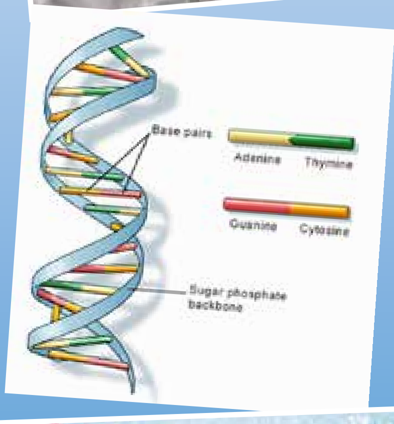
Ocean Exploration and Research

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lesson plan

Mapping the Uncharted Diversity of Arctic Marine Microbes

# Mapping Microbes in the Arctic

## Focus
Arctic marine microbes (Life Science)

## Grade Level
6-12

## Focus Question
Why are Arctic marine microbes important, and how can their populations be studied?

## Learning Objectives
- Students will develop a model to describe the role of marine microbes in cycling of matter and flow of energy among living and nonliving parts of an ecosystem.
- Students will develop and use a model to explain how the structure of DNA determines the structure of proteins that carry out the essential functions of life.
- Students will explain why Arctic marine microbes are important, and how changes in microbial populations might affect Arctic ecosystems.

## Materials
*See descriptions of activity options at the beginning of the Learning Procedure.*

**Activity 1**
- ❑ Computers with Internet access, or printed resource materials copied from sources cited in Resources
- ❑ Copies of *Marine Microbes Inquiry Guide*; one copy for each student or student group

**Activity 2**
For each student group:
- ❑ One Ziploc bag
- ❑ 300 beads (or other small objects), with the following color distribution:
  - White – 105
  - Red – 75
  - Green – 45
  - Pink – 45
  - Blue – 24
  - Purple – 6
- ❑ Sorting tray (to prevent the beads from rolling away)
- ❑ 6 small storage containers

**Activity 3**

For each student or student group:

- ❑ Copies of DNA molecule model with a version for reading and a version for writing, Master code sheet, and worksheet with blank spaces for recording decoded message

**Activity 4**

For each student or student group:

- ❑ Copies of model DNA, Vaccinia virus, Hepatitis B virus
- ❑ Cellophane tape
- ❑ Scissors

**Activity 5**

For each student or student group:

- ❑ Computers with Internet access
- ❑ Set of Microbe Sort cards (http://www.mbari.org/earth/mar_biology/microbial/BLAST/Microbe_sort.pdf) (Note: slow to download)
- ❑ Microbe personality cards (http://www.mbari.org/earth/mar_biology/microbial/BLAST/microbe_personalities_cards.pdf)
- ❑ Copy of Microbial Ecological Roles (http://www.mbari.org/earth/mar_biology/microbial/BLAST/Microbial_Ecological_Roles.pdf)
- ❑ Copy of Gene Sequence Files (http://www.mbari.org/earth/mar_biology/microbial/BLAST/16S_rRNA_sequences.txt)
- ❑ Sea View Software programs to be downloaded to computers (http://doua.prabi.fr/software/seaview.html)

## Audio-Visual Materials

- ❑ (Optional) Interactive whiteboard

## Teaching Time

Depends upon number of activities selected, at least two class periods per activity

## Seating Arrangement

Groups of two to four students

## Maximum Number of Students

30

## Key Words

DNA
DNA sequencing
Gene
Genome
Metagenome
Metagenomic mapping
Metatranscriptome
Metatranscriptomic sequencing

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**Images from Page 1 top to bottom:**

Single-celled (unicellular) algae, which develop in the lowermost sections of sea ice, often forming chains and filaments. Ice algae are an important component of the Arctic marine food web. Image courtesy of the NOAA Arctic Research Program.
http://oceanexplorer.noaa.gov/explorations/15arctic-microbes/background/missionplan/media/arctic-algae.html

DNA is a double helix formed by base pairs attached to a sugar-phosphate backbone. Image courtesy of U.S. National Library of Medicine.
http://oceanexplorer.noaa.gov/explorations/15arctic-microbes/background/dna-classification/media/dna.html

Sterilely sectioning a sea ice core in Franklin Bay, Canada. Image courtesy of Eric Collins.
http://oceanexplorer.noaa.gov/explorations/15arctic-microbes/background/seaice/media/core.html

Bristle worm collected from seafloor mud with a box core during a 2002 Arctic ocean exploration mission.Image courtesy of Bodil Bluhm and Casey Debenham, University of Alaska Fairbanks (UAF).
http://oceanexplorer.noaa.gov/explorations/15arctic-microbes/background/mud-life/mud-life.html

Microbe
Transcriptome

## 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.*

Marine microbes (including Bacteria, Archaea, Eukaryota, and viruses) account for 98% of the biomass in earth's ocean, and most of its biological activity. Marine microbes produce about half of the oxygen in Earth's atmosphere; are involved in most biological, geological, and chemical interactions; and are found in habitats ranging from the ocean surface to deep within rocks beneath the ocean floor. At least ten million bacterial species are estimated to exist in Earth's ocean. In addition to being an essential part of marine ecosystems, marine microbes are the source of valuable natural products that can benefit human health. For example, the harmful algae *Karenia brevis* produces Brevetoxin, a very potent toxin that may aid in stroke recovery. The same microalga also produces Brevenal, which can be used to treat cystic fibrosis and chronic obstructive pulmonary disease (COPD); and Escortin, which has the potential to transform cancer treatment by escorting anti-cancer drugs directly into cancerous cells.

Despite their importance, very little is known about marine microbes because 99% of them cannot be cultured under laboratory conditions, and cannot easily be observed in their natural environment. Recent advances in technologies for genetic analysis, however, are dramatically improving our ability to study marine microbes and their communities.

Improved understanding of marine microbes is particularly critical in the Arctic Ocean, which is one of the most rapidly changing ecosystems on Earth. Organic matter produced in Arctic sea ice is an essential part of pelagic and benthic Arctic ecosystems. For example, essential polyunsaturated fatty acids (PUFAs) are important to the nutrition of many species, but PUFAs cannot be synthesized by most metazoans. Sea ice algae are highly enriched with these compounds, and PUFA-producing bacteria have been found in the guts of deposit-feeders.

Arctic marine microbes can have other effects on ocean health and human wellness. In the last ten years, unusual mortality and unidentified diseases have been observed among Arctic marine mammals (including otters, seals, walruses, and polar bears) and the subsistence hunters that rely upon them, possibly resulting from unidentified infectious microbes or microbial toxins (for more information, please see http://www.alaskafisheries.noaa.gov/protectedresources/seals/ice/diseased/). Warmer waters in the Gulf of Alaska are associated with increased reproduction of *Vibrio parahaemolyticus*, a toxin-producing marine bacterium that has sickened thousands of people and negatively impacted the aquaculture industry in southeast Alaska.

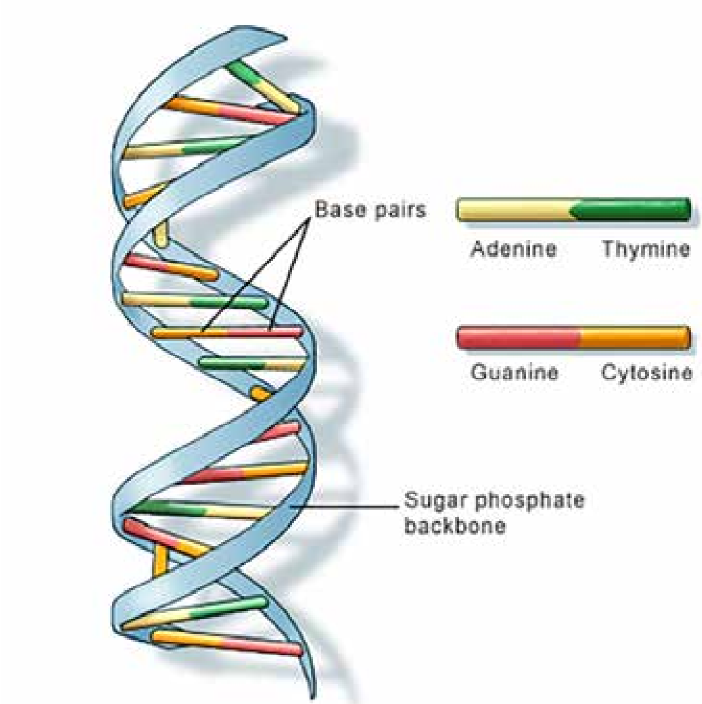
Because Arctic sea ice has been declining for several decades, it is particularly urgent to understand how Arctic marine microbes are responding to global changes and what impact these changes may have on living marine resources and human health.

The purpose of the Mapping the Uncharted Diversity of Arctic Marine Microbes expedition is to discover and characterize the molecular diversity of microbial communities associated with Arctic sea ice and benthic habitats. Specific objectives include:

1. Explore the diversity of expressed genes in Arctic sea ice and surface sediment communities, as well as in the gut and body wall surfaces of various deposit-feeders including holothurians, crustaceans, bivalves, urchins, sipuncula and echiura;
2. Explore the microbial community diversity of genes required for survival in extreme Arctic environments;
3. Compare the phylogenetic diversity of microbial communities of Arctic sea ice and surface sediments; and
4. Prepare visual representations of genetic data from Arctic microbial communities ("metagenomic maps").

To achieve these objectives, expedition scientists will use cutting-edge techniques for analyzing DNA, which is the molecule found in every living organisms that contains information needed for each organism to develop, survive and reproduce. A DNA molecule consists of two strands that are joined together in a shape that resembles a twisted ladder (often called a double helix). The two sides of the "ladder" are formed from alternating sugar (ribose) and phosphate molecules. The rungs of the ladder formed from two nitrogen bases that may be adenine and guanine or cytosine and thymine. The nitrogen bases in a single rung are called a base pair. The sequence of base pairs in a DNA molecule contains the specific genetic information for a particular organism. A sequence of three base pairs, called a triplet, corresponds to a specific amino acid. A series of triplets that specifies all the amino acids

DNA is a double helix formed by base pairs attached to a sugar-phosphate backbone. Image courtesy of U.S. National Library of Medicine.
http://oceanexplorer.noaa.gov/explorations/15arctic-microbes/background/dna-classification/media/dna.html



needed to make a particular protein is called a gene. A strand of DNA contains many genes. The complete set of genes for an organism is called that organism's genome.

Proteins from closely related organisms have similar sequences of amino acids because they share a relatively recent common ancestor. Since individual genes correspond to specific proteins, knowing the sequence of base pairs for a given gene in two organisms gives scientists a way to estimate the "relatedness" of the organisms. Knowing the base pair sequences for several genes generally improves the accuracy of the estimate. This technique is called molecular phylogenetics. The process of determining the sequence of base pairs is known as DNA sequencing. In addition to describing the genes of a single organisms, this process can be used to study the genes of multiple organisms. An inventory of genes in a mixed population of organisms is called a metagenome. Metagenomic mapping is a technique.

While the genes in an organism's DNA contain information to construct thousands of proteins, most of these proteins are not being produced at any given time. When the protein specified by a particular gene is being produced, that gene is said to be expressed. An inventory of expressed genes in an organism is called a transcriptome, and an inventory of expressed genes in a mixed population of organisms is called a metatranscriptome. The process of determining the base pair sequences in a mixed population of organisms is called metatranscriptomic sequencing.

## Learning Procedure

NOTE: Because marine microbes are critically important to Earth's ecosystems, yet are not prominently featured in most science curricula, this lesson provides five activities to introduce marine microbes and how they are investigated using DNA analysis. These activities can be used individually or in combination, depending upon available time and curricular requirements.

**Activity 1 – Introducing Marine Microbes** (grades 6-12; from the "What a Day for the Ocean Microbes! Classroom Activity"; http://www.education.noaa.gov/Special_Topics/docs/OSD%2014%20What%20A%20Day%20(6).pdf): Students conduct guided research to learn basic facts about marine microbes.

**Activity 2 – Simulating Random Sampling of Marine Microbes** (grades 6-12; by Barbara Bruno, Kimberly Tice, Kate Achilles, and Joan Matsuzaki from the American Society of Microbiology Microbial Discovery Activity series; http://www.asm.org/images/Education/K-12/2010%20marine%20microbes.pdf): Students learn how scientists quantify the abundance of marine microbes by randomly sampling a simulated marine microbe population (colored beads in a bag), then comparing the composition of their individual samples, their group's pooled sample data, and composition of the entire population. The file includes teacher background, detailed instructions, materials list, student worksheets, and student reading.

**Activity 3 – Cracking the Code** (grades 6-12; by Patricia Colbert and Phillis Unbehagen from the 1993 Woodrow Wilson Biology Institute; http://www.accessexcellence.org/AE/AEPC/WWC/1993/cracking.php): Students use paper models to demonstrate that the bases of the DNA molecule are analogous to the letters in an alphabet. Just as letters form a word when written in a certain sequence, nucleic acids, when written in a certain sequence, code for the assembling of a specific protein. Using the models, students decode a simulated DNA molecule, read, and then write a message.

**Activity 4 – Cloning Paper Plasmid** (grades 10-12; also by Patricia Colbert and Phillis Unbehagen from the 1993 Woodrow Wilson Biology Institute; http://www.accessexcellence.org/AE/AEPC/WWC/1993/cracking.php): Students use paper models to simulate cloning a DNA molecule to make a vaccine. The process includes the steps of DNA isolation, restriction endonuclease digestion, DNA ligation, and cell transformation.

**Activity 5 – Microbes are a BLAST** (grades 6 - 12; lesson plan from the Monterey Bay Aquarium Research Institute; http://www.mbari.org/earth/mar_biology/microbial/BLAST/micro_blast.html) Students explore the diversity of marine microbes in the marine environment, including classification activities, using DNA sequences to identify relatedness between microbes with phylogenetic trees, and identifying the ecological role of specific microbes by searching for the presence of functional genes. Activities use the SeaView software to compare genetic sequences between organisms, and the BLAST online software to search a genome for a specific function.
http://doua.prabi.fr/software/seaview.html
http://blast.ncbi.nlm.nih.gov/Blast.cgi

1. To prepare for this lesson:
   a. Review background information about the Mapping the Uncharted Diversity of Arctic Marine Microbes expedition (http://oceanexplorer.noaa.gov/explorations/15arctic-microbes/welcome.html), and the "DNA Classification" essay by Eric Collins (http://oceanexplorer.noaa.gov/explorations/15arctic-microbes/background/dna-classification/dna-classification.html).

b. Download and review procedures for one or more of the activities described above.

2. Briefly introduce the Mapping the Uncharted Diversity of Arctic Marine Microbes expedition, and ensure that students are familiar with the concepts of DNA, chromosomes, genes, base pairs, and genomes, and how these concepts apply to populations of multiple species as well as individuals in a single species.

3. Conduct one or more of the activities described above according to instructions included in the referenced files.

4. Lead a discussion about the importance of Arctic marine microbes, and how changes in microbial populations caused by changes in the Arctic climate might impact Arctic ecosystems. Students should realize that marine microbes are the dominant form of biomass in Earth's ocean; produce about half of the oxygen in Earth's atmosphere; are involved in most biological, geological, and chemical interactions; are a source of natural products that can benefit human health; and are an essential part of ocean ecosystems.

## The BRIDGE Connection

www.vims.edu/bridge/ – In the menu on the left, scroll over "Ocean Science Topics," then "Habitats," then click "Polar," for links to information and activities about polar ocean ecosystems.

## The "Me" Connection

Have students write a short essay on why Arctic marine microbes might be directly important to their own lives. Ideas may include microbes as a potential source of pharmaceuticals and other useful biological products, as well as the role of these organisms in polar ecosystems.

## Connections to Other Subjects

English/Language Arts, Mathematics

## Assessment

Student reports produced as part of selected activities, and class discussions provide opportunities for assessment.

## Extensions

1. Visit (http://oceanexplorer.noaa.gov/explorations/15arctic-microbes/welcome.html) for information and updates about discoveries made by the Mapping the Uncharted Diversity of Arctic Marine Microbes expedition.

2. See the "Microbes of Iron" lesson (http://oceanexplorer.noaa.gov/explorations/14fire/background/edu/rof_microbes_2014.pdf) from the 2014 Submarine Ring of Fire – Ironman expedition for an activity in which students create a model ecosystem to investigate succession in chemosynthetic bacterial communities.

## Other Relevant Lessons from NOAA's Ocean Exploration Program

**Microfriends**
(from the *Okeanos Explorer* Educational Materials Collection: Volume 1 Why do We Explore?) [http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/wdwe_microfriends.pdf]

Focus: Beneficial microorganisms

Students describe at least three ways in which microorganisms benefit people, describe aseptic procedures, and obtain and culture a bacterial sample on a nutrient medium.

**Living by the Code**
(from the 2003 Medicines from the Deep Sea expedition) [http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/meds_livingcode.pdf]

Focus: Functions of cell organelles and the genetic code in chemical synthesis

Students explain why new drugs are needed to treat cardiovascular disease, cancer, inflammation, and infections; infer why sessile marine invertebrates appear to be promising sources of new drugs; explain the overall process through which cells manufacture chemicals; and explain why it may be important to synthesize new drugs, rather than relying on the natural production of drugs.

## 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 - Web site for NOAA's Ocean Exploration program

http://oceanexplorer.noaa.gov/explorations/15arctic-microbes/welcome.html – Web site for the Mapping the Uncharted Diversity of Arctic Marine Microbes expedition http://oceanexplorer.noaa.gov/edu/themes/arctic/welcome.html The Ocean Explorer Arctic Theme Page: a compilation of the most useful Arctic educational content on our site, including essays, lesson plans, multimedia, and expeditions.

http://oceanexplorer.noaa.gov/facts/marinemicrobes.html – Ocean Exploration factsheet: What Are Marine Microbes?

http://serc.carleton.edu/microbelife/topics/special_collections/winogradsky.html – Web page from Microbial Life - Educational Resources, a collaborative project of the Marine Biology Laboratory, Woods Hole, MA, and Montana State University, Bozeman, MT

http://www.cosee.net/resources/themes/marinemicrobes/ – Consortium for Ocean Science Exploration and Engagement. Marine microbes resources webpage

http://www.microbeworld.org/types-of-microbes – Web site that describes the six main types of microbes

http://cmore.soest.hawaii.edu/education/kidskorner/index.htm – Center for Microbial Ecology: Research and Education's Education and Outreach Web page, with information and games about marine microbes

http://explore.noaa.gov/sites/OER/Documents/Marine-Microbes-Workshop-Report.pdf – NOAA Marine Microbes Workshop Report

## Next Generation Science Standards

The primary purpose of this lesson is to assist educators with incorporating information about Arctic microbes and the Mapping the Uncharted Diversity of Arctic Marine Microbes expedition into their instructional program. While they are not intended to target specific Next Generation Science Standards, activities in this lesson may be used to support specific NGSS elements as described below.

**MS-LS2 Ecosystems: Interactions, Energy, and Dynamics**

*Performance Expectation*

MS-LS2-3. Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem. [Clarification Statement: Emphasis is on describing the conservation of matter and flow of energy into and out of various ecosystems, and on defining the boundaries of the system.] [Assessment Boundary: Assessment does not include the use of chemical reactions to describe the processes.]

### Science and Engineering Practices

*Developing and Using Models*

- Develop a model to describe phenomena

### Disciplinary Core Ideas

*LS2.B Cycle of Matter and Energy Transfer in Ecosystems*

- Food webs are models that demonstrate how matter and energy is transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem.

### Crosscutting Concepts

*Energy and Matter*

- The transfer of energy can be tracked as energy flows through a natural system

*Connections to Nature of Science*

**Scientific Knowledge Assumes an Order and Consistency in Natural Systems**

- Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation.

*Common Core State Standards Connections:*

**ELA/Literacy –**

SL.8.5 Integrate multimedia and visual displays into presentations to clarify information, strengthen claims and evidence, and add interest.

**Mathematics –**

6.EE.C.9 Use variables to represent two quantities in a real-world problem that change in relationship to one another; write an equation to express one quantity, thought of as the dependent variable, in terms of the other quantity, thought of as the independent variable. Analyze the relationship between the dependent and independent variables using graphs and tables, and relate these to the equation.

**MS-LS3 Heredity: Inheritance and Variation of Traits**

*Performance Expectation*

MS-LS3-1. Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial, or neutral effects to the structure and function of the organism. [Clarification Statement: Emphasis is on conceptual understanding that changes in genetic material may result in making different proteins.] [Assessment Boundary: Assessment does not include specific changes at the molecular level, mechanisms for protein synthesis, or specific types of mutations.]

### Science and Engineering Practices

***Developing and Using Models***

- Develop a model to predict and/or describe phenomena.

### Disciplinary Core Ideas

***LS3.A Inheritance of Traits***

- Genes are located in the chromosomes of cells, with each chromosome pair containing two variants of each of many distinct genes. Each distinct gene chiefly controls the production of specific proteins, which in turn affects the traits of the individual. Changes (mutations) to genes can result in changes to proteins, which can affect the structures and functions of the organism and thereby change traits.

### Crosscutting Concepts

***Structure and Function***

- Complex and microscopic structures and systems can be visualized, modeled, and used to describe how their function depends on the shapes, composition, and relationships among its parts, therefore complex natural and designed structures/systems can be analyzed to determine how they function

***Common Core State Standards Connections:***

**ELA/Literacy -**

RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts.

RST.6-8.4 Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 6-8 texts and topics.

RST.6-8.7 Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).

SL.8.5 Integrate multimedia and visual displays into presentations to clarify information, strengthen claims and evidence, and add interest.

**HS-LS1 From Molecules to Organisms: Structures and Processes**

*Performance Expectation*

HS-LS1-1. Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells. [Assessment Boundary: Assessment does not include identification of specific cell or tissue types, whole body systems, specific protein structures and functions, or the biochemistry of protein synthesis.]

### Science and Engineering Practices

*Constructing Explanations and Designing Solutions*

- Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.

### Disciplinary Core Ideas

*LS1.A Structure and Function*

- Systems of specialized cells within organisms help them perform the essential functions of life.
- All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins, which carry out most of the work of cells.

### Crosscutting Concepts

*Structure and Function*

- Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem.

*Common Core State Standards Connections:*

**ELA/Literacy -**

RST.11.12.1 Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

WHST.9-12.2 Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes.

WHST.9-12.9 Draw evidence from informational texts to support analysis, reflection, and research.

**HS-LS2 Ecosystems: Interactions, Energy, and Dynamics**

*Performance Expectation*

HS-LS2-6. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. [Clarification Statement: Examples of changes in ecosystem conditions could include modest biological or physical changes, such as moderate hunting or a seasonal flood; and extreme changes, such as volcanic eruption or sea level rise.]

### Science and Engineering Practices

***Engaging in Argument from Evidence***

- Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments.

### Disciplinary Core Ideas

***LS2.C Ecosystem Dynamics, Functioning, and Resilience***

- A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability.

### Crosscutting Concepts

***Stability and Change***

- Much of science deals with constructing explanations of how things change and how they remain stable

***Common Core State Standards Connections:***

**ELA/Literacy -**

RST.9-10.8 Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem.

RST.11-12.1 Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

RST.11-12.7 Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

RST.11-12.8 Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

**Mathematics -**

MP.2 Reason abstractly and quantitatively.

HSS-ID.A.1 Represent data with plots on the real number line.

HSS-IC.A.1 Understand statistics as a process for making inferences about population parameters based on a random sample from that population.

HSS-IC.B.6 Evaluate reports based on data.

## Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 3.

The ocean is a major influence on weather and climate.

*Fundamental Concept e*. The ocean dominates Earth's carbon cycle. Half of the primary productivity on Earth takes place in the sunlit layers of the ocean. The ocean absorbs roughly half of all carbon dioxide and methane that are added to the atmosphere.

Essential Principle 5.

The ocean supports a great diversity of life and ecosystems.

*Fundamental Concept a.* Ocean life ranges in size from the smallest living things, microbes, to the largest animal on Earth, blue whales.

*Fundamental Concept b.* Most of the organisms and biomass in the ocean are microbes, which are the basis of all ocean food webs. Microbes are the most important primary producers in the ocean. They have extremely fast growth rates and life cycles, and produce a huge amount of the carbon and oxygen on Earth.

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. The ocean moderates the Earth's climate, influences our weather, and affects human health. *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 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 e.* Use of mathematical models is now an essential part of ocean sciences. Models help us understand the complexity of the ocean and of its interaction with Earth's climate. They process observations and help describe the interactions among systems.

## 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, Mt. Pleasant, SC.
Design/layout: Coastal Images Graphic Design, Mt. Pleasant, SC.

## Credit