Introduction to the Ocean Literacy Scope and Sequence for Grades K through 12

The Ocean Literacy Scope and Sequence for Grades K–12 is a series of 28 conceptual flow diagrams that represent and organize the ideas of the seven Ocean Literacy Principles into four grade bands—K through 2, 3 through 5, 6 through 8, and 9 through 12—effectively showing what students should know at the end of 2nd, 5th, 8th, and 12th grades. This document provides specific guidance to educators, standards committees, curriculum developers, and scientists conducting outreach. It is one part of the Ocean Literacy Framework which comprises four key documents:

» Ocean Literacy: The Essential Principles of Ocean Sciences for Learners of All Ages;

» The Ocean Literacy Scope and Sequence for Grades K–12;

» Alignment of Ocean Literacy to the Next Generation Science Standards; and

» International Ocean Literacy Survey.

The scope and sequence was developed iteratively and thoughtfully with significant and substantive participation by hundreds of scientists, science educators, and classroom teachers around the country. Thus, it represents a community consensus regarding the essential ideas in ocean sciences that all students should understand by the end of Grade 12 and a road map for how to get there.

The scope and sequence conceptual flow diagrams provide specific guidance to help educators as they work to grow their learner’s conceptual understanding of essential ocean concepts. Dive into the conceptual flow diagrams on the following pages.

To access online versions of the Framework documents, please visit www.marine-ed.org/ocean-literacy/overview


4 A more complete history is provided in the introduction to this handbook.
The Ocean Literacy Scope and Sequence comprises 28 conceptual flow diagrams (hereafter referred to as flows). There is one flow for each principle for each grade band (K through 2, 3 through 5, 6 through 8, and 9 through 12). Each flow is read from top to bottom and left to right and represents one possible way of breaking down and organizing the major concepts and supporting ideas for each principle for a grade band.

The essential principle as well as the grade level are listed at the top of the page. The diagram shows three sets of text boxes (called strands) cascading down the page. Each strand represents a topic related to the essential principle and includes concepts and supporting subconcepts focused on the topic.

Conceptual flow diagrams can be used as a suggested instructional sequence, organizer of ideas, and/or indicator of learning progression.

In this flow for Principle 1, Grades 3 through 5, there are three strands of topics and five levels of ideas. Read the flow from top to bottom and left to right, from Strand A (A1 to A5) to Strand B (B1 to B10) to Strand C (C1 to C5). Some of the concepts cross-reference other concepts in other principles within that same grade band. These cross-references are connections between principles.

Dashed lines lead to cross-referenced concept statements in other essential principles.
Strand A of conceptual flow diagram of Principle 1 for Grades 3 to 5. Here is a breakdown of the components in a strand. The strand is identified by topic for easy reference. The strand begins with a major concept and then nested below are two levels of ideas that support the bigger idea. Supporting ideas can be examples, but not always.
**How to Use the Alternative Form of the Conceptual Flow Diagrams**

In addition to the conceptual flow diagrams of the *Ocean Literacy Scope and Sequence for Grades K–12*, we also present the concepts in a tabular format. This helps convey the connections and relationships between concepts, without relying on visual cues.

---

**Strands of connected ideas are organized under a topic title and brief description. Instead of using arrows to convey connections between individual concepts, concepts are stacked in columns in the order in which they should be presented (i.e., top to bottom, then left to right). This means some concepts are repeated under each higher level concept to convey the connections among them. As users of assistive technology navigate the tables, the concepts become more and more specific.**

---

<table>
<thead>
<tr>
<th>Properties of Ocean Water — A</th>
<th>Ocean Circulation — B</th>
<th>Geographic and Geologic Features — C</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>B1</td>
<td>C1</td>
</tr>
<tr>
<td>97% of all water on Earth is salt water in the ocean.</td>
<td>Connected body of water that circulates through all the ocean basins and continents.</td>
<td>The ocean floor has a variety of geological and geographical features comparable to those on land.</td>
</tr>
<tr>
<td>A2</td>
<td>B2</td>
<td>C2</td>
</tr>
<tr>
<td>Only 3% of all water on Earth is fresh water stored in lakes, rivers, underground aquifers, glaciers, and other places.</td>
<td>The ocean, the largest reservoir of water</td>
<td>The ocean has many basins. They are called the Pacific, Atlantic, Indian, Arctic, and Southern basins.</td>
</tr>
<tr>
<td>A3</td>
<td>B3</td>
<td>C3</td>
</tr>
<tr>
<td>Most of all the fresh water in the world is stored in ice caps and glaciers</td>
<td>Water circulating from land to the ocean and back via watersheds and the wind.</td>
<td>The ocean floor has other features such as mountains, plains, valleys, volcanoes, canyons, trenches, and ridges.</td>
</tr>
<tr>
<td>A4</td>
<td>B4</td>
<td>C4</td>
</tr>
<tr>
<td>Ocean salinity and temperature vary throughout the ocean.</td>
<td>Water density-driven currents</td>
<td>The features of the ocean floor influence ocean circulation patterns.</td>
</tr>
<tr>
<td>A5</td>
<td>B5</td>
<td>C5</td>
</tr>
<tr>
<td>Freshwater melting from glaciers contributes to the ocean and can change salinity and temperature and cause sea level to rise.</td>
<td>The ocean is partly driven by these differences in salinity and temperature.</td>
<td>The ocean has the highest mountain on Earth, called Hawaii, an island in the Pacific Ocean.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Principle 1: Earth has one big ocean with many features.**

The ocean, which covers 70% of Earth’s surface, is the defining feature of the planet.
Conceptual Flow Diagrams

Principle 1

Principle 2

Principle 3

Principle 4

Principle 5

Principle 6

Principle 7
Although the ocean is large, its dimensions are limited. Ocean basins are composed of the sea floor and all of its properties of ocean water. Ocean water is in constant motion. Water circulates between the ocean and atmosphere through the water cycle. Waves are a disturbance of water that transfer a large amount of energy over a long distance, but with very little lateral movement of water. Tides are periods of rise and fall that correspond to sea level. 

The ocean, which covers 70% of Earth’s surface, is the defining feature of the planet. The ocean, which covers 70% of Earth’s surface, is the defining feature of the planet. Ocean water is in constant motion. Water circulates between the ocean and atmosphere through the water cycle. Waves are a disturbance of water that transfer a large amount of energy over a long distance, but with very little lateral movement of water. Tides are periods of rise and fall that correspond to sea level.
All life on Earth depends on phosphorus for important compounds, e.g., ATP, DNA, and phospholipids. These include C, P, N, S, O and many metals such as Fe, Zn, Ca, Na, K.

Ocean trenches, island arcs, stratovolcanoes, and some mountain ranges are examples of geologic features associated with subduction.

The ocean is the largest reservoir of uptake carbon dioxide and inorganic carbon on Earth. The ocean absorbs CO₂ from the atmosphere through the process of photosynthesis.

The ocean acts as a reservoir of water in various concentrations. Water transported to the ocean is one of the major sources of water on Earth. The water cycle can also be influenced by the ocean, such as the formation of clouds and precipitation.

For more information, visit oceanliteracyNMEA.org

A Handbook for Increasing Ocean Literacy

Principle 2: The ocean and life in the ocean shape the features of Earth.
A Handbook for Increasing Ocean Literacy

All the rocks on land will end up in the ocean due to weathering and erosion. The continual formation and breakdown of rocks constitutes the rock cycle. The ocean plays a major role in the biogeochemical cycles that are fundamental to life on Earth. Rocks are constantly being broken down and recycled through weathering, erosion, and processes associated with plate tectonics, such as subduction, uplift, and accretion. Accretion is the process by which material is added to the continental plates at convergent plate boundaries. Uplift and accretion processes, as well as sea level changes, may relocate sedimentary rocks containing silica onto land, where rocks can undergo weathering and erosion before eventually returning to the ocean. Soil and carbonate from shells and other skeletal parts. Some organic (e.g., lipids, sugars) and inorganic (e.g., inorganic carbon gas) carbon is converted back to dissolved inorganic forms (e.g., CO₂). Some organic forms of nitrogen (e.g., lipids, sugars) and nitrogen in the form of nitrogen gas (N₂) are converted back to dissolved inorganic forms. Some relatively small fractions of the biogenic silica accumulates in ocean sediments, where it undergoes transformations and, over time, becomes part of sedimentary rocks, such as chert, diatomaceous earth, and glassy siliceous sponges.

**Rock Cycle and Plate Tectonics — A**

- **A1**: All rocks on land will end up in the ocean due to weathering and erosion.
- **A2**: Rocks are constantly being broken down and recycled through weathering, erosion, and processes associated with plate tectonics, such as subduction, uplift, and accretion.
- **A3**: Accretion is the process by which material is added to the continental plates at convergent plate boundaries.
- **A4**: Uplift and accretion processes, as well as sea level changes, may relocate sedimentary rocks containing silica onto land, where rocks can undergo weathering and erosion before eventually returning to the ocean.
- **A5**: Some organic carbon rocks to the ocean floor, where they accumulate over time and may become fossil fuel.
- **A6**: Some organic (e.g., lipids, sugars) and inorganic (e.g., inorganic carbon gas) carbon is converted back to dissolved inorganic forms (e.g., CO₂).
- **A7**: Some organic forms of nitrogen (e.g., lipids, sugars) and nitrogen in the form of nitrogen gas (N₂) are converted back to dissolved inorganic forms. Some relatively small fractions of the biogenic silica accumulates in ocean sediments, where it undergoes transformations and, over time, becomes part of sedimentary rocks, such as chert, diatomaceous earth, and glassy siliceous sponges.

**Biogeochemical Cycles — B**

- **B1**: All elements are present in ocean water at various concentrations. Many elements in the ocean are held by living organisms. These include C, N, P, Si, and O, and many others such as Fe, Mn, Cu, Na, K. Other elements (Si, Cl) are needed by some select organisms.
- **B2**: Oceanic organisms (e.g., diatoms, radiolaria) accumulate in ocean sediments, where they become part of the organic matter in sedimentary rocks.
- **B3**: Some organic forms of nitrogen (e.g., lipids, sugars) and inorganic (e.g., inorganic carbon gas) carbon is converted back to dissolved inorganic forms (e.g., CO₂). Some organic forms of nitrogen (e.g., lipids, sugars) and nitrogen in the form of nitrogen gas (N₂) are converted back to dissolved inorganic forms. Some relatively small fractions of the biogenic silica accumulates in ocean sediments, where it undergoes transformations and, over time, becomes part of sedimentary rocks, such as chert, diatomaceous earth, and glassy siliceous sponges.
- **B4**: Uplift and accretion processes, as well as sea level changes, may relocate sedimentary rocks containing silica onto land, where rocks can undergo weathering and erosion before eventually returning to the ocean.
- **B5**: Anthropogenic burning of fossil fuels increases carbon dioxide and releases carbon back into the atmosphere, which affects the climate and pull carbon out of the ocean.
- **B6**: Anthropogenic burning of fossil fuels increases carbon dioxide and releases carbon back into the atmosphere, which affects the climate and pull carbon out of the ocean.

**Rock Cycle and Plate Tectonics — A**

- **A1**: All rocks on land will end up in the ocean due to weathering and erosion. The continual formation and breakdown of rocks constitutes the rock cycle. The ocean plays a major role in the biogeochemical cycles that are fundamental to life on Earth.
- **A2**: Rocks are constantly being broken down and recycled through weathering, erosion, and processes associated with plate tectonics, such as subduction, uplift, and accretion. Accretion is the process by which material is added to the continental plates at convergent plate boundaries. Uplift and accretion processes, as well as sea level changes, may relocate sedimentary rocks containing silica onto land, where rocks can undergo weathering and erosion before eventually returning to the ocean.
- **A3**: Some organic carbon rocks to the ocean floor, where they accumulate over time and may become fossil fuel.
- **A4**: Some organic (e.g., lipids, sugars) and inorganic (e.g., inorganic carbon gas) carbon is converted back to dissolved inorganic forms (e.g., CO₂).
- **A5**: Some organic forms of nitrogen (e.g., lipids, sugars) and nitrogen in the form of nitrogen gas (N₂) are converted back to dissolved inorganic forms. Some relatively small fractions of the biogenic silica accumulates in ocean sediments, where it undergoes transformations and, over time, becomes part of sedimentary rocks, such as chert, diatomaceous earth, and glassy siliceous sponges.

**Biogeochemical Cycles — B**

- **B1**: All elements are present in ocean water at various concentrations. Many elements in the ocean are held by living organisms. These include C, N, P, Si, and O, and many others such as Fe, Mn, Cu, Na, K. Other elements (Si, Cl) are needed by some select organisms.
- **B2**: Oceanic organisms (e.g., diatoms, radiolaria) accumulate in ocean sediments, where they become part of the organic matter in sedimentary rocks.
- **B3**: Some organic forms of nitrogen (e.g., lipids, sugars) and inorganic (e.g., inorganic carbon gas) carbon is converted back to dissolved inorganic forms (e.g., CO₂). Some organic forms of nitrogen (e.g., lipids, sugars) and nitrogen in the form of nitrogen gas (N₂) are converted back to dissolved inorganic forms. Some relatively small fractions of the biogenic silica accumulates in ocean sediments, where it undergoes transformations and, over time, becomes part of sedimentary rocks, such as chert, diatomaceous earth, and glassy siliceous sponges.
- **B4**: Uplift and accretion processes, as well as sea level changes, may relocate sedimentary rocks containing silica onto land, where rocks can undergo weathering and erosion before eventually returning to the ocean.
- **B5**: Anthropogenic burning of fossil fuels increases carbon dioxide and releases carbon back into the atmosphere, which affects the climate and pull carbon out of the ocean.
- **B6**: Anthropogenic burning of fossil fuels increases carbon dioxide and releases carbon back into the atmosphere, which affects the climate and pull carbon out of the ocean.
## Principle 3: The ocean is a major influence on weather and climate.

*The interaction of oceanic and atmospheric processes controls weather and climate by dominating Earth’s energy system.*

### Weather and Climate — A

<table>
<thead>
<tr>
<th>Global Climate Change — B</th>
<th>Consequences of Global Climate Change — C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Climate and weather are influenced by energy transfer from the sun. Energy transfer from the sun is controlled by the sun, the large mass of gas that surrounds Earth, and other factors.</td>
<td>Changes in the ocean/atmosphere system can result in changes to the climate.</td>
</tr>
<tr>
<td>The ocean is a major heat reservoir, with a large capacity to absorb and store solar energy.</td>
<td>Changes in temperature and circulation patterns can alter atmospheric processes and affect climate.</td>
</tr>
<tr>
<td>The ocean absorbs most of the solar radiation reaching Earth. Differential heating of Earth results in circulation patterns in the atmosphere and ocean that globally distribute the heat.</td>
<td>Differential heating also drives the circulation of the ocean, which moderates the global climate.</td>
</tr>
<tr>
<td>The ocean transports heat through ocean basins.</td>
<td>Ocean circulation, driven by wind patterns, is a primary mechanism for heat transport.</td>
</tr>
<tr>
<td>Those wind patterns transfer heat to the ocean.</td>
<td>The increase in sea surface temperature is a consequence of increased heat input from the atmosphere.</td>
</tr>
<tr>
<td>Ocean cur</td>
<td>Ocean cur</td>
</tr>
<tr>
<td>Additional factors that affect wind patterns include El Niño and La Niña events, which can alter weather patterns globally.</td>
<td>Additional factors that affect wind patterns include El Niño and La Niña events, which can alter weather patterns globally.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Weather and Climate — A

<table>
<thead>
<tr>
<th>Ocean Currents</th>
<th>Climate Patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean currents are driven by the Coriolis effect and differences in ocean temperature and salinity.</td>
<td>Climate patterns are influenced by ocean currents, which can alter weather and climate.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Weather and Climate — A

<table>
<thead>
<tr>
<th>Ocean Acidification</th>
<th>Other Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>The increase in ocean acidity is a consequence of increased carbon dioxide levels in the atmosphere.</td>
<td>Ocean acidification can affect the structure, ecology, and productivity of marine ecosystems.</td>
</tr>
<tr>
<td>As more carbon dioxide dissolves in the ocean, it forms carbonic acid, which increases the acidity of the ocean.</td>
<td>Higher acidity can affect the shells and skeletons of marine species, including coral and shellfish.</td>
</tr>
<tr>
<td>Ocean acidification can cause further changes in the ocean, such as changes in marine ecosystems and the productivity of marine plants and animals.</td>
<td>As a result, ecosystems can become more vulnerable to changes in the ocean.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Weather and Climate — A

<table>
<thead>
<tr>
<th>Climate Change and Human Activity</th>
<th>Other Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate change is caused by human activity, including the burning of fossil fuels and deforestation.</td>
<td>Climate change can have physical, chemical, biological, economic, and social consequences.</td>
</tr>
<tr>
<td>Human activity is one of the main drivers of climate change.</td>
<td>Climate change can cause sea-level rise, which can affect coastal communities and ecosystems.</td>
</tr>
<tr>
<td>Climate change can cause sea-level rise, which can affect coastal communities and ecosystems.</td>
<td>Climate change can cause sea-level rise, which can affect coastal communities and ecosystems.</td>
</tr>
<tr>
<td>Climate change can cause sea-level rise, which can affect coastal communities and ecosystems.</td>
<td>Climate change can cause sea-level rise, which can affect coastal communities and ecosystems.</td>
</tr>
</tbody>
</table>

### Weather and Climate — A

<table>
<thead>
<tr>
<th>Climate Change and Feedback Loops</th>
<th>Other Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedback loops can cause rapid and on a larger scale.</td>
<td>Climate change can cause important changes to the ocean and atmosphere, including changes to ocean circulation patterns, which can alter weather and climate.</td>
</tr>
<tr>
<td>As glaciers and ice shelves melt, sea level can rise.</td>
<td>Climate change can cause important changes to the ocean and atmosphere, including changes to ocean circulation patterns, which can alter weather and climate.</td>
</tr>
<tr>
<td>As glaciers and ice shelves melt, sea level can rise.</td>
<td>Climate change can cause important changes to the ocean and atmosphere, including changes to ocean circulation patterns, which can alter weather and climate.</td>
</tr>
<tr>
<td>As glaciers and ice shelves melt, sea level can rise.</td>
<td>Climate change can cause important changes to the ocean and atmosphere, including changes to ocean circulation patterns, which can alter weather and climate.</td>
</tr>
</tbody>
</table>

### Weather and Climate — A

<table>
<thead>
<tr>
<th>Climate Change and Ocean Chemistry</th>
<th>Other Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changes in ocean chemistry can alter the balance of gases in the atmosphere.</td>
<td>Climate change can cause important changes to the ocean and atmosphere, including changes to ocean circulation patterns, which can alter weather and climate.</td>
</tr>
<tr>
<td>Changes in ocean chemistry can alter the balance of gases in the atmosphere.</td>
<td>Climate change can cause important changes to the ocean and atmosphere, including changes to ocean circulation patterns, which can alter weather and climate.</td>
</tr>
<tr>
<td>Changes in ocean chemistry can alter the balance of gases in the atmosphere.</td>
<td>Climate change can cause important changes to the ocean and atmosphere, including changes to ocean circulation patterns, which can alter weather and climate.</td>
</tr>
<tr>
<td>Changes in ocean chemistry can alter the balance of gases in the atmosphere.</td>
<td>Climate change can cause important changes to the ocean and atmosphere, including changes to ocean circulation patterns, which can alter weather and climate.</td>
</tr>
</tbody>
</table>

### Weather and Climate — A

<table>
<thead>
<tr>
<th>Climate Change and Economic Impacts</th>
<th>Other Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic impacts of climate change can include changes in agricultural productivity, which can affect food security and economic stability.</td>
<td>Climate change can cause important changes to the ocean and atmosphere, including changes to ocean circulation patterns, which can alter weather and climate.</td>
</tr>
<tr>
<td>Economic impacts of climate change can include changes in agricultural productivity, which can affect food security and economic stability.</td>
<td>Climate change can cause important changes to the ocean and atmosphere, including changes to ocean circulation patterns, which can alter weather and climate.</td>
</tr>
<tr>
<td>Economic impacts of climate change can include changes in agricultural productivity, which can affect food security and economic stability.</td>
<td>Climate change can cause important changes to the ocean and atmosphere, including changes to ocean circulation patterns, which can alter weather and climate.</td>
</tr>
<tr>
<td>Economic impacts of climate change can include changes in agricultural productivity, which can affect food security and economic stability.</td>
<td>Climate change can cause important changes to the ocean and atmosphere, including changes to ocean circulation patterns, which can alter weather and climate.</td>
</tr>
</tbody>
</table>
**Principle 4:**

**The ocean makes Earth habitable.**

- **A.** The accumulation of oxygen in Earth's atmosphere through photosynthesis was necessary for life to develop and be sustained on land.
  - **A.1.** All oxygen gas came originally from photosynthetic organisms in the ocean.
  - **A.2.** About 3 billion years ago, cyanobacteria, with the ability to use sunlight, water, and gases to synthesize organic molecules, produced oxygen gas as a waste product.
  - **A.3.** Until about 2.5 billion years ago, the majority of oxygen gas produced through photosynthesis was consumed in the process of oxidizing reduced compounds, forming vast sedimentary deposits, and changing the chemistry of the ocean and sediments.
  - **A.4.** Dissolved oxygen started to accumulate in the ocean when much of the free reduced compounds were oxidized.
  - **A.5.** The accumulation of oxygen in the ocean allowed for the development of aerobic bacteria that used oxygen in a new biochemical pathway, producing ATP more efficiently.
  - **A.6.** This energy efficient biochemical pathway that developed in aerobic bacteria, along with oxygen in the ocean, allowed for the development of complex oceanic eukaryotic cells about 2 billion years ago.
  - **A.7.** Between 2.3 and 2.4 billion years ago, the oxygen concentration in the ocean was high enough that it started to escape and accumulate in the atmosphere, where it formed ozone, blocking much of the UV radiation from reaching Earth's surface.
  - **A.8.** Multicellular life, which requires high oxygen levels, developed about 1 billion years ago. By 550 million years ago, free oxygen and ozone levels were high enough to allow the development of terrestrial organisms.

- **B.** Life started in the ocean and the earliest evidence of life is found in ancient ocean sediments.
  - **B.1.** The millions of different species of organisms on Earth today are related by descent from common ancestors that evolved in the ocean and continue to evolve today.
  - **B.2.** The fossil record of ancient lifeforms provides evidence for the theory of evolution and the important role the ocean played in the evolution of life on Earth.
  - **B.3.** The first multicellular organisms to invade land from the ocean were plants, followed by arthropods. Later, organisms, such as lobe-finned fishes, started moving between the shallows and the land. These fishes evolved into amphibians.
  - **B.4.** One dominant theory about the evolution of early lifeforms (prokaryotes) is that they evolved about 3.5 billion years ago near a hydrothermal vent in the ocean.
  - **B.5.** Most living organisms, including all animals, plants, fungi, and protists, are eukaryotes that evolved from prokaryotes.

See Principle 5: C12

See Principle 6: A3
### Principle 4: The ocean makes Earth habitable.

<table>
<thead>
<tr>
<th>Oxygen Production — A</th>
<th>Origins of Life — B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A1</strong> All oxygen gas came originally from photosynthetic organisms in the ocean.</td>
<td><strong>A9</strong> Photosynthesis produces oxygen gas and is balanced by a loss of oxygen gas through respiration, decay of organisms, and oxidation of exposed minerals. The burial of some dead organisms in the sea floor sediments prevents their decay and keeps atmospheric oxygen near 20%.</td>
</tr>
<tr>
<td><strong>A2</strong> About 3 billion years ago, cyanobacteria, with the ability to use sunlight, water, and gases to synthesize organic molecules, produced oxygen gas as a waste product.</td>
<td><strong>A10</strong> There is no steady state of oxygen gas on geological time scales. Oxygen and carbon dioxide concentrations in the atmosphere change within relatively wide limits, controlled by a combination of biological, geological, and chemical processes.</td>
</tr>
<tr>
<td><strong>A3</strong> Until about 2.5 billion years ago, the majority of oxygen gas produced through photosynthesis was consumed in the process of oxidizing reduced compounds, forming vast sedimentary deposits, and changing the chemistry of the ocean and sediments.</td>
<td><strong>A4</strong> Dissolved oxygen started to accumulate in the ocean when much of the free reduced compounds were oxidized.</td>
</tr>
<tr>
<td><strong>A5</strong> The accumulation of oxygen in the ocean allowed for the development of aerobic bacteria that used oxygen in a new biochemical pathway, producing ATP more efficiently.</td>
<td><strong>A7</strong> Between 2.3 and 2.4 billion years ago, the oxygen concentration in the ocean was high enough that it started to escape and accumulate in the atmosphere, where it formed ozone, blocking much of the UV radiation from reaching Earth's surface.</td>
</tr>
<tr>
<td><strong>A6</strong> This energy efficient biological pathway that developed in aerobic bacteria, along with oxygen in the ocean, allowed for the development of complex oceanic eukaryotic cells about 2 billion years ago.</td>
<td><strong>A8</strong> Multicellular life, which requires high oxygen levels, developed about 1 billion years ago. By 550 million years ago, free oxygen and ozone levels were high enough to allow the development of terrestrial organisms.</td>
</tr>
<tr>
<td><strong>B1</strong> The millions of different species of organisms on Earth today are related by descent from common ancestors that evolved in the ocean and continue to evolve today.</td>
<td><strong>B2</strong> The fossil record of ancient lifeforms provides evidence for the theory of evolution and the important role the ocean played in the evolution of life on Earth.</td>
</tr>
<tr>
<td><strong>B3</strong> One dominant theory about the evolution of early lifeforms (prokaryotes) is that they evolved about 3.5 billion years ago near a hydrothermal vent in the ocean.</td>
<td><strong>B5</strong> The first multicellular organisms to invade land from the ocean were plants, followed by arthropods. Later, organisms, such as lobe-finned fishes, started moving between the shallows and the land. These fishes evolved into amphibians.</td>
</tr>
<tr>
<td><strong>B4</strong> Most living organisms, including all animals, plants, fungi, and protists, are eukaryotes that evolved from prokaryotes.</td>
<td><strong>B6</strong></td>
</tr>
</tbody>
</table>
nutrient recycling. Nitrogen, primary productivity are near the
A5
Principle 5
The diversity of ocean ecosystems allows for many lifeforms and adaptations of ocean organisms.
Diverse Adaptations to Environmental Factors — C22
Organisms in the ocean exhibit a wide variety of adaptations to survive in a watery environment.
C48
C27
C38
Diversity of Feeding Behaviors — C37
A7
C31
C50
C34
Organisms in the ocean have a variety of reproductive strategies and life cycles.
B12
C52
C36
B8
C28
C16
C23
The great diversity and number of species of ma
aries and kelp forests, support a
ecosystems on Earth, thrive in nu
ganisms are adapted
to live within specific
zonation exists as distinct, vertically distributed zones. Vertical zonation exists as distinct

density
live only within
land. Some members
live in marine environments.
flowering plants.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Dinoflagellates are phyto
produced on Earth. Diatoms
have cell walls made of glass-
hard to find, some strategies include:
filtering large quantities of
down detritus and recycle
made most of the oxygen
an increase in the numbers
Coastal pollution can cause
leading to disease in humans
organisms such as corals.
Principle 6: The ocean and humans are inextricably interconnected.

The ocean has an incredible array of renewable and non-renewable resources that humans use. Aquaculture has increased the amount of food organisms in the ocean provide, most of the photosynthetic energy resources and thus increased demand. Many of our medicines, bacteria, algae, sponges, and raw materials are extracted or derived from the ocean.

Use of the Ocean — A

- Topography is a common area:
  - Coastal areas provide opportunities for recreation, inspiration, and cultural rejuvenation.
- The deliberate alteration of the ocean and/or terrestrial topography can have negative impacts on marine ecosystems.
  - Some of these impacts include sedimentation that impacts on marine ecosystems, block coral growth, the loss of fish habitats, the disruption of migration predator/prey relationships, which destabilizes food webs and leads to a loss of biodiversity.
- Biological changes of ocean ecosystems:
  - Increased carbon emissions into the atmosphere disrupt relationships between organisms, such as symbiotic relationships between coral and zooxanthellae.
- The exponential growth of human populations, together with technological advances, have exacerbated changes in the ocean and atmosphere. Concerned citizens, scientists, and organizations have worked to minimize the effects of some human actions that are responsible for the disruption of migration patterns, and fisheries. To do this, laws concerning marine resources have been passed and regulations and accords aimed toward environmental sustainability. It is important for the public to learn about the issues regarding the ocean and to take action.
- The deliberate alteration of the ocean and/or terrestrial topography can have negative impacts on marine ecosystems.
  - Some of these impacts include sedimentation that impacts on marine ecosystems, block coral growth, the loss of fish habitats, the disruption of migration predator/prey relationships, which destabilizes food webs and leads to a loss of biodiversity.
- Biological changes of ocean ecosystems:
  - Increased carbon emissions into the atmosphere disrupt relationships between organisms, such as symbiotic relationships between coral and zooxanthellae.
- The exponential growth of human populations, together with technological advances, have exacerbated changes in the ocean and atmosphere. Concerned citizens, scientists, and organizations have worked to minimize the effects of some human actions that are responsible for the disruption of migration patterns, and fisheries. To do this, laws concerning marine resources have been passed and regulations and accords aimed toward environmental sustainability. It is important for the public to learn about the issues regarding the ocean and to take action.

Human Impact on the Ocean and Atmosphere — D

- The ocean is a global economy and thus increased demand.
- The ocean and its resources provide most of the food we eat.
- The ocean connects people from all over the world, contributing to their lives. The ocean provides a source of inspiration for recreation, and thus increased demand.
- Topography is a common area:
  - Coastal areas provide opportunities for recreation, inspiration, and cultural rejuvenation.
- The deliberate alteration of the ocean and/or terrestrial topography can have negative impacts on marine ecosystems.
  - Some of these impacts include sedimentation that impacts on marine ecosystems, block coral growth, the loss of fish habitats, the disruption of migration predator/prey relationships, which destabilizes food webs and leads to a loss of biodiversity.
- Biological changes of ocean ecosystems:
  - Increased carbon emissions into the atmosphere disrupt relationships between organisms, such as symbiotic relationships between coral and zooxanthellae.
- The exponential growth of human populations, together with technological advances, have exacerbated changes in the ocean and atmosphere. Concerned citizens, scientists, and organizations have worked to minimize the effects of some human actions that are responsible for the disruption of migration patterns, and fisheries. To do this, laws concerning marine resources have been passed and regulations and accords aimed toward environmental sustainability. It is important for the public to learn about the issues regarding the ocean and to take action.

Humans contribute to biological changes of ocean ecosystems.

- Increased human population, social, and ecological changes in the current patterns in the ocean can affect climate and weather.
- Changes in the weather and climate affect humans living in coastal areas for many reasons.
- The ocean continues to carry people and raw materials.
- More effective, efficient, less polluting technologies may also adversely affect people.
- Coastal populations and cause a large fraction of the world's natural disasters on land.
- Increased carbon emissions into the atmosphere result in a decrease of pH of ocean water connecting the ocean to their own lives. The deliberate alteration of the ocean and/or terrestrial topography can have negative impacts on marine ecosystems.
  - Some of these impacts include sedimentation that impacts on marine ecosystems, block coral growth, the loss of fish habitats, the disruption of migration predator/prey relationships, which destabilizes food webs and leads to a loss of biodiversity.
- Biological changes of ocean ecosystems:
  - Increased carbon emissions into the atmosphere disrupt relationships between organisms, such as symbiotic relationships between coral and zooxanthellae.
- The exponential growth of human populations, together with technological advances, have exacerbated changes in the ocean and atmosphere. Concerned citizens, scientists, and organizations have worked to minimize the effects of some human actions that are responsible for the disruption of migration patterns, and fisheries. To do this, laws concerning marine resources have been passed and regulations and accords aimed toward environmental sustainability. It is important for the public to learn about the issues regarding the ocean and to take action.
Principle 7

The ocean is largely unexplored.

Oceans" knowledge is critical to our understanding of many systems.

Knowledge of the ocean provides a basis for understanding many systems in science, technology, and human affairs.

The ocean contains a large number of important species, many of which are unique to specific regions.

The ocean provides a variety of resources, such as food, energy, and raw materials.

The ocean is a key component of the Earth's climate system.

The ocean is a source of many important chemicals, including oils, gases, and minerals.

The ocean is a major source of renewable energy, such as tidal and wave power.

The ocean is a major source of greenhouse gases, such as carbon dioxide.

The ocean is a major source of oxygen, which is essential for life on Earth.

The ocean is a major source of nutrients, which are essential for growth and development.

The ocean is a major source of water, which is essential for all living things.
There are many opportunities for ocean exploration, which can lead to hypothesis-generated science. Exploration leads to a better understanding of ocean systems. Since 1970, the use of ocean resources has increased significantly. The sustainability of accurate and timely information allows decision-makers at all levels to make decisions that promote sustainability of the ocean.

Ocean exploration involves collaboration of people in different careers, disciplines, countries, and organizations, which include universities, research institutes, government agencies, and private industries.

Ocean Exploration Requires Technological Innovations — C3

Data gathered from advanced technology enable scientists to make discoveries and predictions of physical and biological phenomena. Scientific models and simulations are used to describe, manipulate, and experiment with ocean systems, in order to better understand and predict the complexity and changing state of the ocean. Scientific models are limited by the accuracy of their mathematical equations; our ability to collect sufficient types and quantity of data over time and geographic locations; and the power of computers to use these data to recreate the systems and make calculations and simulations.

Advances in technology, such as HOVs, ROVs, AUVs, and Isotope analysis, provide scientists with more detailed information on organisms and their interactions with the physical environment. Improvements in scientific models offer scientists extensive real-time data over time and space.

Principle 7: The ocean is largely unexplored.

Tools and technologies have been developed and deployed both in outer and inner space to collect a wide variety of data from ocean systems over time and geographic location. For example, data from oceanographic sensors and equipment, such as HOVs, ROVs, AUVs, Isotope analysis, and Isotope analysis, provide scientists with more detailed information on organisms and their interactions with the physical environment.

Groundbreaking research, such as the discovery of life at hydrothermal vents, has offered scientists extensive real-time data over time and space. Satellites, sea floor and sea surface observatories, and digital media, have facilitated the geographic coverage and length of HOVs, ROVs, and AUVs.

Scientists can use these data to map, chart, and predict the locations of change at these locations. Scientists can use this data to understand the geographic range and distribution, habitats, and biodiversity of these organisms. Scientists can use this data to understand the geographic range and distribution, habitats, and biodiversity of these organisms. Scientists can use this data to understand the geographic range and distribution, habitats, and biodiversity of these organisms.