

2. Briefly introduce the 2007: Exploring the Inner Space of the Celebes Sea Expedition, focusing on the importance of midwater animals and why these animals have not been well-studied. Show students a map of the Celebes Sea and describe the general path of the Indonesian Throughflow. Discuss the concept of biodiversity, highlighting why biodiversity is important to humans and that Indonesia is one of Earth's major biodiversity centers.

3. Tell students that their assignment is to investigate some aspects of biodiversity in the vicinity of the Celebes Sea. Provide each student or student group with a copy of the "Celebes Sea Biodiversity Worksheet."

4. Lead a discussion of students' answers to questions on the worksheet. The following points should be included:

   - The "classical" definition of a species is "A population or a series of populations of individuals that interbreed freely with one another." Note that in this context, "population" means a group of organisms that interbreed and share a gene pool.

   - This definition does not work for species that reproduce asexually because individuals of these species do not interbreed. An alternative approach is to define a species as a group of organisms whose DNA nucleotide sequences do not differ by more than an arbitrary percentage (30% in the case of bacteria). Students should realize that two "species" identified by this definition might be quite similar or very different. In fact, a similar uncertainty results from the "classical" definition as well: There is a big difference between two populations that are biologically unable to interbreed (dogs and sparrows, for example) and two populations that are biologically capable of interbreeding but do not do so because of geographic isolation (such as fishes in two widely separated lakes).

   - Factors that favor an increase in the number of species in an ecosystem include energy (abundant and diverse food sources favor more species), stability (more species accumulate in a stable ecosystem because there is more time to adapt to particular niches), and area (larger areas are able to accommodate more species).

   - Speciation is the process in which related organisms change to a point at which they are different enough to be considered separate species. Sympatric speciation occurs among similar organisms in close proximity that don't interbreed because of differences in behavior, even though they theoretically could. Allopatric speciation occurs among similar organisms that theoretically could interbreed but do not because they are geographically separated.

   - Population size is critical to survival. As population size decreases, there is increasing probability that lethal genes will occur. Wilson states that a population size of 500 individuals is the minimum needed to keep a species alive and healthy, while a population size of 50 individuals is only adequate for a short period of time.

- Species are disappearing from Earth's ecosystems approximately 1,000 times more rapidly than new species are appearing.

- E.O. Wilson's "hot spots" include tropical forests, freshwater systems, and coral reefs.
  • An endemic organism is found in only one area or location, and nowhere else. "Endemism" refers to the tendency for organisms in an area to be endemic to that area. So, a high degree of endemism means that there are a relatively high number of endemic organisms in an area.

- Wallace's Line is an imaginary boundary that separates the zoogeographic regions of Asia (species such as tigers and rhinoceros) and Australia (species such as kangaroos). The separation is particularly noticeable on some islands that are only a few miles apart. Wallace's Line extends from the middle of the Celebes Sea, through the Makassar Strait between Borneo and Celebes, through the strait between Bali and Lombok.

- Wallacea is the area surrounding Wallace's Line, which is characterized by particularly high biological diversity and endemism. Endemic species are species that are found nowhere else.

- Some explanations for the high number of endemic species in Wallacea include:
  - High temperatures associated with the tropical climate are thought to increase rates of mutation, which in turn increase the opportunity for new species to arise;
  - The presence of many islands creates habitats that are more or less isolated from each other, and such isolation favors the evolution of new species that are uniquely adapted to local conditions; and
  - During past ice-ages, lower sea levels created land bridges between the islands of Java, Borneo, Sumatra and Bali and allowed species to spread among these islands, but deep ocean trenches prevented migrations to islands to the east.

- The close proximity of the Celebes Sea, South China Sea, Tomini Bay, Flores Sea, Java Sea, as well as strong current flowing between these features, would seem to reduce the likelihood of endemism between these areas.

- The observations of Barber et al. are not consistent with the idea of low endemism between the areas listed in Question 12. Isolation due to ice-age sea levels might explain how populations in these areas became different from one another, but that still leaves the question of why there hasn't been more mixing since sea levels rose again? One possibility is that the organisms investigated in this study are abnormal and do not represent a larger trend among populations of other marine species in these areas. Another possibility is that organisms may have developed specific defenses against larvae of very similar species that might compete for the same ecological niche. It is also possible that one or more factors may cause larvae to be retained near the area in which they are produced, rather than be dispersed into currents that could transport them away from suitable habitats. Students may suggest other possibilities, and since there are no definite explanations for these observations at this point, their suggestions may be correct!

The Bridge Connection

www.vims.edu/bridge/ – In the "Site Navigation" menu on the left, click on "Ocean Science Topics," then

"Biology," then "Biodiversity for links to topics on biodiversity and evolution.

The "Me" Connection

Have students write a short essay exploring at least three ways in which global biodiversity is of personal importance.

Connections to Other Subjects

Earth Science

Assessment

Worksheets and discussions provide opportunities for assessment.

Extensions

1. Visit oceanexplorer.noaa.gov to keep up to date with the latest 2007: Exploring the Inner Space of the Celebes Sea Expedition discoveries, and to find out what researchers are learning.

2. For another activity involving biogeography and speciation, see: http://www.ucmp.berkeley.edu/fosrec/Filson.html

3. For an activity about the concept of a "species," see http://www.actionbioscience.org/biodiversity/lessons/pagelessons.pdf

Multimedia Learning Objects

http://www.learningdemo.com/noaa/ – Click on the links to Lessons 8 and 12 for interactive multimedia presentations and Learning Activities on Ocean Currents and Food, Water, and Medicine from the Sea.

Other Relevant Lesson Plans from the Ocean Exploration Program

Blinded By the Light!! [http://www.oceanexplorer.noaa.gov/explorations/02sab/background/edu/media/sab_blinded.pdf] (6 pages, 460k) (from the Islands in the Stream 2002: Exploring Underwater Oases Expedition)

Focus: Physical Science – Absorption, Scattering, and Reflection of Light in the Deep Sea

In this activity, students will recognize that the colors they see are a result of the reflection of light and that other colors of light are absorbed; predict what color an object will appear when light of different colors is shined upon it; predict what color(s) will be produced when different colors of light are mixed; and identify the three primary colors and three secondary colors of light.

Drifting Downward [http://www.oceanexplorer.noaa.gov/explorations/02sab/background/edu/media/sab_drifting.pdf] (6 pages, 464k) (from the Islands in the Stream 2002: Exploring Underwater Oases Expedition)

Focus: Biology – Adaptations of planktonic organisms in the ocean

In this activity, students will describe the characteristics of plankton; develop abilities necessary to do scientific inquiry; test the effects of different salinity and temperature on the vertical movement of a model of a planktonic organism; and calculate the velocity of the plankton model.

How Diverse is That? [http://www.oceanexplorer.noaa.gov/explorations/03windows/background/education/media/03win_hdiverse.pdf] (6 pages, 552k) (from the 2003 Windows to the Deep Expedition)

Focus: Quantifying biological diversity (Life Science)

In this activity, students will be able to discuss the meaning of "biological diversity" and will be able to compare and contrast the concepts of "variety" and "relative abundance" as they relate to biological diversity. Given abundance and distribution data of species in two communities, students will be able to calculate an appropriate numeric indicator that describes the biological diversity of these communities.

Where Is That Light Coming From? [http://www.oceanexplorer.noaa.gov/explorations/04deepscope/background/edu/media/WhereisLight.pdf] (PDF, 208Kb) (from the 2004 Operation Deep Scope 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.

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.

http://oceanexplorer.noaa.gov – Web site for NOAA's Ocean Exploration program

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

Barber, P. H., Palumbi, S. R., Erdmann, M. V., and M. K. Moosa. 2000. A marine Wallace's Line? Nature 406:692-693. Available online at http://www.stanford.edu/group/Palumbi/manuscripts/BARBER_ET._AL_2000.PDF_copy.pdf

http://www.actionbioscience.org/biodiversity/wilson.html "Speciation and Biodiversity," an interview with Edward O. Wilson

http://www.pbs.org/wgbh/evolution/library/glossary/ – A glossary from PBS of terms related to evolution

National Science Education Standards

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

Content Standard C: Life Science
- Biological evolution
- Interdependence of organisms

Content Standard D: Earth and Space Science
- Energy in the Earth system

Content Standard F: Science in Personal and Social Perspectives
- Personal and community health
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

Content Standard G: History and Nature of Science
- Historical perspectives

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.
The Earth has one big ocean with many features.

Fundamental Concept a. The ocean is the dominant physical feature on our planet Earth— covering approximately 70% of the planet's surface. There is one ocean with many ocean basins, such as the North Pacific, South Pacific, North Atlantic, South Atlantic, Indian and Arctic.

Fundamental Concept c. Throughout the ocean there is one interconnected circulation system powered by wind, tides, the force of the Earth's rotation (Coriolis effect), the Sun, and water density differences. The shape of ocean basins and adjacent land masses influence the path of circulation.

Fundamental Concept d. Sea level is the average height of the ocean relative to the land, taking into account the differences caused by tides. Sea level changes as plate tectonics cause the volume

of ocean basins and the height of the land to change. It changes as ice caps on land melt or grow. It also changes as sea water expands and contracts when ocean water warms and cools.
Fundamental Concept h. Although the ocean is large, it is finite and resources are limited.

Essential Principle 2.
The ocean and life in the ocean shape the features of the Earth.
Fundamental Concept b. Sea level changes over time have expanded and contracted continental shelves, created and destroyed inland seas, and shaped the surface of land..
Fundamental Concept e. Tectonic activity, sea level changes, and force of waves influence the physical structure and landforms of the coast.

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 e. The ocean is three-dimensional, offering vast living space and diverse habitats from the surface through the water column to the seafloor. Most of the living space on Earth is in the ocean.
Fundamental Concept f. Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is "patchy." Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.

Essential Principle 6.
The ocean and humans are inextricably interconnected.
Fundamental Concept a. The ocean affects every human life. It supplies freshwater (most rain comes from the ocean) and nearly all Earth's oxygen. It moderates the Earth's climate, influences our weather, and affects human health.
Fundamental Concept b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.
Fundamental Concept 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 40 years, use of ocean resources has increased significantly, therefore the future sustainability of ocean resources depends on our understanding of those resources and their potential and limitations.
Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.
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 send your comments to:
oceanexeducation@noaa.gov

For More Information

Paula Keener-Chavis, Director, Education Programs
NOAA Ocean Exploration Program
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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Celebes Sea Biodiversity Worksheet

Read the interview with Edward O. Wilson titled "Speciation and Biodiversity" (http://www.actionbioscience.org/biodiversity/wilson.html). Using information from this interview, as well as other Web sites and/or library resources, answer the following questions:

1. What is the "classical" definition of a species?

2. Does this definition work for species that reproduce asexually? If not, what is an alternative definition that includes these kinds of species?

3. What factors favor an increase in the number of species in an ecosystem?

4. What is speciation? What is the difference between sympatric and allopatric speciation?

5. What is the relationship between population size and survival of a species?

6. How rapidly are species disappearing from Earth's ecosystems compared to how rapidly new species are appearing?

7. What areas does E. O. Wilson identify as "hot spots" where habitats are most endangered and have the largest number of species found nowhere else?

8. What is endemism?

9. What is Wallace's Line?

10. What is Wallacea?

11. What are some of the possible explanations for the unusually large number of endemic species in Wallacea?

12. Refer to a map of the Celebes Sea and adjacent islands and waterbodies. Locate:
    - South China Sea
    - Tomini Bay
    - Flores Sea
    - Java Sea

13. Recall your teacher's description of the Indonesian Throughflow (or look it up if you don't remember the discussion). Look at the map of the Celebes Sea and think about what you know of the currents flowing through the area. How much endemism would you expect between the areas named in question 12 (that is, how different would you expect the plants and animals to be between these areas)? Why?

14. In the August 17, 2000, issue of the journal *Nature*, Barber, et al. report significant differences in the genetic structure of stomatopod populations in the Celebes Sea, South China Sea, Tomini Bay, Flores Sea, and Java Sea (stomatopods are a type of crustacean found around coral reefs). Do these observations confirm your ideas about endemism between these areas? What might account for these observations?