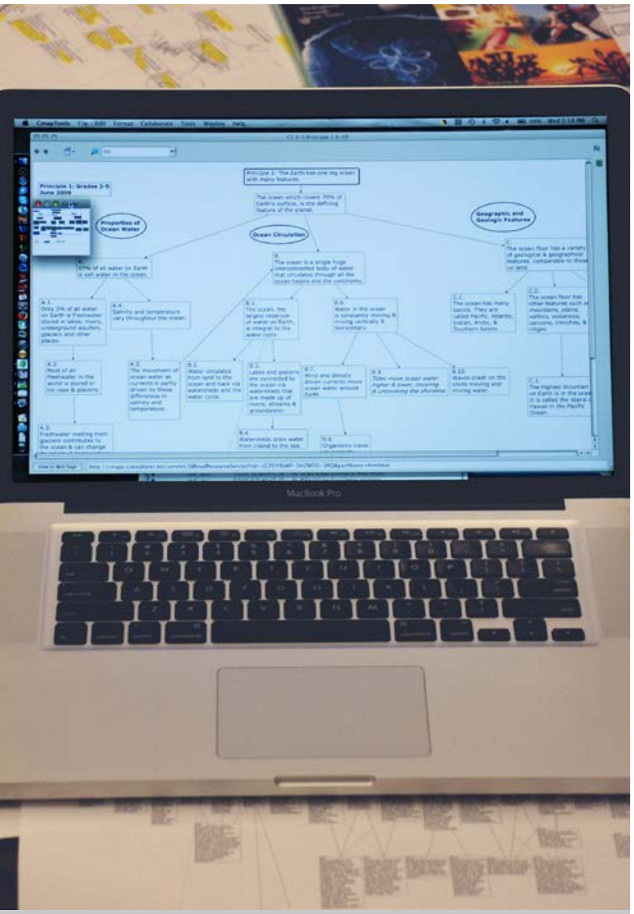


The freeware **CmapTools** was used in developing the conceptual flow diagrams (Photo credit: Craig Strang)

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[3] 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.[4] 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**

3 See "Developing the Ideas of Ocean Literacy Using Conceptual Flow Diagrams" in this handbook.

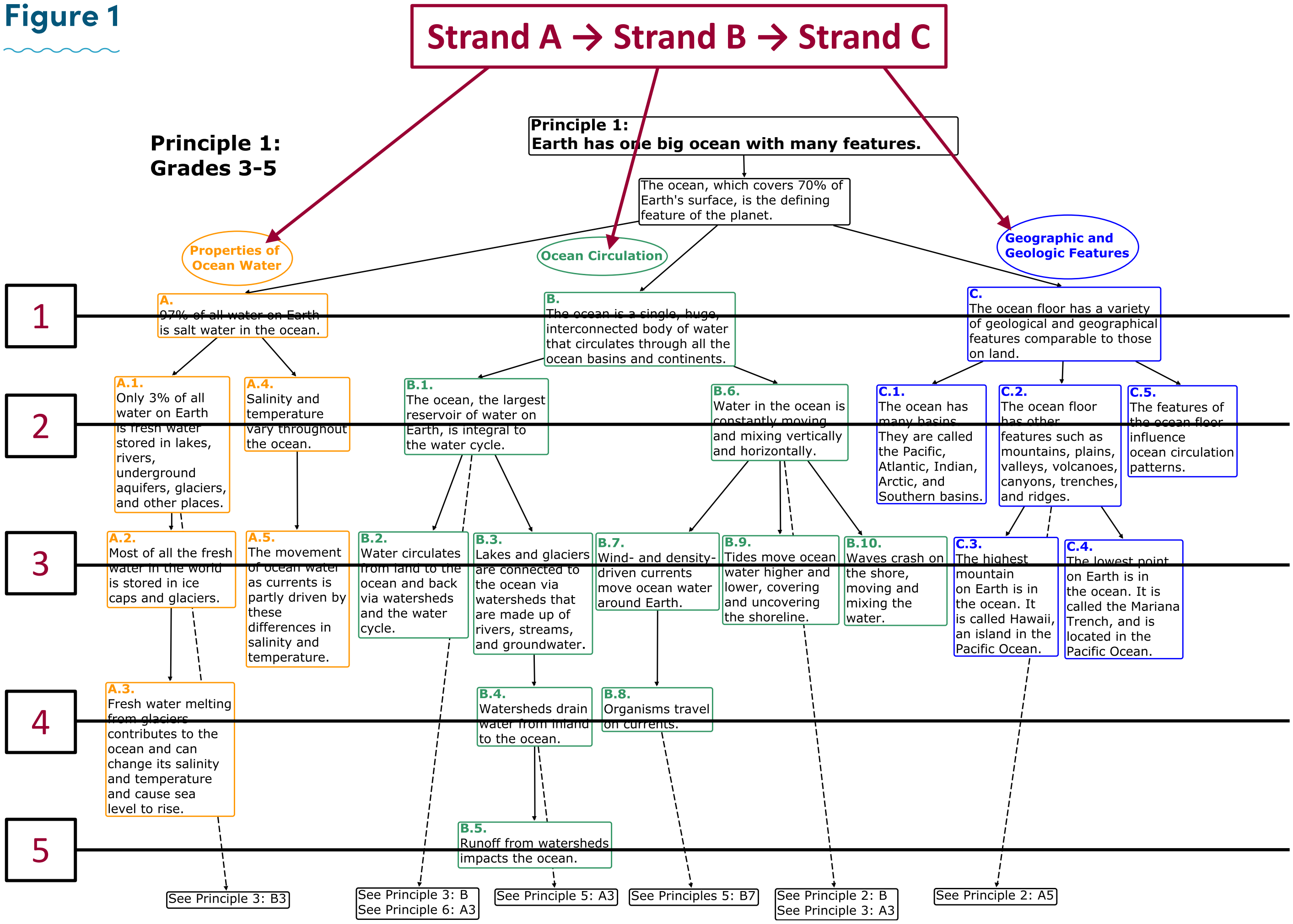
4 A more complete history is provided in the introduction to this handbook.

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.

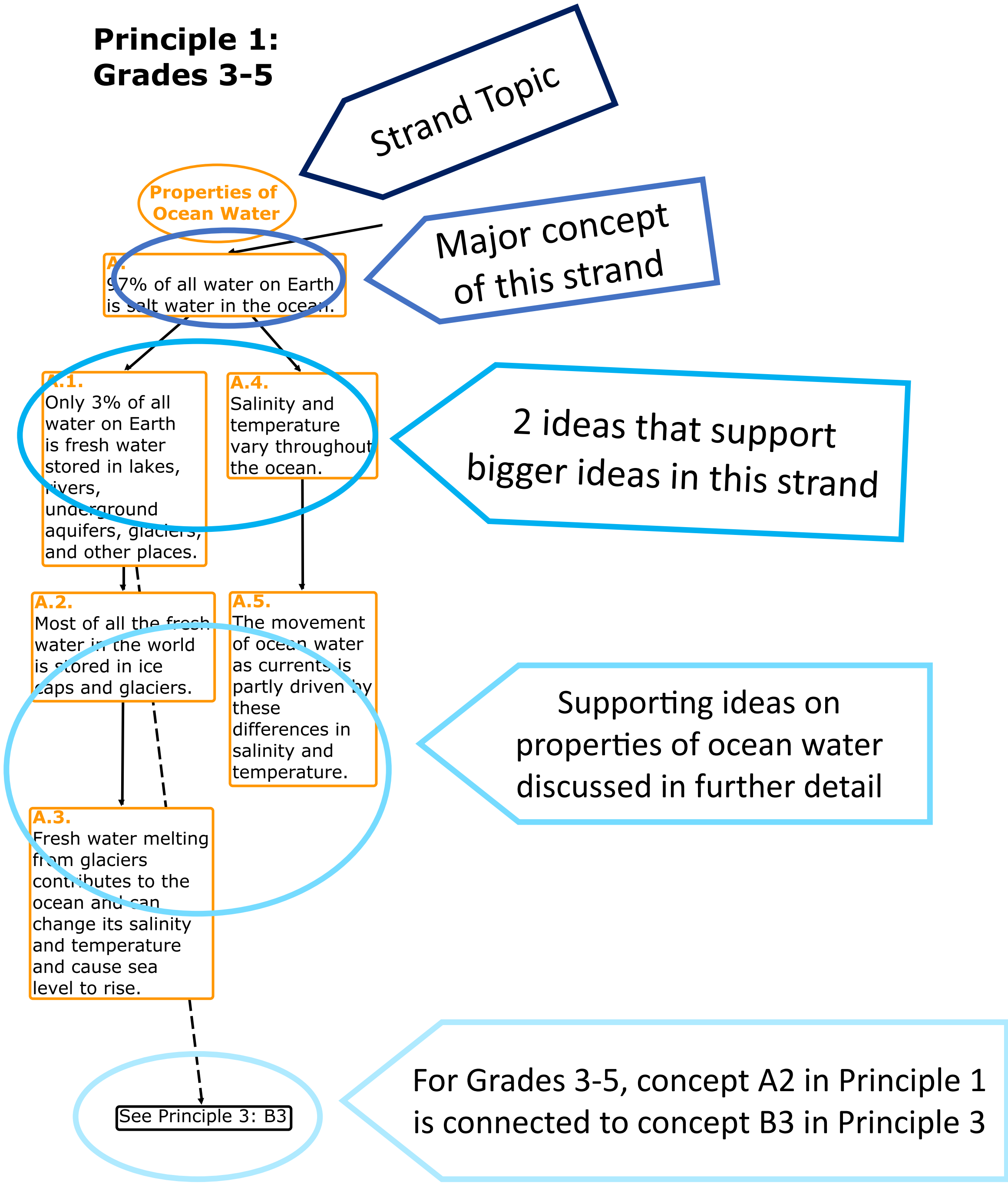
Figure 1



Dashed lines lead to cross-referenced concept statements in other essential principles.

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.

Figure 2

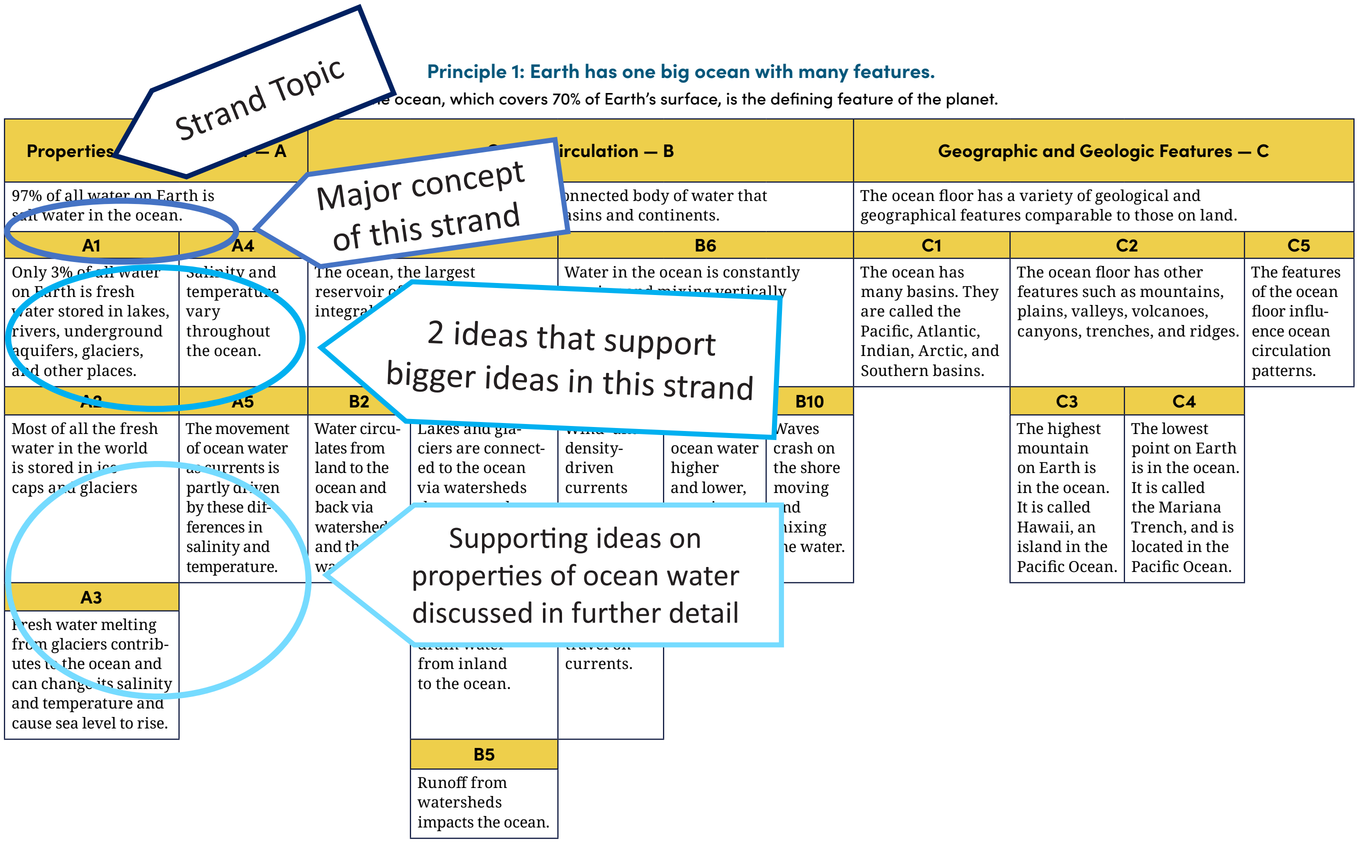


Strand A of conceptual flow diagram of Principle 1 for Grades 3 to 5. Here is a breakdown of the components in a strand. The strand is identified by topic for easy reference. The strand begins with a major concept and then nested below are two levels of ideas that support the bigger idea. Supporting ideas can be examples, but not always.

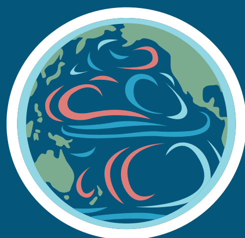
How to Use the Alternative Form of the Conceptual Flow Diagrams

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.



Conceptual Flow Diagrams



Principle 1

Principle 2

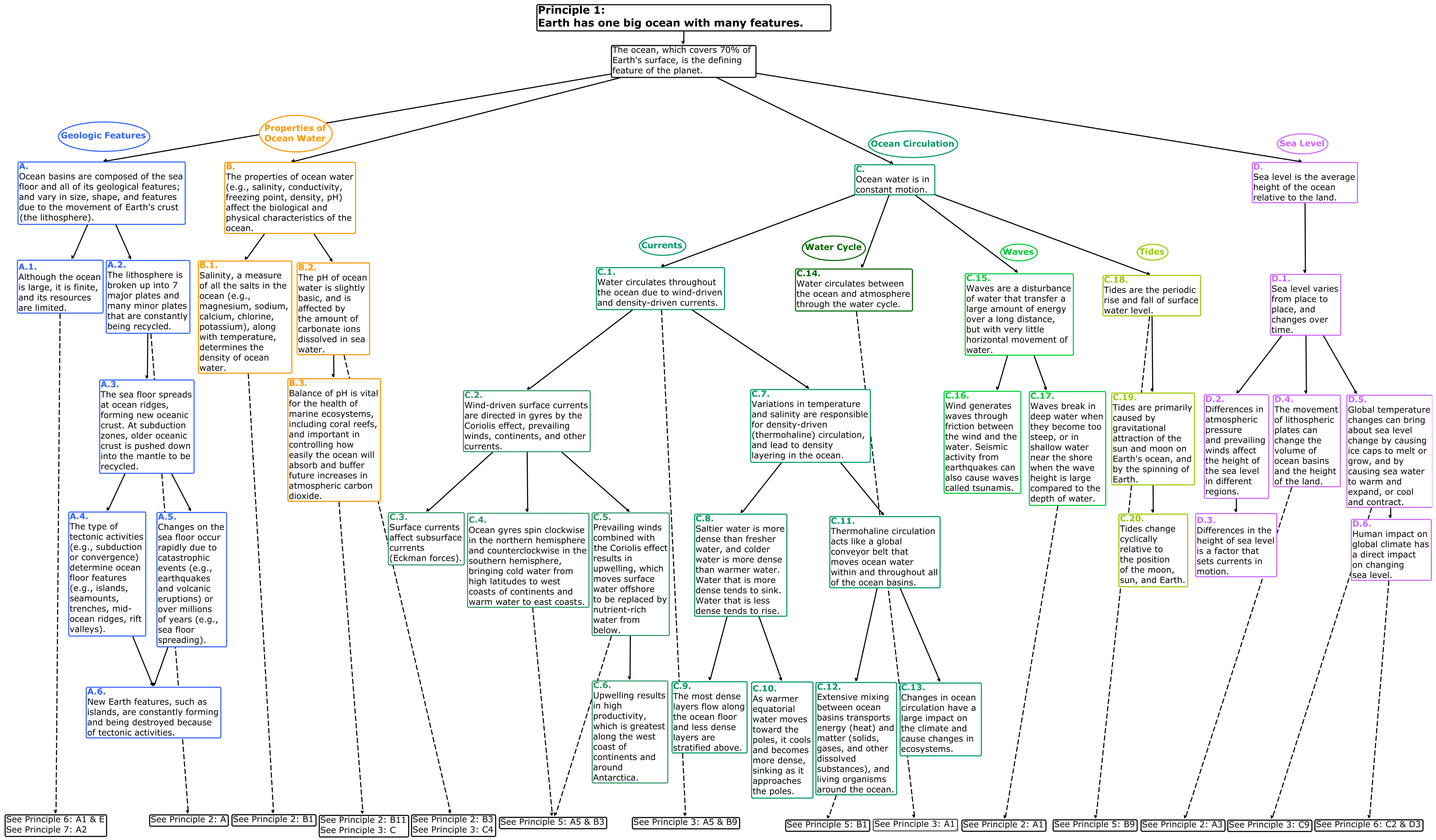
Principle 3

Principle 4

Principle 5

Principle 6

Principle 7


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.
Geologic Features
Properties of Ocean Water
Ocean Circulation
Sea Level
A. Ocean basins are composed of the sea floor and all of its geological features; and vary in size, shape, and features due to the movement of Earth's crust (the lithosphere).
B. The properties of ocean water (e.g., salinity, conductivity, freezing point, density, pH) affect the biological and physical characteristics of the ocean.
C. Ocean water is in constant motion.
D. Sea level is the average height of the ocean relative to the land.
A.1. Although the ocean is large, it is finite, and its resources are limited.
A.2. The lithosphere is broken up into 7 major plates and many minor plates that are constantly being recycled.
B.1. Salinity, a measure of all the salts in the ocean (e.g., magnesium, sodium, calcium, chlorine, potassium), along with temperature, determines the density of ocean water.
B.2. The pH of ocean water is slightly basic, and is affected by the amount of carbonate ions dissolved in sea water.
Currents
Water Cycle
Waves
Tides
C.1. Water circulates throughout the ocean due to wind-driven and density-driven currents.
C.14. Water circulates between the ocean and atmosphere through the water cycle.
C.15. Waves are a disturbance of water that transfer a large amount of energy over a long distance, but with very little horizontal movement of water.
C.18. Tides are the periodic rise and fall of surface water level.
D.1. Sea level varies from place to place, and changes over time.
A.3. The sea floor spreads at ocean ridges, forming new oceanic crust. At subduction zones, older oceanic crust is pushed down into the mantle to be recycled.
B.3. Balance of pH is vital for the health of marine ecosystems, including coral reefs, and important in controlling how easily the ocean will absorb and buffer future increases in atmospheric carbon dioxide.
C.2. Wind-driven surface currents are directed in gyres by the Coriolis effect, prevailing winds, continents, and other currents.
C.7. Variations in temperature and salinity are responsible for density-driven (thermohaline) circulation, and lead to density layering in the ocean.
C.16. Wind generates waves through friction between the wind and the water. Seismic activity from earthquakes can also cause waves called tsunamis.
C.17. Waves break in deep water when they become too steep, or in shallow water near the shore when the wave height is large compared to the depth of water.
C.19. Tides are primarily caused by gravitational attraction of the sun and moon on Earth's ocean, and by the spinning of Earth.
D.2. Differences in atmospheric pressure and prevailing winds affect the height of the sea level in different regions.
D.4. The movement of lithospheric plates can change the volume of ocean basins and the height of the land.
D.5. Global temperature changes can bring about sea level change by causing ice caps to melt or grow, and by causing sea water to warm and expand, or cool and contract.
A.4. The type of tectonic activities (e.g., subduction or convergence) determine ocean floor features (e.g., islands, seamounts, trenches, mid-ocean ridges, rift valleys).
A.5. Changes on the sea floor occur rapidly due to catastrophic events (e.g., earthquakes and volcanic eruptions) or over millions of years (e.g., sea floor spreading).
C.3. Surface currents affect subsurface currents (Eckman forces).
C.4. Ocean gyres spin clockwise in the northern hemisphere and counterclockwise in the southern hemisphere, bringing cold water from high latitudes to west coasts of continents and warm water to east coasts.
C.5. Prevailing winds combined with the Coriolis effect results in upwelling, which moves surface water offshore to be replaced by nutrient-rich water from below.
C.8. Saltier water is more dense than fresher water, and colder water is more dense than warmer water. Water that is more dense tends to sink. Water that is less dense tends to rise.
C.11. Thermohaline circulation acts like a global conveyor belt that moves ocean water within and throughout all of the ocean basins.
C.20. Tides change cyclically relative to the position of the moon, sun, and Earth.
D.3. Differences in the height of sea level is a factor that sets currents in motion.
D.6. Human impact on global climate has a direct impact on changing sea level.
A.6. New Earth features, such as islands, are constantly forming and being destroyed because of tectonic activities.
C.6. Upwelling results in high productivity, which is greatest along the west coast of continents and around Antarctica.
C.9. The most dense layers flow along the ocean floor and less dense layers are stratified above.
C.10. As warmer equatorial water moves toward the poles, it cools and becomes more dense, sinking as it approaches the poles.
C.12. Extensive mixing between ocean basins transports energy (heat) and matter (solids, gases, and other dissolved substances), and living organisms around the ocean.
C.13. Changes in ocean circulation have a large impact on the climate and cause changes in ecosystems.
See Principle 6: A1 & E
See Principle 7: A2
See Principle 2: A
See Principle 2: B1
See Principle 2: B11
See Principle 3: C
See Principle 2: B3
See Principle 3: C4
See Principle 5: A5 & B3
See Principle 3: A5 & B9
See Principle 5: B1
See Principle 3: A1
See Principle 2: A1
See Principle 5: B9
See Principle 2: A3
See Principle 3: C9
See Principle 6: C2 & D3

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.

Geologic Features — A

Ocean basins are composed of the sea floor and all of its geological features; and vary in size, shape, and features due to the movement of Earth's crust (the lithosphere).

A1 Although the ocean is large, it is finite, and its resources are limited.

A2 The lithosphere is broken up into 7 major plates and many minor plates that are constantly being recycled.

A3 The sea floor spreads at ocean ridges, forming new oceanic crust. At subduction zones, older oceanic crust is pushed down into the mantle to be recycled.

A4 The type of tectonic activities (e.g., subduction or convergence) determine ocean floor features (e.g., islands, seamounts, trenches, mid-ocean ridges, rift valleys).

A5 Changes on the sea floor occur rapidly due to catastrophic events (e.g., earthquakes and volcanic eruptions) or over millions of years (e.g., sea floor spreading).

A6 New Earth features, such as islands, are constantly forming and being destroyed because of tectonic activities.

A6 New Earth features, such as islands, are constantly forming and being destroyed because of tectonic activities.

Properties of Ocean Water — B

The properties of ocean water (e.g., salinity, conductivity, freezing point, density, pH) affect the biological and physical characteristics of the ocean.

B1 Salinity, a measure of all the salts in the ocean (e.g., magnesium, sodium, calcium, chlorine, potassium), along with temperature, determines the density of ocean water.

B2 The pH of ocean water is slightly basic, and is affected by the amount of carbonate ions dissolved in sea water.

B3 Balance of pH is vital for the health of marine ecosystems, including coral reefs, and important in controlling how easily the ocean will absorb and buffer future increases in atmospheric carbon dioxide.

Ocean Circulation — C

Ocean water is in constant motion.

Currents — C1

Water circulates throughout the ocean due to wind-driven and density-driven currents.

C2 Wind-driven surface currents are directed in gyres by the Coriolis effect, prevailing winds, continents, and other currents.

C3 Surface currents affect subsurface currents (Eckman forces).

C4 Ocean gyres spin clockwise in the northern hemisphere and counterclockwise in the southern hemisphere, bringing cold water from high latitudes to west coasts of continents and warm water to east coasts.

C5 Prevailing winds combined with the Coriolis effect results in upwelling, which moves surface water offshore to be replaced by nutrient-rich water from below.

C6 Upwelling results in high productivity, which is greatest along the west coast of continents and around Antarctica.

C7 Variations in temperature and salinity are responsible for density-driven (thermohaline) circulation, and lead to density layering in the ocean.

C8 Saltier water is more dense than fresher water, and colder water is more dense than warmer water. Water that is more dense tends to sink. Water that is less dense tends to rise.

C9 The most dense layers flow along the ocean floor and less dense layers are stratified above.

C10 As warmer equatorial water moves toward the poles, it cools and becomes more dense, sinking as it approaches the poles.

C11 Thermohaline circulation acts like a global conveyor belt that moves ocean water within and throughout all of the ocean basins.

C12 Extensive mixing between ocean basins transports energy (heat) and matter (solids, gases, and other dissolved substances), and living organisms around the ocean.

C13 Changes in ocean circulation have a large impact on the climate and cause changes in ecosystems.

Water Cycle — C14

Water circulates between the ocean and atmosphere through the water cycle.

Waves — C15

Waves are a disturbance of water that transfer a large amount of energy over a long distance, but with very little horizontal movement of water.

C16 Wind generates waves through friction between the wind and the water. Seismic activity from earthquakes can also cause waves called tsunamis.

C17 Waves break in deep water when they become too steep, or in shallow water near the shore when the wave height is large compared to the depth of water.

Tides — C18

Tides are the periodic rise and fall of surface water level.

C19 Tides are primarily caused by gravitational attraction of the sun and moon on Earth's ocean, and by the spinning of Earth.

C20 Tides change cyclically relative to the position of the moon, sun, and Earth.

Sea Level — D

Sea level is the average height of the ocean relative to the land.

D1 Sea level varies from place to place, and changes over time.

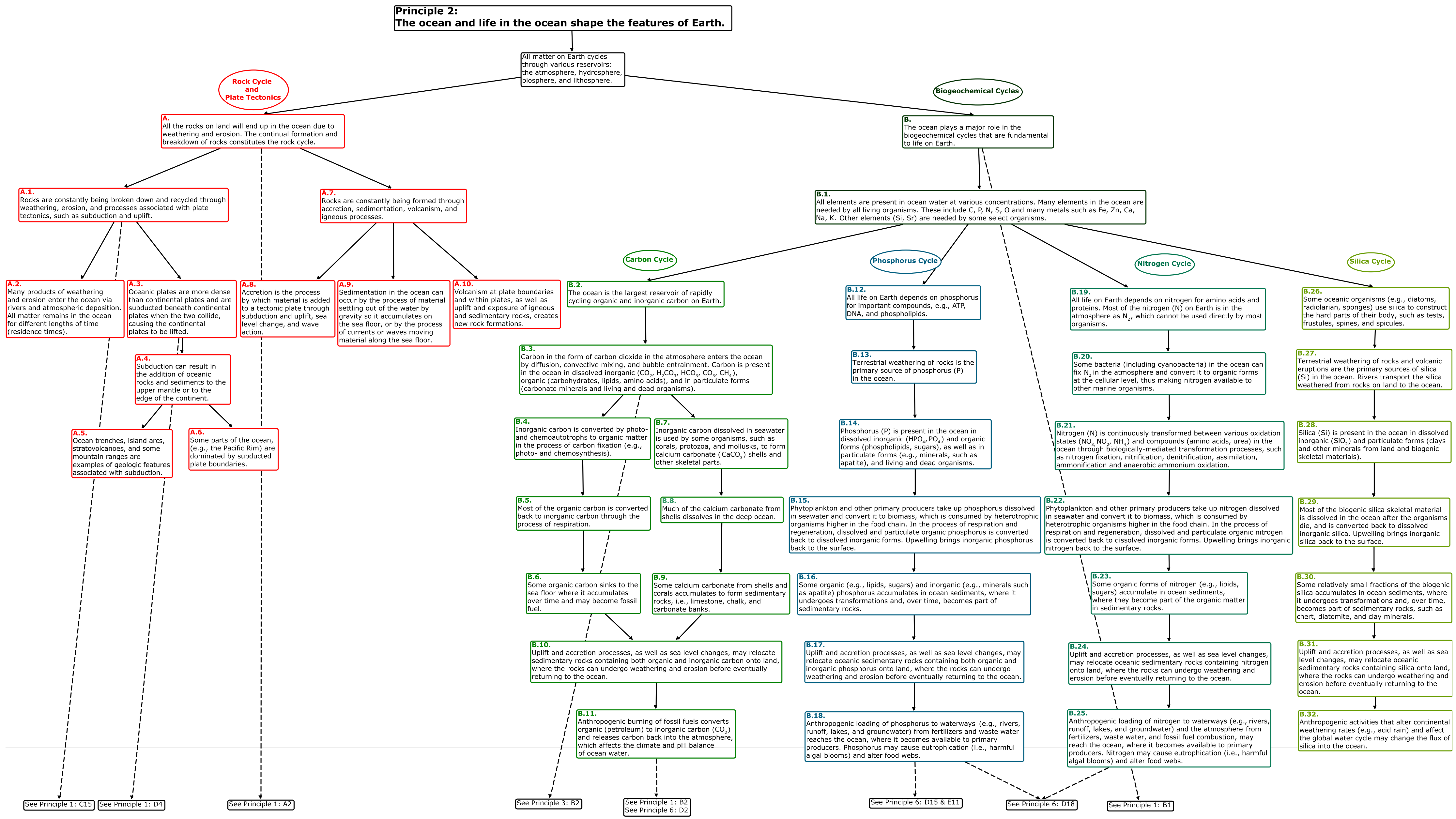
D2 Differences in atmospheric pressure and prevailing winds affect the height of the sea level in different regions.

D3 Differences in the height of sea level is a factor that sets currents in motion.

D4 The movement of lithospheric plates can change the volume of ocean basins and the height of the land.

D5 Global temperature changes can bring about sea level change by causing ice caps to melt or grow, and by causing sea water to warm and expand, or cool and contract.

D6 Human impact on global climate has a direct impact on changing sea level.


Principle 2:
The ocean and life in the ocean shape the features of Earth.
All matter on Earth cycles through various reservoirs: the atmosphere, hydrosphere, biosphere, and lithosphere.
Rock Cycle and Plate Tectonics
A. 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.
A.1. Rocks are constantly being broken down and recycled through weathering, erosion, and processes associated with plate tectonics, such as subduction and uplift.
A.2. Many products of weathering and erosion enter the ocean via rivers and atmospheric deposition. All matter remains in the ocean for different lengths of time (residence times).
A.3. Oceanic plates are more dense than continental plates and are subducted beneath continental plates when the two collide, causing the continental plates to be lifted.
A.4. Subduction can result in the addition of oceanic rocks and sediments to the upper mantle or to the edge of the continent.
A.5. Ocean trenches, island arcs, stratovolcanoes, and some mountain ranges are examples of geologic features associated with subduction.
A.6. Some parts of the ocean, (e.g., the Pacific Rim) are dominated by subducted plate boundaries.
A.7. Rocks are constantly being formed through accretion, sedimentation, volcanism, and igneous processes.
A.8. Accretion is the process by which material is added to a tectonic plate through subduction and uplift, sea level change, and wave action.
A.9. Sedimentation in the ocean can occur by the process of material settling out of the water by gravity so it accumulates on the sea floor, or by the process of currents or waves moving material along the sea floor.
A.10. Volcanism at plate boundaries and within plates, as well as uplift and exposure of igneous and sedimentary rocks, creates new rock formations.
See Principle 1: C15
See Principle 1: D4
See Principle 1: A2
Biogeochemical Cycles
B. The ocean plays a major role in the biogeochemical cycles that are fundamental to life on Earth.
B.1. All elements are present in ocean water at various concentrations. Many elements in the ocean are needed by all living organisms. These include C, P, N, S, O and many metals such as Fe, Zn, Ca, Na, K. Other elements (Si, Sr) are needed by some select organisms.
Carbon Cycle
B.2. The ocean is the largest reservoir of rapidly cycling organic and inorganic carbon on Earth.
B.3. Carbon in the form of carbon dioxide in the atmosphere enters the ocean by diffusion, convective mixing, and bubble entrainment. Carbon is present in the ocean in dissolved inorganic (CO_2, H_2CO_3, HCO_3, CO_3, CH_4), organic (carbohydrates, lipids, amino acids), and in particulate forms (carbonate minerals and living and dead organisms).
B.4. Inorganic carbon is converted by photo- and chemoautotrophs to organic matter in the process of carbon fixation (e.g., photo- and chemosynthesis).
B.5. Most of the organic carbon is converted back to inorganic carbon through the process of respiration.
B.6. Some organic carbon sinks to the sea floor where it accumulates over time and may become fossil fuel.
B.7. Inorganic carbon dissolved in seawater is used by some organisms, such as corals, protozoa, and mollusks, to form calcium carbonate ($CaCO_3$) shells and other skeletal parts.
B.8. Much of the calcium carbonate from shells dissolves in the deep ocean.
B.9. Some calcium carbonate from shells and corals accumulates to form sedimentary rocks, i.e., limestone, chalk, and carbonate banks.
B.10. Uplift and accretion processes, as well as sea level changes, may relocate sedimentary rocks containing both organic and inorganic carbon onto land, where the rocks can undergo weathering and erosion before eventually returning to the ocean.
B.11. Anthropogenic burning of fossil fuels converts organic (petroleum) to inorganic carbon (CO_2) and releases carbon back into the atmosphere, which affects the climate and pH balance of ocean water.
See Principle 3: B2
See Principle 1: B2
See Principle 6: D2
Phosphorus Cycle
B.12. All life on Earth depends on phosphorus for important compounds, e.g., ATP, DNA, and phospholipids.
B.13. Terrestrial weathering of rocks is the primary source of phosphorus (P) in the ocean.
B.14. Phosphorus (P) is present in the ocean in dissolved inorganic (HPO_4, PO_4) and organic forms (phospholipids, sugars), as well as in particulate forms (e.g., minerals, such as apatite), and living and dead organisms.
B.15. Phytoplankton and other primary producers take up phosphorus dissolved in seawater and convert it to biomass, which is consumed by heterotrophic organisms higher in the food chain. In the process of respiration and regeneration, dissolved and particulate organic phosphorus is converted back to dissolved inorganic forms. Upwelling brings inorganic phosphorus back to the surface.
B.16. Some organic (e.g., lipids, sugars) and inorganic (e.g., minerals such as apatite) phosphorus accumulates in ocean sediments, where it undergoes transformations and, over time, becomes part of sedimentary rocks.
B.17. Uplift and accretion processes, as well as sea level changes, may relocate oceanic sedimentary rocks containing both organic and inorganic phosphorus onto land, where the rocks can undergo weathering and erosion before eventually returning to the ocean.
B.18. Anthropogenic loading of phosphorus to waterways (e.g., rivers, runoff, lakes, and groundwater) from fertilizers and waste water reaches the ocean, where it becomes available to primary producers. Phosphorus may cause eutrophication (i.e., harmful algal blooms) and alter food webs.
See Principle 6: D15 & E11
See Principle 6: D18
Nitrogen Cycle
B.19. All life on Earth depends on nitrogen for amino acids and proteins. Most of the nitrogen (N) on Earth is in the atmosphere as N_2, which cannot be used directly by most organisms.
B.20. Some bacteria (including cyanobacteria) in the ocean can fix N_2 in the atmosphere and convert it to organic forms at the cellular level, thus making nitrogen available to other marine organisms.
B.21. Nitrogen (N) is continuously transformed between various oxidation states (NO_3, NO_2, NH_4) and compounds (amino acids, urea) in the ocean through biologically-mediated transformation processes, such as nitrogen fixation, nitrification, denitrification, assimilation, ammonification and anaerobic ammonium oxidation.
B.22. Phytoplankton and other primary producers take up nitrogen dissolved in seawater and convert it to biomass, which is consumed by heterotrophic organisms higher in the food chain. In the process of respiration and regeneration, dissolved and particulate organic nitrogen is converted back to dissolved inorganic forms. Upwelling brings inorganic nitrogen back to the surface.
B.23. Some organic forms of nitrogen (e.g., lipids, sugars) accumulate in ocean sediments, where they become part of the organic matter in sedimentary rocks.
B.24. Uplift and accretion processes, as well as sea level changes, may relocate oceanic sedimentary rocks containing nitrogen onto land, where the rocks can undergo weathering and erosion before eventually returning to the ocean.
B.25. Anthropogenic loading of nitrogen to waterways (e.g., rivers, runoff, lakes, and groundwater) and the atmosphere from fertilizers, waste water, and fossil fuel combustion, may reach the ocean, where it becomes available to primary producers. Nitrogen may cause eutrophication (i.e., harmful algal blooms) and alter food webs.
See Principle 1: B1
Silica Cycle
B.26. Some oceanic organisms (e.g., diatoms, radiolarian, sponges) use silica to construct the hard parts of their body, such as tests, frustules, spines, and spicules.
B.27. Terrestrial weathering of rocks and volcanic eruptions are the primary sources of silica (Si) in the ocean. Rivers transport the silica weathered from rocks on land to the ocean.
B.28. Silica (Si) is present in the ocean in dissolved inorganic (SiO_2) and particulate forms (clays and other minerals from land and biogenic skeletal materials).
B.29. Most of the biogenic silica skeletal material is dissolved in the ocean after the organisms die, and is converted back to dissolved inorganic silica. Upwelling brings inorganic silica back to the surface.
B.30. 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, diatomite, and clay minerals.
B.31. Uplift and accretion processes, as well as sea level changes, may relocate oceanic sedimentary rocks containing silica onto land, where the rocks can undergo weathering and erosion before eventually returning to the ocean.
B.32. Anthropogenic activities that alter continental weathering rates (e.g., acid rain) and affect the global water cycle may change the flux of silica into the ocean.

Principle 2: The ocean and life in the ocean shape the features of Earth.

All matter on Earth cycles through various reservoirs: the atmosphere, hydrosphere, biosphere, and lithosphere.

Rock Cycle and Plate Tectonics — A

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.

A1

Rocks are constantly being broken down and recycled through weathering, erosion, and processes associated with plate tectonics, such as subduction and uplift.

A2

Many products of weathering and erosion enter the ocean via rivers and atmospheric deposition. All matter remains in the ocean for different lengths of time (residence times).

A3

Oceanic plates are more dense than continental plates and are subducted beneath continental plates when the two collide, causing the continental plates to be lifted.

A4

Subduction can result in the addition of oceanic rocks and sediments to the upper mantle or to the edge of the continent.

A5

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

A6

Some parts of the ocean (e.g. the Pacific Rim) are dominated by subducted plate boundaries.

A7

Rocks are constantly being formed through accretion, sedimentation, volcanism, and igneous processes.

A8

Accretion is the process by which material is added to a tectonic plate through subduction and uplift, sea level change, and wave action.

A9

Sedimentation in the ocean can occur by the process of material settling out of the water by gravity so it accumulates on the sea floor, or by the process of currents or waves moving material along the sea floor.

A10

Volcanism at plate boundaries and within plates, as well as uplift and exposure of igneous and sedimentary rocks, creates new rock formations.

Biogeochemical Cycles — B

The ocean plays a major role in the biogeochemical cycles that are fundamental to life on Earth.

B1

All elements are present in ocean water at various concentrations. Many elements in the ocean are needed by all living organisms. These include C, P, N, S, O and many metals such as Fe, Zn, Ca, Na, K. Other elements (Si, Sr) are needed by some select organisms.

Carbon Cycle — B2

The ocean is the largest reservoir of rapidly cycling organic and inorganic carbon on Earth.

B3

Carbon in the form of carbon dioxide in the atmosphere enters the ocean by diffusion, convective mixing, and bubble entrainment. Carbon is present in the ocean in dissolved inorganic (CO_2, H_2CO_3, HCO_3, CO_3, CH_4), organic (carbohydrates, lipids, amino acids), and in particulate forms (carbonate minerals and living and dead organisms).

B4

Inorganic carbon is converted by photo- and chemoautotrophs to organic matter in the process of carbon fixation (e.g., photo- and chemosynthesis.

B5

Most of the organic carbon is converted back to inorganic carbon through the process of respiration.

B6

Some organic carbon sinks to the sea floor where it accumulates over time and may become fossil fuel.

B7

Inorganic carbon dissolved in seawater is used by some organisms, such as corals, protozoa, and mollusks, to form calcium carbonate ($CaCO_3$) shells and other skeletal parts.

B8

Much of the calcium carbonate from shells dissolves in the deep ocean.

B9

Some calcium carbonate from shells and corals accumulates to form sedimentary rocks, i.e., limestone, chalk, and carbonate banks.

B10

Uplift and accretion processes, as well as sea level changes, may relocate sedimentary rocks containing both organic and inorganic carbon onto land, where rocks can undergo weathering and erosion before eventually returning to the ocean.

B11

Anthropogenic burning of fossil fuels converts organic (petroleum) to inorganic carbon (CO_2) and releases carbon back into the atmosphere, which affects the climate and pH balance of ocean water.

Phosphorus Cycle — B12

All life on Earth depends on phosphorus for important compounds, e.g., ATP, DNA, and phospholipids.

B13

Terrestrial weathering of rocks is the primary source of phosphorus (P) in the ocean.

B14

Phosphorus (P) is present in the ocean in dissolved inorganic (HPO_4, PO_4) and organic forms (phospholipids, sugars) as well as in particulate forms (e.g., minerals, such as apatite), and living and dead organisms.

B15

Phytoplankton and other primary producers take up phosphorus dissolved in seawater and convert it to biomass, which is consumed by heterotrophic organisms higher in the food chain. In the process of respiration and regeneration, dissolved and particulate organic phosphorus is converted back to dissolved inorganic forms. Upwelling brings inorganic phosphorus back to the surface.

B16

Some organic (e.g., lipids, sugars) and inorganic (e.g., minerals such as apatite) phosphorus accumulates in ocean sediments, where it undergoes transformations and, over time, becomes part of sedimentary rocks.

B17

Uplift and accretion processes, as well as sea level changes may relocate oceanic sedimentary rocks containing both organic and inorganic phosphorus onto land, where the rocks can undergo weathering and erosion before eventually returning to the ocean.

B18

Anthropogenic loading of phosphorus to waterways, (e.g., rivers, runoff, lakes, and groundwater) from fertilizers and waste water reaches the ocean, where it becomes available to primary producers. Phosphorus may cause eutrophication (i.e., harmful algal blooms) and alter food webs.

Nitrogen Cycle — B19

All life on Earth depends on nitrogen for amino acids and proteins. Most of the nitrogen (N) on Earth is in the atmosphere as N_2, which cannot be used directly by most organisms.

B20

Some bacteria (including some cyanobacteria) in the ocean can fix N_2 in the atmosphere and convert it to organic forms at the cellular level, thus making nitrogen available to other marine organisms.

B21

Nitrogen (N) is continuously transformed between various oxidation states (NO_3, NO_2, NH_4) and compounds (amino acids, urea) in the ocean through biologically-mediated transformation processes, such as nitrogen fixation, nitrification, denitrification, assimilation, ammonification, and anaerobic ammonium oxidation.

B22

Phytoplankton and other primary producers take up nitrogen dissolved in seawater and convert it to biomass, which is consumed by heterotrophic organisms higher in the food chain. In the process of respiration and regeneration, dissolved and particulate organic nitrogen is converted back to dissolved inorganic forms. Upwelling brings inorganic nitrogen back to the surface.

B23

Some organic forms of nitrogen (e.g., lipids, sugars) accumulate in ocean sediments, where they become part of the organic matter in sedimentary rocks.

B24

Uplift and accretion processes, as well as sea level changes may relocate oceanic sedimentary rocks containing nitrogen onto land, where the rocks can undergo weathering and erosion before eventually returning to the ocean.

B25

Anthropogenic loading of nitrogen to waterways (e.g., rivers, runoff, lakes, and groundwater) and the atmosphere from fertilizers, waste water, and fossil fuel combustion, may reach the ocean, where it becomes available to primary producers. Nitrogen may cause eutrophication (i.e., harmful algal blooms) and alter food webs.

Silica Cycle — B26

Some oceanic organisms (e.g., diatoms, radiolarian, sponges) use silica to construct the hard parts of their body, such as tests, frustules, spines, and spicules.

B27

Terrestrial weathering of rocks and volcanic eruptions are the primary sources of silica (Si) in the ocean. Rivers transport the silica weathered from rocks on land to the ocean.

B28

Silica (Si) is present in the ocean in dissolved inorganic (SiO_2) and particulate forms (clays and other materials from land and biogenic skeletal materials).

B29

Most of the biogenic silica skeletal material is dissolved in the ocean after the organisms die, and is converted back to dissolved inorganic silica. Upwelling brings inorganic silica back to the surface.

B30

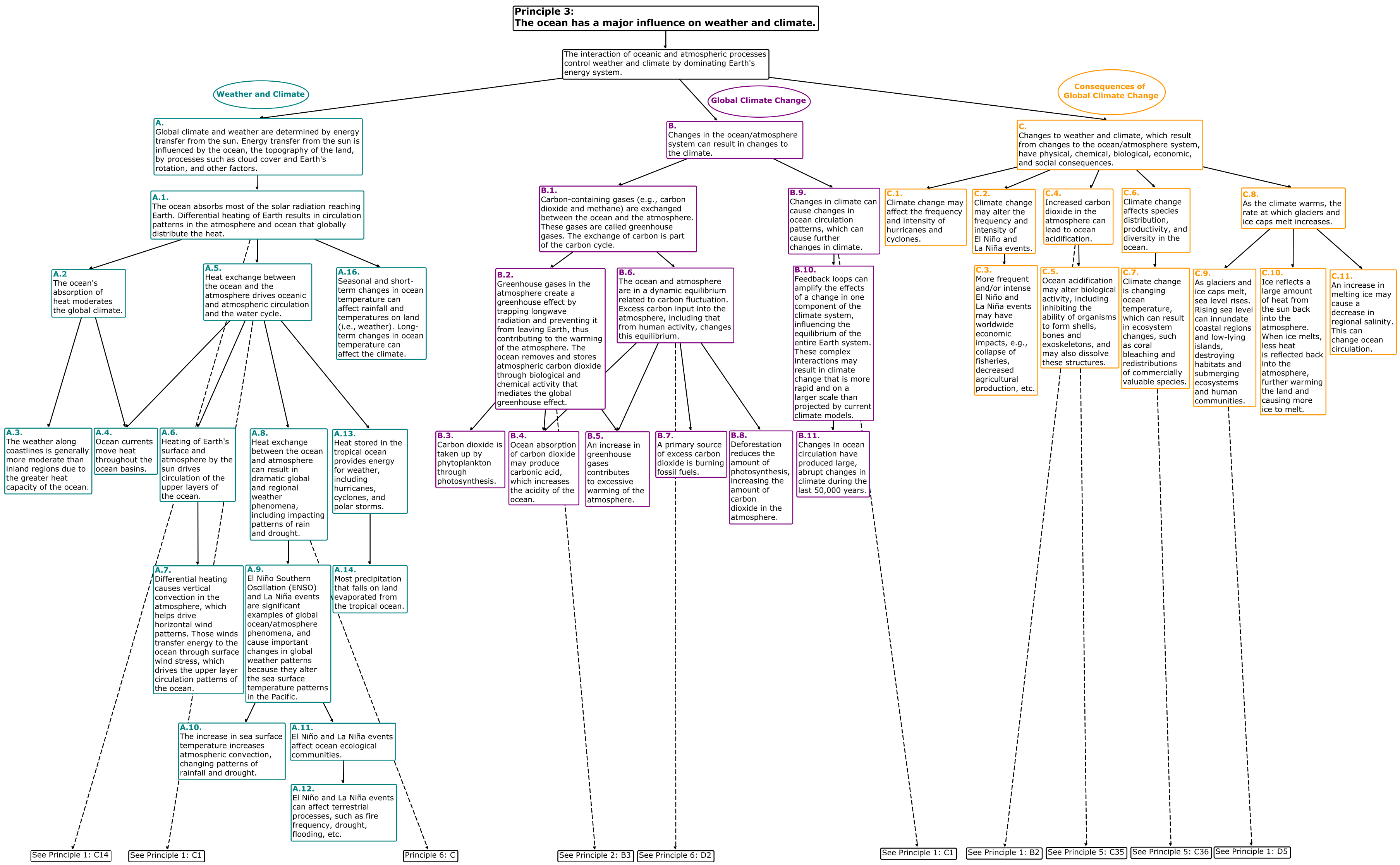
Some relatively small fractions of the biogenic silica accumulates in ocean sediments, where it undergoes transformations and, over time, becomes part of sedimentary rocks, such as chert, diatomite, and clay materials.

B31

Uplift and accretion processes, as well as sea level changes, may relocate oceanic sedimentary rocks containing silica onto land, where the rocks can undergo weathering and erosion before eventually returning to the ocean.

B32

Anthropogenic activities that alter continental weathering rates (e.g., acid rain) and affect the global water cycle may change the flux of silica into the ocean.


Principle 3:
The ocean has a major influence on weather and climate.
The interaction of oceanic and atmospheric processes control weather and climate by dominating Earth's energy system.
Weather and Climate
Global Climate Change
Consequences of Global Climate Change
A. Global climate and weather are determined by energy transfer from the sun. Energy transfer from the sun is influenced by the ocean, the topography of the land, by processes such as cloud cover and Earth's rotation, and other factors.
A.1. 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.
A.2 The ocean's absorption of heat moderates the global climate.
A.5. Heat exchange between the ocean and the atmosphere drives oceanic and atmospheric circulation and the water cycle.
A.16. Seasonal and short-term changes in ocean temperature can affect rainfall and temperatures on land (i.e., weather). Long-term changes in ocean temperature can affect the climate.
A.3. The weather along coastlines is generally more moderate than inland regions due to the greater heat capacity of the ocean.
A.4. Ocean currents move heat throughout the ocean basins.
A.6. Heating of Earth's surface and atmosphere by the sun drives circulation of the upper layers of the ocean.
A.8. Heat exchange between the ocean and atmosphere can result in dramatic global and regional weather phenomena, including impacting patterns of rain and drought.
A.13. Heat stored in the tropical ocean provides energy for weather, including hurricanes, cyclones, and polar storms.
A.7. Differential heating causes vertical convection in the atmosphere, which helps drive horizontal wind patterns. Those winds transfer energy to the ocean through surface wind stress, which drives the upper layer circulation patterns of the ocean.
A.9. El Niño Southern Oscillation (ENSO) and La Niña events are significant examples of global ocean/atmosphere phenomena, and cause important changes in global weather patterns because they alter the sea surface temperature patterns in the Pacific.
A.14. Most precipitation that falls on land evaporated from the tropical ocean.
A.10. The increase in sea surface temperature increases atmospheric convection, changing patterns of rainfall and drought.
A.11. El Niño and La Niña events affect ocean ecological communities.
A.12. El Niño and La Niña events can affect terrestrial processes, such as fire frequency, drought, flooding, etc.
B. Changes in the ocean/atmosphere system can result in changes to the climate.
B.1. Carbon-containing gases (e.g., carbon dioxide and methane) are exchanged between the ocean and the atmosphere. These gases are called greenhouse gases. The exchange of carbon is part of the carbon cycle.
B.9. Changes in climate can cause changes in ocean circulation patterns, which can cause further changes in climate.
B.2. Greenhouse gases in the atmosphere create a greenhouse effect by trapping longwave radiation and preventing it from leaving Earth, thus contributing to the warming of the atmosphere. The ocean removes and stores atmospheric carbon dioxide through biological and chemical activity that mediates the global greenhouse effect.
B.6. The ocean and atmosphere are in a dynamic equilibrium related to carbon fluctuation. Excess carbon input into the atmosphere, including that from human activity, changes this equilibrium.
B.10. Feedback loops can amplify the effects of a change in one component of the climate system, influencing the equilibrium of the entire Earth system. These complex interactions may result in climate change that is more rapid and on a larger scale than projected by current climate models.
B.3. Carbon dioxide is taken up by phytoplankton through photosynthesis.
B.4. Ocean absorption of carbon dioxide may produce carbonic acid, which increases the acidity of the ocean.
B.5. An increase in greenhouse gases contributes to excessive warming of the atmosphere.
B.7. A primary source of excess carbon dioxide is burning fossil fuels.
B.8. Deforestation reduces the amount of photosynthesis, increasing the amount of carbon dioxide in the atmosphere.
B.11. Changes in ocean circulation have produced large, abrupt changes in climate during the last 50,000 years.
C. Changes to weather and climate, which result from changes to the ocean/atmosphere system, have physical, chemical, biological, economic, and social consequences.
C.1. Climate change may affect the frequency and intensity of hurricanes and cyclones.
C.2. Climate change may alter the frequency and intensity of El Niño and La Niña events.
C.4. Increased carbon dioxide in the atmosphere can lead to ocean acidification.
C.6. Climate change affects species distribution, productivity, and diversity in the ocean.
C.8. As the climate warms, the rate at which glaciers and ice caps melt increases.
C.3. More frequent and/or intense El Niño and La Niña events may have worldwide economic impacts, e.g., collapse of fisheries, decreased agricultural production, etc.
C.5. Ocean acidification may alter biological activity, including inhibiting the ability of organisms to form shells, bones and exoskeletons, and may also dissolve these structures.
C.7. Climate change is changing ocean temperature, which can result in ecosystem changes, such as coral bleaching and redistributions of commercially valuable species.
C.9. As glaciers and ice caps melt, sea level rises. Rising sea level can innundate coastal regions and low-lying islands, destroying habitats and submerging ecosystems and human communities.
C.10. Ice reflects a large amount of heat from the sun back into the atmosphere. When ice melts, less heat is reflected back into the atmosphere, further warming the land and causing more ice to melt.
C.11. An increase in melting ice may cause a decrease in regional salinity. This can change ocean circulation.
See Principle 1: C14
See Principle 1: C1
Principle 6: C
See Principle 2: B3
See Principle 6: D2
See Principle 1: C1
See Principle 1: B2
See Principle 5: C35
See Principle 5: C36
See Principle 1: D5

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

Global climate and weather are determined by energy transfer from the sun. Energy transfer from the sun is influenced by the ocean, the topography of the land, by processes such as cloud cover and Earth's rotation, and other factors.

A1	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.
A2	The ocean's absorption of heat moderates the global climate.
A5	Heat exchange between the ocean and the atmosphere drives oceanic and atmospheric circulation and the water cycle.
A16	Seasonal and short-term changes in ocean temperature can affect rainfall and temperature on land (i.e., the weather). Long-term changes in ocean temperature can affect the climate.
A3	The weather along coastlines is generally more moderate than inland regions due to the greater heat capacity of the ocean.
A4	Ocean currents move heat through-out the ocean basins.
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A6	Heating of Earth's surface and atmosphere by the sun drives circulation of the upper layers of the ocean.
A8	Heat exchange between the ocean and atmosphere can result in dramatic global and regional weather phenomena, including impacting patterns of rain and drought.
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Global Climate Change — B

Changes in the ocean/atmosphere system can result in changes to the climate.

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B9	Changes in climate can cause changes in ocean circulation patterns, which can cause further changes in climate.
B2	Greenhouse gases in the atmosphere create a greenhouse effect by trapping longwave radiation and preventing it from leaving Earth, thus contributing to the warming of the atmosphere. The ocean removes and stores atmospheric carbon dioxide through biological and chemical activity that mediates the global greenhouse effect.
B6	The ocean and atmosphere are in dynamic equilibrium related to carbon fluctuation. Excess carbon input into the atmosphere, including that from human activity, changes this equilibrium.
B10	Feedback loops can amplify the effects of a change in one component of the climate system, influencing the equilibrium of the entire Earth system. These complex interactions may result in climate change that is more rapid and on a larger scale than projected by current climate models.
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B7	A primary source of excess carbon dioxide is burning fossil fuels.
B8	Deforestation reduces the amount of photosynthesis, increasing the amount of carbon dioxide in the atmosphere.
B11	Changes in ocean circulation have produced large, abrupt changes in climate during the last 50,000 years.

Consequences of Global Climate Change — C

Changes to weather and climate, which result from changes to the ocean/atmosphere system, have physical, chemical, biological, economic, and social consequences.

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C2	Climate change may alter the frequency and intensity of El Niño and La Niña events.
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C8	As the climate warms, the rate at which glaciers and ice caps melt increases.
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C5	Ocean acidification may alter biological activity, including inhibiting the ability of organisms to form shells, bones and exoskeletons, and may also dissolve these structures.
C7	Climate change is changing ocean temperature, which can result in ecosystem changes, such as coral bleaching and redistributions of commercially valuable species.
C9	As glaciers and ice caps melt, sea level rises. Rising sea level can inundate coastal regions and low-lying islands, destroying habitats and submerging ecosystems and human communities.
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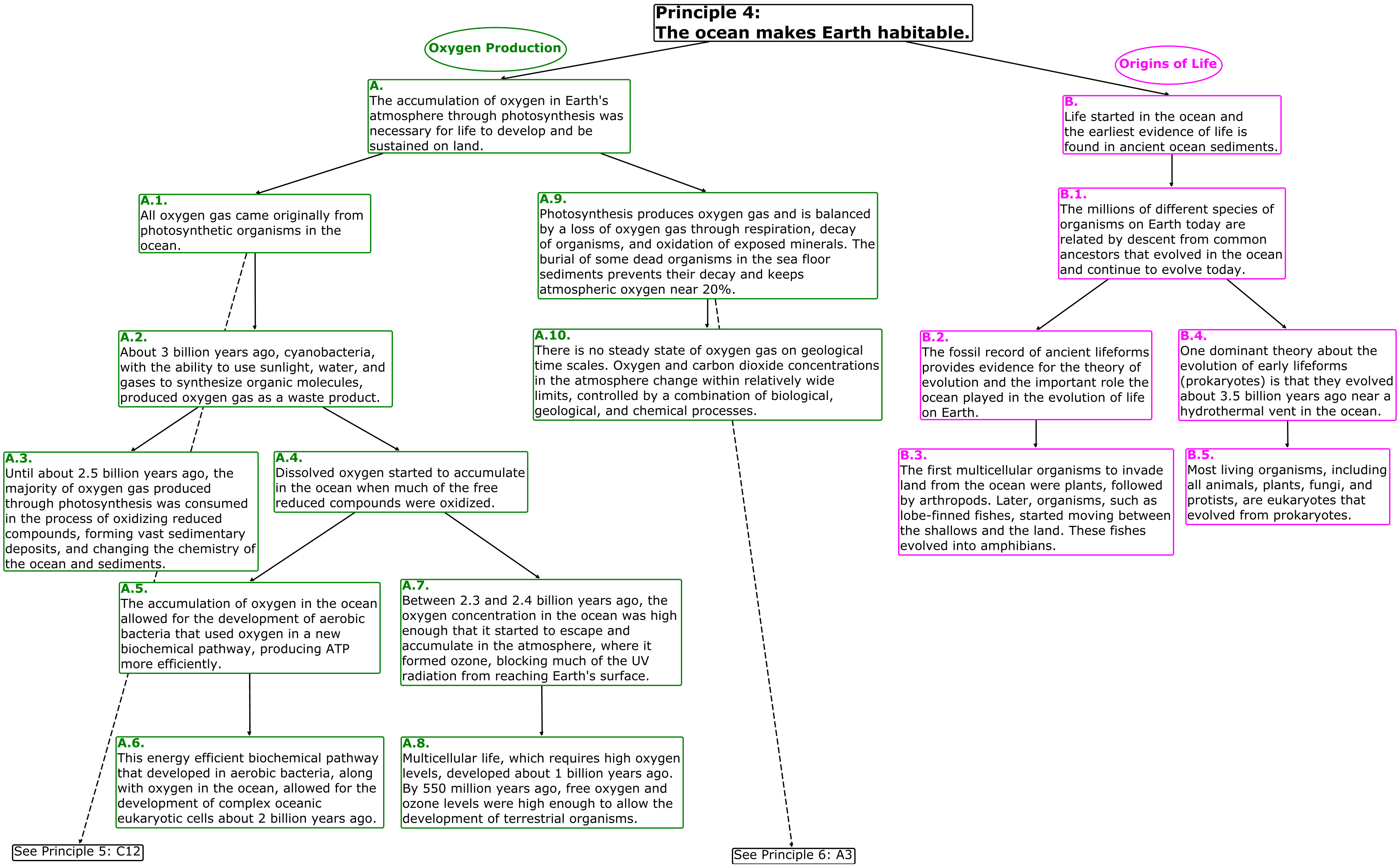
C11	An increase in melting ice may cause a decrease in regional salinity. This can change ocean circulation.


Principle 4:
The ocean makes Earth habitable.
Oxygen Production
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.
A.9.
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%.
A.10.
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.
See Principle 5: C12
See Principle 6: A3
Origins of Life
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.

Principle 4: The ocean makes Earth habitable.

Oxygen Production — A

The accumulation of oxygen in Earth's atmosphere through photosynthesis was necessary for life to develop and be sustained on land.

A1

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A8

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Origins of Life — B

Life started in the ocean and the earliest evidence of life is found in ancient ocean sediments.

B1

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.

B2

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.

B4

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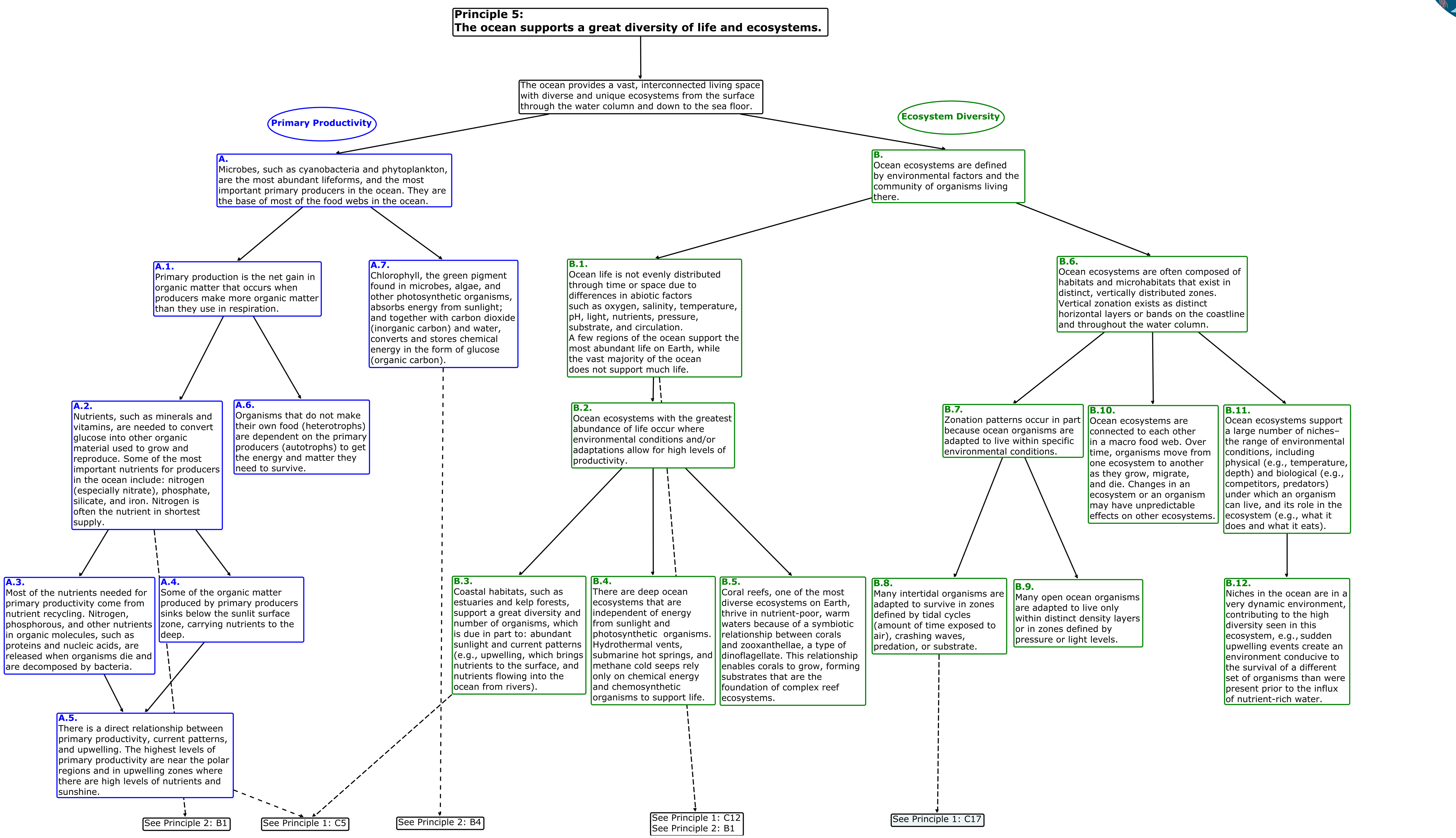
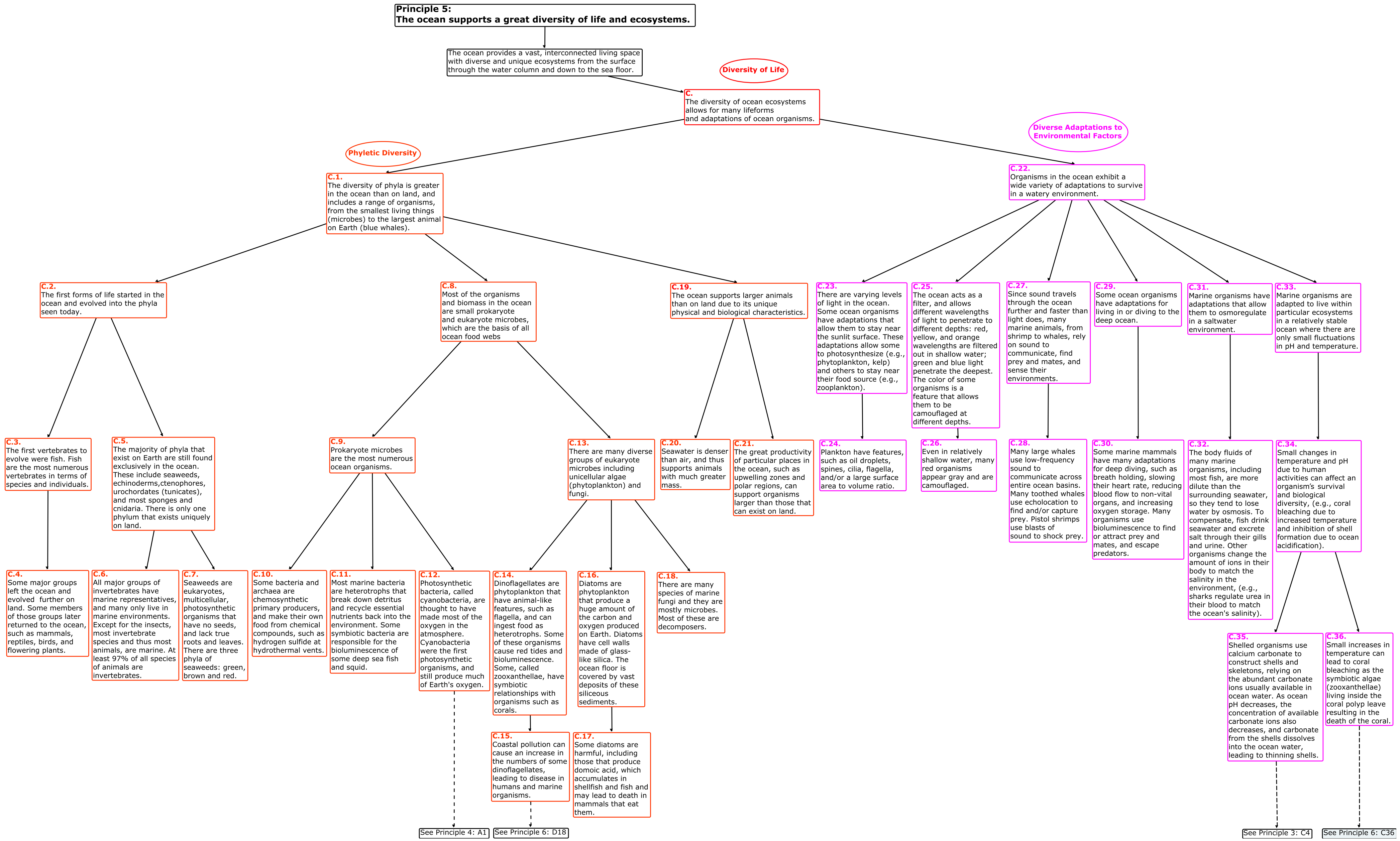
The first multicellular organisms to invade land from the ocean were plants, followed by arthropods. Later, organisms, such as lobe-finned fishes, started moving between the shallows and the land. These fishes evolved into amphibians.

B5

Most living organisms, including all animals, plants, fungi, and protists, are eukaryotes that evolved from prokaryotes.


Principle 5:
The ocean supports a great diversity of life and ecosystems.
The ocean provides a vast, interconnected living space with diverse and unique ecosystems from the surface through the water column and down to the sea floor.
Primary Productivity
Ecosystem Diversity
A. Microbes, such as cyanobacteria and phytoplankton, are the most abundant lifeforms, and the most important primary producers in the ocean. They are the base of most of the food webs in the ocean.
B. Ocean ecosystems are defined by environmental factors and the community of organisms living there.
A.1. Primary production is the net gain in organic matter that occurs when producers make more organic matter than they use in respiration.
A.7. Chlorophyll, the green pigment found in microbes, algae, and other photosynthetic organisms, absorbs energy from sunlight; and together with carbon dioxide (inorganic carbon) and water, converts and stores chemical energy in the form of glucose (organic carbon).
B.1. Ocean life is not evenly distributed through time or space due to differences in abiotic factors such as oxygen, salinity, temperature, pH, light, nutrients, pressure, substrate, and circulation. A few regions of the ocean support the most abundant life on Earth, while the vast majority of the ocean does not support much life.
B.6. Ocean ecosystems are often composed of habitats and microhabitats that exist in distinct, vertically distributed zones. Vertical zonation exists as distinct horizontal layers or bands on the coastline and throughout the water column.
A.2. Nutrients, such as minerals and vitamins, are needed to convert glucose into other organic material used to grow and reproduce. Some of the most important nutrients for producers in the ocean include: nitrogen (especially nitrate), phosphate, silicate, and iron. Nitrogen is often the nutrient in shortest supply.
A.6. Organisms that do not make their own food (heterotrophs) are dependent on the primary producers (autotrophs) to get the energy and matter they need to survive.
B.2. Ocean ecosystems with the greatest abundance of life occur where environmental conditions and/or adaptations allow for high levels of productivity.
B.7. Zonation patterns occur in part because ocean organisms are adapted to live within specific environmental conditions.
B.10. Ocean ecosystems are connected to each other in a macro food web. Over time, organisms move from one ecosystem to another as they grow, migrate, and die. Changes in an ecosystem or an organism may have unpredictable effects on other ecosystems.
B.11. Ocean ecosystems support a large number of niches–the range of environmental conditions, including physical (e.g., temperature, depth) and biological (e.g., competitors, predators) under which an organism can live, and its role in the ecosystem (e.g., what it eats and what it eats).
A.3. Most of the nutrients needed for primary productivity come from nutrient recycling. Nitrogen, phosphorous, and other nutrients in organic molecules, such as proteins and nucleic acids, are released when organisms die and are decomposed by bacteria.
A.4. Some of the organic matter produced by primary producers sinks below the sunlit surface zone, carrying nutrients to the deep.
B.3. Coastal habitats, such as estuaries and kelp forests, support a great diversity and number of organisms, which is due in part to: abundant sunlight and current patterns (e.g., upwelling, which brings nutrients to the surface, and nutrients flowing into the ocean from rivers).
B.4. There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, and methane cold seeps rely only on chemical energy and chemosynthetic organisms to support life.
B.5. Coral reefs, one of the most diverse ecosystems on Earth, thrive in nutrient-poor, warm waters because of a symbiotic relationship between corals and zooxanthellae, a type of dinoflagellate. This relationship enables corals to grow, forming substrates that are the foundation of complex reef ecosystems.
B.8. Many intertidal organisms are adapted to survive in zones defined by tidal cycles (amount of time exposed to air), crashing waves, predation, or substrate.
B.9. Many open ocean organisms are adapted to live only within distinct density layers or in zones defined by pressure or light levels.
B.12. Niches in the ocean are in a very dynamic environment, contributing to the high diversity seen in this ecosystem, e.g., sudden upwelling events create an environment conducive to the survival of a different set of organisms than were present prior to the influx of nutrient-rich water.
A.5. There is a direct relationship between primary productivity, current patterns, and upwelling. The highest levels of primary productivity are near the polar regions and in upwelling zones where there are high levels of nutrients and sunshine.
See Principle 2: B1
See Principle 1: C5
See Principle 2: B4
See Principle 1: C12
See Principle 2: B1
See Principle 1: C17



Principle 5: The ocean supports a great diversity of life and ecosystems.
The ocean provides a vast, interconnected living space with diverse and unique ecosystems from the surface through the water column and down to the sea floor.
Diversity of Life
C. The diversity of ocean ecosystems allows for many lifeforms and adaptations of ocean organisms.
Phyletic Diversity
C.1. The diversity of phyla is greater in the ocean than on land, and includes a range of organisms, from the smallest living things (microbes) to the largest animal on Earth (blue whales).
C.2. The first forms of life started in the ocean and evolved into the phyla seen today.
C.3. The first vertebrates to evolve were fish. Fish are the most numerous vertebrates in terms of species and individuals.
C.4. Some major groups left the ocean and evolved further on land. Some members of those groups later returned to the ocean, such as mammals, reptiles, birds, and flowering plants.
C.5. The majority of phyla that exist on Earth are still found exclusively in the ocean. These include seaweeds, echinoderms,ctenophores, urochordates (tunicates), and most sponges and cnidaria. There is only one phylum that exists uniquely on land.
C.6. All major groups of invertebrates have marine representatives, and many only live in marine environments. Except for the insects, most invertebrate species and thus most animals, are marine. At least 97% of all species of animals are invertebrates.
C.7. Seaweeds are eukaryotes, multicellular, photosynthetic organisms that have no seeds, and lack true roots and leaves. There are three phyla of seaweeds: green, brown and red.
C.8. Most of the organisms and biomass in the ocean are small prokaryote and eukaryote microbes, which are the basis of all ocean food webs
C.9. Prokaryote microbes are the most numerous ocean organisms.
C.10. Some bacteria and archaea are chemosynthetic primary producers, and make their own food from chemical compounds, such as hydrogen sulfide at hydrothermal vents.
C.11. Most marine bacteria are heterotrophs that break down detritus and recycle essential nutrients back into the environment. Some symbiotic bacteria are responsible for the bioluminescence of some deep sea fish and squid.
C.12. Photosynthetic bacteria, called cyanobacteria, are thought to have made most of the oxygen in the atmosphere. Cyanobacteria were the first photosynthetic organisms, and still produce much of Earth's oxygen.
See Principle 4: A1
C.13. There are many diverse groups of eukaryote microbes including unicellular algae (phytoplankton) and fungi.
C.14. Dinoflagellates are phytoplankton that have animal-like features, such as flagella, and can ingest food as heterotrophs. Some of these organisms cause red tides and bioluminescence. Some, called zooxanthellae, have symbiotic relationships with organisms such as corals.
C.15. Coastal pollution can cause an increase in the numbers of some dinoflagellates, leading to disease in humans and marine organisms.
See Principle 6: D18
C.16. Diatoms are phytoplankton that produce a huge amount of the carbon and oxygen produced on Earth. Diatoms have cell walls made of glass-like silica. The ocean floor is covered by vast deposits of these siliceous sediments.
C.17. Some diatoms are harmful, including those that produce domoic acid, which accumulates in shellfish and fish and may lead to death in mammals that eat them.
C.18. There are many species of marine fungi and they are mostly microbes. Most of these are decomposers.
C.19. The ocean supports larger animals than on land due to its unique physical and biological characteristics.
C.20. Seawater is denser than air, and thus supports animals with much greater mass.
C.21. The great productivity of particular places in the ocean, such as upwelling zones and polar regions, can support organisms larger than those that can exist on land.
Diverse Adaptations to Environmental Factors
C.22. Organisms in the ocean exhibit a wide variety of adaptations to survive in a watery environment.
C.23. There are varying levels of light in the ocean. Some ocean organisms have adaptations that allow them to stay near the sunlit surface. These adaptations allow some to photosynthesize (e.g., phytoplankton, kelp) and others to stay near their food source (e.g., zooplankton).
C.24. Plankton have features, such as oil droplets, spines, cilia, flagella, and/or a large surface area to volume ratio.
C.25. The ocean acts as a filter, and allows different wavelengths of light to penetrate to different depths: red, yellow, and orange wavelengths are filtered out in shallow water; green and blue light penetrate the deepest. The color of some organisms is a feature that allows them to be camouflaged at different depths.
C.26. Even in relatively shallow water, many red organisms appear gray and are camouflaged.
C.27. Since sound travels through the ocean further and faster than light does, many marine animals, from shrimp to whales, rely on sound to communicate, find prey and mates, and sense their environments.
C.28. Many large whales use low-frequency sound to communicate across entire ocean basins. Many toothed whales use echolocation to find and/or capture prey. Pistol shrimps use blasts of sound to shock prey.
C.29. Some ocean organisms have adaptations for living in or diving to the deep ocean.
C.30. Some marine mammals have many adaptations for deep diving, such as breath holding, slowing their heart rate, reducing blood flow to non-vital organs, and increasing oxygen storage. Many organisms use bioluminescence to find or attract prey and mates, and escape predators.
C.31. Marine organisms have adaptations that allow them to osmoregulate in a saltwater environment.
C.32. The body fluids of many marine organisms, including most fish, are more dilute than the surrounding seawater, so they tend to lose water by osmosis. To compensate, fish drink seawater and excrete salt through their gills and urine. Other organisms change the amount of ions in their body to match the salinity in the environment, (e.g., sharks regulate urea in their blood to match the ocean's salinity).
C.33. Marine organisms are adapted to live within particular ecosystems in a relatively stable ocean where there are only small fluctuations in pH and temperature.
C.34. Small changes in temperature and pH due to human activities can affect an organism's survival and biological diversity, (e.g., coral bleaching due to increased temperature and inhibition of shell formation due to ocean acidification).
C.35. Shelled organisms use calcium carbonate to construct shells and skeletons, relying on the abundant carbonate ions usually available in ocean water. As ocean pH decreases, the concentration of available carbonate ions also decreases, and carbonate from the shells dissolves into the ocean water, leading to thinning shells.
See Principle 3: C4
C.36. Small increases in temperature can lead to coral bleaching as the symbiotic algae (zooxanthellae) living inside the coral polyp leave resulting in the death of the coral.
See Principle 6: C36

Principle 5: The ocean supports a great diversity of life and ecosystems.

The ocean provides a vast, interconnected living space with diverse and unique ecosystems from the surface through the water column and down to the sea floor.

Diversity of Life

C. The diversity of ocean ecosystems allows for many lifeforms and adaptations of ocean organisms.

Diversity of Feeding Behaviors

C.37. Many marine organisms have adaptations for feeding, capturing prey, and avoiding predators.

- **C.38.** Some marine organisms have strategies and/or structures for finding food in the vast ocean where there is: varied abundance of food in specific locations like in coastal regions and upwelling zones; or scarcity of food in large expanses like the open ocean and deep sea.
  - **C.39.** For exploiting patchy distribution of food, some strategies include: migrating long distances (e.g., Gray whales, chambered nautili, and zooplankton); and having fat reserves (e.g., marine mammals and sea birds). For surviving in environments where prey are hard to find, some strategies include: having large stomachs and mouths (e.g., deep-sea hatchet fish and gulper eels) to take advantage of prey when they find it; and hydrodynamic tuna that chase down prey at high speeds.
- **C.40.** Marine organisms have strategies and/or structures for capturing food in a watery environment where: food may be suspended in the water column; the organism has to contend with the fluid friction of water and buoyancy.
  - **C.41.** These strategies include: catching food in suspension (e.g., cnidarians, crinoids); filtering large quantities of water to strain out smaller organisms (e.g., baleen in whales, siphons in clams, modified legs in barnacles); and having strong muscles or fast reflexes to chase down and snatch prey (e.g., fast swimming tuna and marlin, tentacles of squids and octopuses).
- **C.42.** Some marine organisms have symbiotic relationships that help them acquire energy.
  - **C.43.** Dinoflagellates called zooxanthellae live in the tissues of coral polyps. Coral gets sugars and oxygen from photosynthesis by the zooxanthellae and the zooxanthallae gets carbon dioxide, nutrients and shelter from the coral. Other examples of mutualism include clown fish living among anemone tentacles and cleaner fish removing parasites from other fish.

Diversity of Life Cycles and Reproductive Strategies

C.44. Organisms in the ocean have a variety of reproductive strategies and life cycles.

- **C.45.** Marine organisms have different lifestyles (i.e., planktonic, nektonic, benthic), and many transition between lifestyles as part of their life cycle, which allows them to survive in different ecosystems at different stages in their development. This is advantageous for a variety of reasons, such as: juveniles accessing different resources than adults (e.g., food and space); limiting competition between juveniles and adults; decreased predation rates on, and increased available nutrients for, juveniles.
  - **C.46.** Some examples of these changes between lifestyles include: benthic adult crabs in the intertidal with a juvenile planktonic larval form; and sessile adult mollusks with a planktonic larval form.
- **C.47.** Marine organisms have a range of life cycles and reproductive modes from simple, asexual reproduction to complex sexual reproduction, and some species shift between asexual and sexual (alternation of generation).
  - **C.48.** Some common forms of asexual reproduction among marine organisms include: splitting or fission (e.g., anemones) and budding (e.g., sponges). Organisms that reproduce asexually can have extremely fast growth rates under favorable environmental conditions (e.g., microbes, algae).
  - **C.49.** Some marine organisms have alternation of generations, switching between sexual and asexual reproduction each generation (e.g., jellyfish, seaweed). For seaweeds, diploid sporophyte generation produces haploid spores through meiosis, and a haploid gametophyte generation produces haploid gametes. The fertilized gametes produce the sporophyte. In some green and brown algae, the gametophyte and the sporophyte look identical, while in kelps the large organism we see is the sporophyte. The kelp gametophyte is microscopic.
  - **C.50.** Sexual reproduction may involve separate males and females; or switching between male and female or vice versa or have both male and female reproductive organs simultaneously (i.e., hermaphroditic). Some hermaphroditic species change sex in response to age, population changes, and shifts in environmental factors (e.g., brittlestars, coral reef fish).
- **C.51.** Reproductive strategies of marine organisms tend to be related to population density of the species, and thus are connected to mate competition and chances of finding mates.
  - **C.52.** In places with high-population density where there is high mate competition, organisms may change sex (e.g., blue head wrasse) or have multiple mates (e.g., squid). In places with low-population density, organisms may be monogamous (e.g., pelagic species like mahimahi), or develop parasitic relationships (e.g., anglerfish and isopods).
- **C.53.** Marine organisms have strategies for finding mates and maximizing fertilization of eggs in the vast ocean.
  - **C.54.** These strategies include: using mulitple environmental cues, such as day length, tidal cycles, seasonal variations in current patterns, to synchronize their breeding or spawning cycles (e.g., grunions, elephant seals, and butterfly fish). For species that have external fertilization, females and males produce millions of eggs and sperms (e.g., sea urchins, squids); and for deep sea and pelagic species, producing bioluminescent signals to attract mates (e.g., some pelagic octopuses).
- **C.55.** Marine organisms have strategies for maximizing survival and dispersal of offspring that have a range of parental care levels, thus the strategies entail different amounts of energy resources and investments from the parents.
  - **C.56.** These strategies include: releasing millions of eggs and sperm into the water (broadcast spawning), which offers no parental care, but increases probability for survival and dispersal of offspring by ocean currents (e.g., clams, corals, and most fish); brooding young inside male or female adults or defending patches of fertilized eggs, which offers some parental care (e.g., seahorse, octopus, some sharks, and surf perch); and intense parental care where one or both parents invest tremendous energy to nurture young until they are large enough to fend for themselves (e.g., marine mammals, sea birds).

Principle 5: The ocean supports a great diversity of life and ecosystems.

The ocean provides a vast, interconnected living space with diverse and unique ecosystems from the surface through the water column and down to the sea floor.

Primary Productivity — A

Microbes, such as cyanobacteria and phytoplankton, are the most abundant lifeforms, and the most important primary producers in the ocean. They are the base of most of the food webs in the ocean.

A1 — Primary production is the net gain in organic matter that occurs when producers make more organic matter than they use in respiration.

A7 — Chlorophyll, the green pigment found in microbes, algae, and other photosynthetic organisms, absorbs energy from sunlight; and together with carbon dioxide (inorganic carbon) and water, converts and stores chemical energy in the form of glucose (organic carbon).

A2 — Nutrients, such as minerals and vitamins, are needed to convert glucose into other organic material used to grow and reproduce. Some of the most important nutrients for producers in the ocean include: nitrogen (especially nitrate), phosphate, silicate, and iron. Nitrogen is often the nutrient in shortest supply.

A6 — Organisms that do not make their own food (heterotrophs) are dependent on the primary producers (autotrophs) to get the energy and matter they need to survive.

A3 — Most of the nutrients needed for primary productivity come from nutrient recycling. Nitrogen, phosphorus, and other nutrients in organic molecules, such as proteins and nucleic acids, are released when organisms die and are decomposed by bacteria.

A4 — Some of the organic matter produced by primary producers sinks below the sunlit surface zone, carrying nutrients to the deep.

A5 — There is a direct relationship between primary productivity, current patterns, and upwelling. The highest levels of primary productivity are near the polar regions and in upwelling zones where there are high levels of nutrients and sunshine.

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Ecosystem Diversity — B

Ocean ecosystems are defined by environmental factors and the community of organisms living there.

B1 — Ocean life is not evenly distributed through time or space due to differences in abiotic factors such as oxygen, salinity, temperature, pH, light, nutrients, pressure, substrate, and circulation. A few regions of the ocean support the most abundant life on Earth, while the vast majority of the ocean does not support much life.

B6 — Ocean ecosystems are often composed of habitats and microhabitats that exist in distinct, vertically distributed zones. Vertical zonation exists as distinct horizontal layers or bands on the coastline and throughout the water column.

B2 — Ocean ecosystems with the greatest abundance of life occur where environmental conditions and/or adaptations allow for high levels of productivity.

B7 — Zonation patterns occur in part because ocean organisms are adapted to live within specific environmental conditions.

B10 — Ocean ecosystems are connected to each other in a macro food web. Over time, organisms move from one ecosystem to another as they grow, migrate, and die. Changes in an ecosystem or an organism may have unpredictable effects on other ecosystems.

B11 — Ocean ecosystems support a large number of niches — the range of environmental conditions, including physical (e.g., temperature, depth) and biological (e.g., competitors, predators) under which an organism can live, and its role in the ecosystem (e.g., what it does and what it eats).

B3 — Coastal habitats, such as estuaries and kelp forests, support a great diversity and number of organisms, which is due in part to: abundant sunlight and current patterns (e.g., upwelling, which brings nutrients to the surface, and nutrients flowing into the ocean from rivers).

B4 — There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, and methane cold seeps rely only on chemical energy and chemosynthetic organisms to support life.

B5 — Coral reefs, one of the most diverse ecosystems on Earth, thrive in nutrient-poor, warm waters because of a symbiotic relationship between corals and zooxanthellae, a type of dinoflagellate. This relationship enables corals to grow, forming substrates that are the foundation of complex reef ecosystems.

B8 — Many intertidal organisms are adapted to survive in zones defined by tidal cycles (amount of time exposed to air), crashing waves, predation, or substrate.

B9 — Many open ocean organisms are adapted to live only within distinct density layers or in zones defined by pressure or light levels.

B12 — Niches in the ocean are in a very dynamic environment, contributing to the high diversity seen in this ecosystem, e.g., sudden upwelling events create an environment conducive to the survival of a different set of organisms than were present prior to the influx of nutrient-rich water.

Diversity of Life — C

The diversity of ocean ecosystems allows for many lifeforms and adaptations of ocean organisms.

Phyletic Diversity — C1

The diversity of phyla is greater in the ocean than on land, and includes a range of organisms, from the smallest living things (microbes) to the largest animal on Earth (blue whale).

C2 — The first forms of life started in the ocean and evolved into the phyla seen today.

C8 — Most of the organisms and biomass in the ocean are small prokaryote and eukaryote microbes, which are the basis of all ocean food webs.

C19 — The ocean supports larger animals than on land due to its unique physical and biological characteristics.

C3 — The first vertebrates to evolve were fish. Fish are the most numerous vertebrates in terms of species and individuals.

C5 — The majority of phyla that exist on Earth are still found exclusively in the ocean. These include seaweeds, echinoderms, ctenophores, urochordates (tunicates), and most sponges and cnideria. There is only one phylum that exists uniquely on land.

C9 — Prokaryote microbes are the most numerous ocean organisms.

C13 — There are many diverse groups of eukaryote microbes including unicellular algae (phytoplankton) and fungi.

C20 — Seawater is denser than air, and thus supports animals with much greater mass.

C21 — The great productivity of particular places in the ocean, such as upwelling zones and polar regions, can support organisms larger than those that can exist on land.

C4 — Some major groups left the ocean and evolved further on land. Some members of those groups later returned to the ocean, such as mammals, reptiles, birds, and flowering plants.

C6 — All major groups of invertebrates have marine representatives, and many only live in marine environments. Except for the insects, most invertebrate species and thus most animals, are marine. At least 97% of all species of animals are invertebrates.

C7 — Seaweeds are eukaryotes, multicellular photosynthetic organisms that have no seeds, and lack true roots and leaves. There are three phyla of seaweeds: green, brown, and red.

C10 — Some bacteria and archaea are chemosynthetic primary producers, and make their own food from chemical compounds, such as hydrogen sulfide at hydrothermal vents.

C11 — Most marine bacteria are heterotrophs that break down detritus and recycle essential nutrients back into the environment. Some symbiotic bacteria are responsible for the bioluminescence of some deep sea fish and squid.

C12 — Photosynthetic bacteria, called cyanobacteria, are thought to have made most of the oxygen in the atmosphere. Cyanobacteria were the first photosynthetic organisms, and still produce much of Earth's oxygen.

C14 — Dinoflagellates are phytoplankton that have animal-like features, such as flagella, and can ingest food as heterotrophs. Some of these organisms cause red tides and bioluminescence. Some, called zooxanthellae, have symbiotic relationships with organisms such as corals.

C16 — Diatoms are phytoplankton that produce a huge amount of the carbon and oxygen produced on Earth. Diatoms have cell walls made of glass-like silica. The ocean floor is covered by vast deposits of these siliceous sediments.

C18 — There are many species of marine fungi and they are mostly microbes. Most of these are decomposers.

C15 — Coastal pollution can cause an increase in the numbers of some dinoflagellates, leading to disease in humans and marine organisms.

C17 — Some diatoms are harmful, including those that produce domoic acid, which accumulates in shellfish and fish and may lead to death in mammals that eat them.

Diverse Adaptations to Environmental Factors — C22

Organisms in the ocean exhibit a wide variety of adaptations to survive in a watery environment.

C23 — There are varying levels of light in the ocean. Some ocean organisms have adaptations that allow them to stay near the sunlit surface. These adaptations allow some to photosynthesize (e.g., phytoplankton, kelp) and others to stay near their food source (e.g., zooplankton).

C25 — The ocean acts as a filter, and allows different wavelengths of light to penetrate to different depths: red, yellow, and orange wavelengths are filtered out in shallow water; green and blue light penetrate the deepest. The color of some organisms is a feature that allows them to be camouflaged at different depths.

C27 — Since sound travels through the ocean further and faster than light does, many marine animals, from shrimp to whales, rely on sound to communicate, find prey and mates, and sense their environments.

C29 — Some ocean organisms have adaptations for living in or diving to the deep ocean.

C31 — Marine organisms have adaptations that allow them to osmoregulate in a saltwater environment.

C33 — Marine organisms are adapted to live within particular ecosystems in a relatively stable ocean where there are only small fluctuations in pH and temperature.

C24 — Plankton have features, such as oil droplets, spines, cilia, flagella, and/or a large surface area to volume ratio.

C26 — Even in relatively shallow water, many red organisms appear gray and are camouflaged.

C28 — Many large whales use low-frequency sound to communicate across entire ocean basins. Many toothed whales use echolocation to find and/or capture prey. Pistol shrimps use blasts of sound to shock prey.

C30 — Some marine mammals have many adaptations for deep diving, such as breath holding, slowing their heart rate, reducing blood flow to non-vital organs, and increasing oxygen storage. Many organisms use bioluminescence to find or attract prey and mates, and escape predators.

C32 — The body fluids of many marine organisms, including most fish, are more dilute than the surrounding seawater, so they tend to lose water by osmosis. To compensate, fish drink seawater and excrete salt through their gills and urine. Other organisms change the amount of ions in their body to match the salinity in the environment, (e.g., sharks regulate urea in their blood to match the ocean's salinity).

C34 — Small changes in temperature and pH due to human activities can affect an organism's survival and biological diversity, (e.g., coral bleaching due to increased temperature and inhibition of shell formation due to ocean acidification).

C35 — Shelled organisms use calcium carbonate to construct shells and skeletons, relying on the abundant carbonate ions usually available in ocean water. As ocean pH decreases, the concentration of available carbonate ions also decreases, and carbonate from shells dissolves into the ocean water, leading to thinning shells.

C36 — Small increases in temperature can lead to coral bleaching as the symbiotic algae (zooxanthellae) living inside the coral polyp leave resulting in the death of the coral.

Diversity of Feeding Behaviors — C37

Many marine organisms have adaptations for feeding, capturing prey, and avoiding predators.

C38 — Some marine organisms have strategies and/or structures for finding food in the vast ocean where there is: varied abundance of food in specific locations like in coastal regions and upwelling zones; or scarcity of food in large expanses like the open ocean and deep sea.

C40 — Marine organisms have strategies and/or structures for capturing food in a watery environment where: food may be suspended in the water column; the organism has to contend with the fluid friction of water and buoyancy.

C42 — Some marine organisms have symbiotic relationships that help them acquire energy.

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C41 — These strategies include: catching food in suspension (e.g., cnidarians, crinoids); filtering large quantities of water to strain out smaller organisms (e.g., baleen in whales, siphons in clams, modified legs in barnacles); and having strong muscles or fast reflexes to chase down and snatch prey (e.g., fast swimming tuna and marlin, tentacles of squids and octopuses).

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Diversity of Life Cycles and Reproductive Strategies — C44

Organisms in the ocean have a variety of reproductive strategies and life cycles.

C45 — Marine organisms have different lifestyles (i.e., planktonic, nektonic, benthic), and many transition between lifestyles as part of their life cycle, which allows them to survive in different ecosystems at different stages in their development. This is advantageous for a variety of reasons, such as: juveniles accessing different resources than adults (e.g., food and space); limiting competition between juveniles and adults; decreased predation rates on, and increased available nutrients for, juveniles.

C47 — Marine organisms have a range of life cycles and reproductive modes from simple, asexual reproduction to complex sexual reproduction, and some species shift between asexual and sexual (alternation of generation).

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C46 — Some examples of these changes between lifestyles include: benthic adult crabs in the intertidal with a juvenile planktonic larval form; and sessile adult mollusks with a planktonic larval form.

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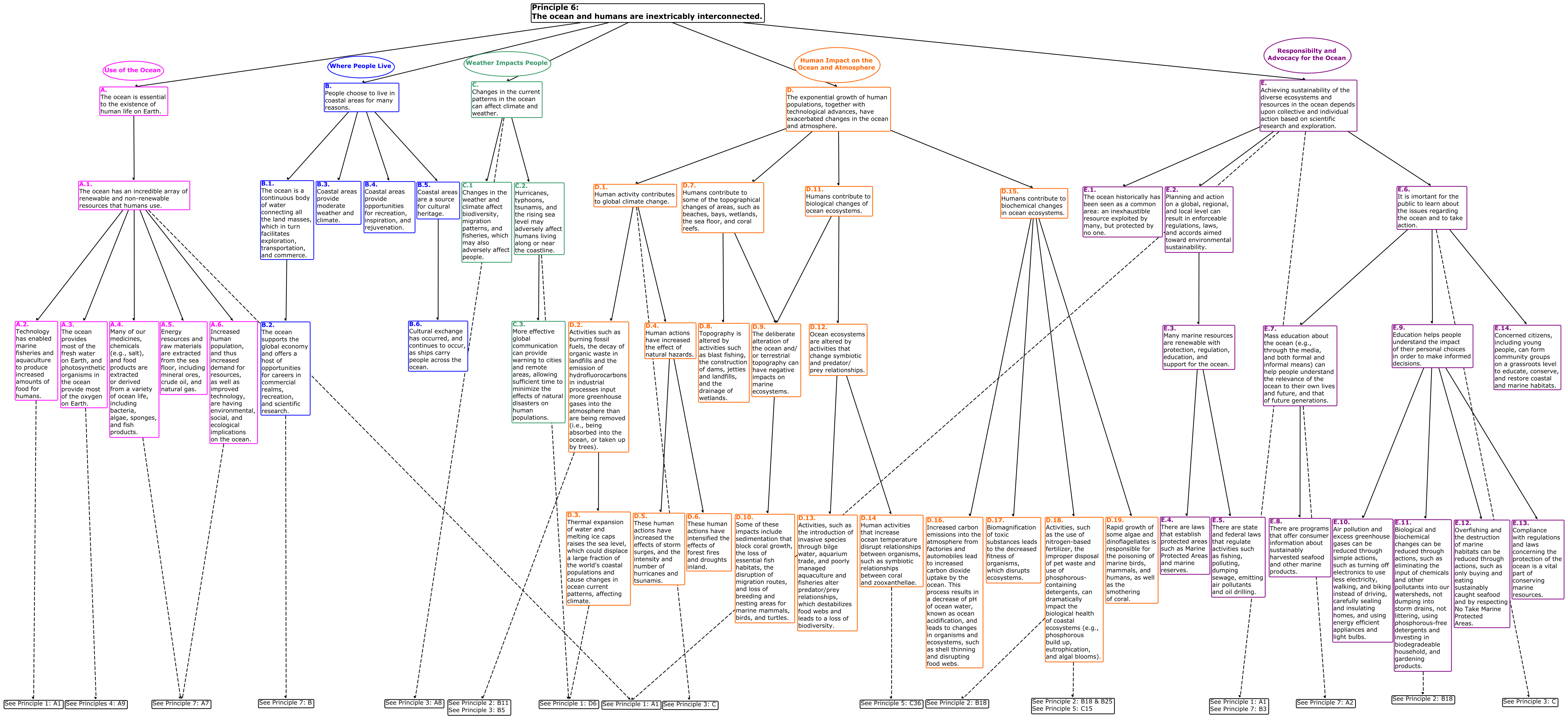
C49 — Some marine organisms have alternation of generations, switching between sexual and asexual reproduction each generation (e.g., jellyfish, seaweed). For seaweeds, diploid sporophyte generation produces haploid spores through meiosis, and a haploid gametophyte generation produces haploid gametes. The fertilized gametes produce the sporophyte. In some green and brown algae, the gametophyte and the sporophyte look identical, while in kelps the large organism we see is the sporophyte. The kelp gametophyte is microscopic.

C50 — Sexual reproduction may involve separate males and females; or switching between male and female or vice versa or have both male and female reproductive organs simultaneously (i.e., hermaphroditic). Some hermaphroditic species change sex in response to age, population changes, and shifts in environmental factors (e.g., brittlestars, coral reef fish).

C52 — In places with high-population density, where there is high mate competition, organisms may change sex (e.g., blue head wrasse) or have multiple mates (e.g., squid). In places with low-population density, organisms may be monogamous (e.g., pelagic species like mahimahi), or develop parasitic relationships (e.g., anglerfish and isopods).

C54 — These strategies include: using multiple environmental cues, such as day length, tidal cycles, seasonal variations in current patterns, to synchronize their breeding or spawning cycles (e.g., grunions, elephant seals, and butterfly fish). For species that have external fertilization, females and males produce millions of eggs and sperms (e.g., sea urchins, squids); and for deep sea and pelagic species, producing bioluminescent signals to attract mates (e.g., some pelagic octopuses).

C56 — These strategies include: releasing millions of eggs and sperm into the water (broadcast spawning), which offers no parental care, but increases probability for survival and dispersal of offspring by ocean currents (e.g., clams, corals, and most fish); brooding young inside male or female adults or defending patches of fertilized eggs, which offers some parental care (e.g., seahorse, octopus, some sharks, and surf perch); and intense parental care where one or both parents invest tremendous energy to nurture young until they are large enough to fend for themselves (e.g., marine mammals, sea birds).


Principle 6:
The ocean and humans are inextricably interconnected.
Use of the Ocean
Where People Live
Weather Impacts People
Human Impact on the Ocean and Atmosphere
Responsibilty and Advocacy for the Ocean
A. The ocean is essential to the existence of human life on Earth.
A.1. The ocean has an incredible array of renewable and non-renewable resources that humans use.
A.2. Technology has enabled marine fisheries and aquaculture to produce increased amounts of food for humans.
A.3. The ocean provides most of the fresh water on Earth, and photosynthetic organisms in the ocean provide most of the oxygen on Earth.
A.4. Many of our medicines, chemicals (e.g., salt), and food products are extracted or derived from a variety of ocean life, including bacteria, algae, sponges, and fish products.
A.5. Energy resources and raw materials are extracted from the sea floor, including mineral ores, crude oil, and natural gas.
A.6. Increased human population, and thus increased demand for resources, as well as improved technology, are having environmental, social, and ecological implications on the ocean.
B. People choose to live in coastal areas for many reasons.
B.1. The ocean is a continuous body of water connecting all the land masses, which in turn facilitates exploration, transportation, and commerce.
B.2. The ocean supports the global economy and offers a host of opportunities for careers in commercial realms, recreation, and scientific research.
B.3. Coastal areas provide moderate weather and climate.
B.4. Coastal areas provide opportunities for recreation, inspiration, and rejuvenation.
B.5. Coastal areas are a source for cultural heritage.
B.6. Cultural exchange has occurred, and continues to occur, as ships carry people across the ocean.
C. Changes in the current patterns in the ocean can affect climate and weather.
C.1 Changes in the weather and climate affect biodiversity, migration patterns, and fisheries, which may also adversely affect people.
C.2. Hurricanes, typhoons, tsunamis, and the rising sea level may adversely affect humans living along or near the coastline.
C.3. More effective global communication can provide warning to cities and remote areas, allowing sufficient time to minimize the effects of natural disasters on human populations.
D. The exponential growth of human populations, together with technological advances, have exacerbated changes in the ocean and atmosphere.
D.1. Human activity contributes to global climate change.
D.2. Activities such as burning fossil fuels, the decay of organic waste in landfills and the emission of hydrofluorocarbons in industrial processes input more greenhouse gases into the atmosphere than are being removed (i.e., being absorbed into the ocean, or taken up by trees).
D.3. Thermal expansion of water and melting ice caps raises the sea level, which could displace a large fraction of the world's coastal populations and cause changes in ocean current patterns, affecting climate.
D.4. Human actions have increased the effect of natural hazards.
D.5. These human actions have increased the effects of storm surges, and the intensity and number of hurricanes and tsunamis.
D.6. These human actions have intensified the effects of forest fires and droughts inland.
D.7. Humans contribute to some of the topographical changes of areas, such as beaches, bays, wetlands, the sea floor, and coral reefs.
D.8. Topography is altered by activities such as blast fishing, the construction of dams, jetties and landfills, and the drainage of wetlands.
D.9. The deliberate alteration of the ocean and/ or terrestrial topography can have negative impacts on marine ecosystems.
D.10. Some of these impacts include sedimentation that block coral growth, the loss of essential fish habitats, the disruption of migration routes, and loss of breeding and nesting areas for marine mammals, birds, and turtles.
D.11. Humans contribute to biological changes of ocean ecosystems.
D.12. Ocean ecosystems are altered by activities that change symbiotic and predator/ prey relationships.
D.13. Activities, such as the introduction of invasive species through bilge water, aquarium trade, and poorly managed aquaculture and fisheries alter predator/prey relationships, which destabilizes food webs and leads to a loss of biodiversity.
D.14 Human activities that increase ocean temperature disrupt relationships between organisms, such as symbiotic relationships between coral and zooxanthellae.
D.15. Humans contribute to biochemical changes in ocean ecosystems.
D.16. Increased carbon emissions into the atmosphere from factories and automobiles lead to increased carbon dioxide uptake by the ocean. This process results in a decrease of pH of ocean water, known as ocean acidification, and leads to changes in organisms and ecosystems, such as shell thinning and disrupting food webs.
D.17. Biomagnification of toxic substances leads to the decreased fitness of organisms, which disrupts ecosystems.
D.18. Activities, such as the use of nitrogen-based fertilizer, the improper disposal of pet waste and use of phosphorous-containing detergents, can dramatically impact the biological health of coastal ecosystems (e.g., phosphorous build up, eutrophication, and algal blooms).
D.19. Rapid growth of some algae and dinoflagellates is responsible for the poisoning of marine birds, mammals, and humans, as well as the smothering of coral.
E. Achieving sustainability of the diverse ecosystems and resources in the ocean depends upon collective and individual action based on scientific research and exploration.
E.1. The ocean historically has been seen as a common area: an inexhaustible resource exploited by many, but protected by no one.
E.2. Planning and action on a global, regional, and local level can result in enforceable regulations, laws, and accords aimed toward environmental sustainability.
E.3. Many marine resources are renewable with protection, regulation, education, and support for the ocean.
E.4. There are laws that establish protected areas such as Marine Protected Areas and marine reserves.
E.5. There are state and federal laws that regulate activities such as fishing, polluting, dumping sewage, emitting air pollutants and oil drilling.
E.6. It is imortant for the public to learn about the issues regarding the ocean and to take action.
E.7. Mass education about the ocean (e.g., through the media, and both formal and informal means) can help people understand the relevance of the ocean to their own lives and future, and that of future generations.
E.8. There are programs that offer consumer information about sustainably harvested seafood and other marine products.
E.9. Education helps people understand the impact of their personal choices in order to make informed decisions.
E.10. Air pollution and excess greenhouse gases can be reduced through simple actions, such as turning off electronics to use less electricity, walking, and biking instead of driving, carefully sealing and insulating homes, and using energy efficient appliances and light bulbs.
E.11. Biological and biochemical changes can be reduced through actions, such as eliminating the input of chemicals and other pollutants into our watersheds, not dumping into storm drains, not littering, using phosphorous-free detergents and investing in biodegradeable household, and gardening products.
E.12. Overfishing and the destruction of marine habitats can be reduced through actions, such as only buying and eating sustainably caught seafood and by respecting No Take Marine Protected Areas.
E.13. Compliance with regulations and laws concerning the protection of the ocean is a vital part of conserving marine resources.
E.14. Concerned citizens, including young people, can form community groups on a grassroots level to educate, conserve, and restore coastal and marine habitats.
See Principle 1: A1
See Principles 4: A9
See Principle 7: A7
See Principle 7: B
See Principle 3: A8
See Principle 2: B11
See Principle 3: B5
See Principle 1: D6
See Principle 1: A1
See Principle 3: C
See Principle 5: C36
See Principle 2: B18
See Principle 2: B18 & B25
See Principle 5: C15
See Principle 1: A1
See Principle 7: B3
See Principle 7: A2
See Principle 2: B18
See Principle 3: C

Principle 6: The ocean and humans are inextricably interconnected.

Use of the Ocean — A

The ocean is essential to the existence of human life on Earth.

A1	The ocean has an incredible array of renewable and non-renewable resources that humans use
A2	Technology has enabled marine fisheries and aquaculture to produce increased amounts of food for humans.
A3	The ocean provides most of the fresh water on Earth, and photosynthetic organisms in the ocean provide most of the oxygen on Earth.
A4	Many of our medicines, chemicals (e.g., salt), and food products are extracted or derived from a variety of ocean life, including bacteria, algae, sponges, and fish products.
A5	Energy resources and raw materials are extracted from the sea floor, including mineral ores, crude oil, and natural gas.
A6	Increased human population, and thus increased demand for resources, as well as improved technology, are having environmental, social, and ecological implications on the ocean.

Where People Live — B

People choose to live in coastal areas for many reasons.

B1	The ocean is a continuous body of water connecting all the land masses, which in turn facilitates exploration, transportation, and commerce.
B3	Coastal areas provide moderate weather and climate.
B4	Coastal areas provide opportunities for recreation, inspiration, and rejuvenation.
B5	Coastal areas are a source for cultural heritage.
B2	The ocean supports the global economy and offers a host of opportunities for careers in commercial realms, recreation, and scientific research.
B6	Cultural exchange has occurred, and continues to occur, as ships carry people across the ocean.

Weather Impacts People — C

Changes in the current patterns in the ocean can affect climate and weather.

C1	Changes in the weather and climate affect biodiversity, migration patterns, and fisheries, which may also adversely affect people.
C2	Hurricanes, typhoons, tsunamis, and the rising sea level may adversely affect humans living along or near the coastline.
C3	More effective global communication can provide warning to cities and remote areas, allowing sufficient time to minimize the effects of natural disasters on human populations.

Human Impact on the Ocean and Atmosphere — D

The exponential growth of human populations, together with technological advances, have exacerbated changes in the ocean and atmosphere.

D1	Human activity contributes to global climate change.
D7	Humans contribute to some of the topographical changes of areas, such as beaches, bays, wetlands, the sea floor, and coral reefs.
D11	Humans contribute to biological changes of ocean ecosystems.
D15	Humans contribute to biochemical changes in ocean ecosystems.
D2	Activities such as burning fossil fuels, the decay of organic waste in landfills, and the emission of hydrofluorocarbons in industrial processes input more greenhouse gases into the atmosphere than are being removed (i.e., being absorbed into the ocean, or taken up by trees).
D4	Human actions have increased the effect of natural hazards.
D8	Topography is altered by activities such as blast fishing, the construction of dams, jetties, and landfills, and the drainage of wetlands.
D9	The deliberate alteration of the ocean and/or terrestrial topography can have negative impacts on marine ecosystems.
D9	The deliberate alteration of the ocean and/ or terrestrial topography can have negative impacts on marine ecosystems.
D12	Ocean ecosystems are altered by activities that change symbiotic and predator/prey relationships.
D3	Thermal expansion of water and melting ice caps raises the sea level, which could displace a large fraction of the world's coastal populations and cause changes in ocean current patterns, affecting climate.
D5	These human actions have increased the effects of storm surges, and the intensity and number of hurricanes and tunamis.
D6	These human actions have intensified the effects of forest fires and droughts inland.
D10	Some of these impacts include sedimentation that block coral growth, the loss of essential fish habitats, the disruption of migration routes, and loss of breeding and nesting areas for marine mammals, birds, and turtles.
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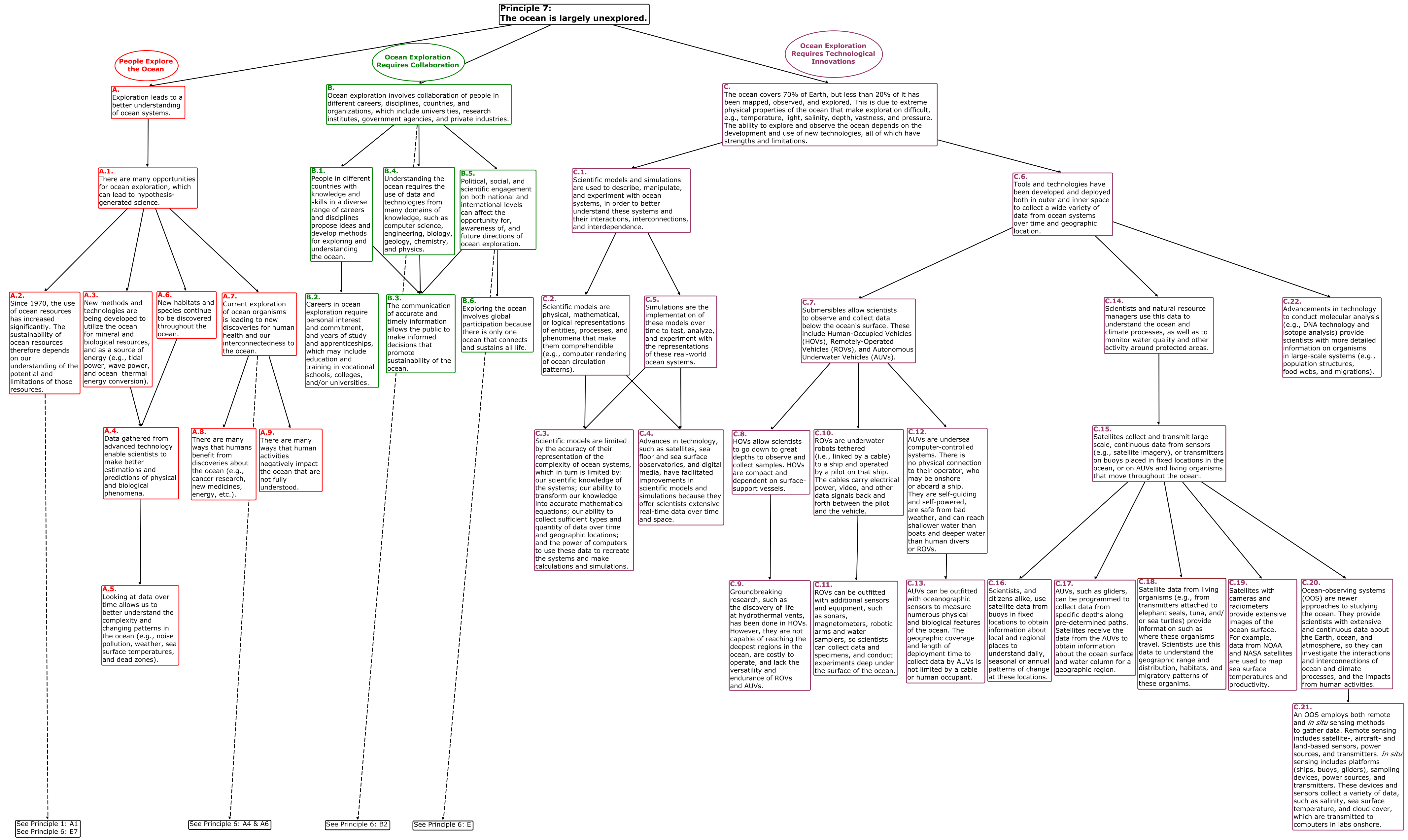
D13	Activities, such as the introduction of invasive species through bilge water, aquarium trade, and poorly managed aquaculture and fisheries alter predator/prey relationships, which destabilizes food webs and leads to a loss of biodiversity.
D14	Human activities that increase ocean temperature disrupt relationships between organisms, such as symbiotic relationships between coral and zooxanthellae.
D16	Increased carbon emissions into the atmosphere from factories and automobiles lead to increased carbon dioxide uptake by the ocean. This process results in a decrease of pH of ocean water, known as ocean acidification, and leads to changes in organisms and ecosystems, such as shell thinning and disrupting food webs.
D17	Biomagnification of toxic substances leads to the decreased fitness of organisms, which disrupts ecosystems.
D18	Activities, such as the use of nitrogen-based fertilizer, the improper disposal of pet waste, and use of phosphorous-containing detergents, can dramatically impact the biological health of coastal ecosystems (e.g., phosphorous build up, eutrophication, and algal blooms).
D19	Rapid growth of some algae and dinoflagellates is responsible for the poisoning of marine birds, mammals, and humans, as well as the smothering of coral.

Responsibility and Advocacy for the Ocean — E

Achieving sustainability of the diverse ecosystems and resources in the ocean depends upon collective and individual action based on scientific research and exploration.

E1	The ocean historically has been seen as a common area: an inexhaustible resource exploited by many, but protected by no one.
E2	Planning and action on a global, regional, and local level can result in enforceable regulations, laws, and accords aimed toward environmental sustainability.
E6	It is important for the public to learn about the issues regarding the ocean and to take action.
E3	Many marine resources are renewable with protection, regulation, education, and support for the ocean.
E7	Mass education about the ocean (e.g., through the media, and both formal and informal means) can help people understand the relevance of the ocean to their own lives and future, and that of future generations.
E9	Education helps people understand the impact of their personal choices in order to make informed decisions.
E14	Concerned citizens, including young people, can form community groups on a grassroots level to educate, conserve, and restore coastal and marine habitats.
E4	There are laws that establish protected areas such as Marine Protected Areas and marine reserves.
E5	There are state and federal laws that regulate activities such as fishing, polluting, dumping sewage, emitting air pollutants, and oil drilling.
E8	There are programs that offer consumer information about sustainably harvested seafood and other marine products.
E10	Air pollution and excess greenhouse gases can be reduced through simple actions, such as turning off electronics to use less electricity, walking and biking instead of driving, carefully sealing and insulating homes, and using energy efficient appliances and light bulbs.
E11	Biological and biochemical changes can be reduced through actions, such as eliminating the input of chemicals and other pollutants into our watersheds, not dumping into storm drains, not littering, using phosphorous- free detergents, and investing in biodegradeable household and gardening products.
E12	Overfishing and the destruction of marine habitats can be reduced through actions, such as only buying and eating sustainably caught seafood and by respecting No Take Marine Protected Areas.
E13	Compliance with regulations and laws concerning the protection of the ocean is a vital part of conserving marine resources.

Principle 7


Principle 7:
The ocean is largely unexplored.
People Explore the Ocean
Ocean Exploration Requires Collaboration
Ocean Exploration Requires Technological Innovations
A. Exploration leads to a better understanding of ocean systems.
A.1. There are many opportunities for ocean exploration, which can lead to hypothesis-generated science.
A.2. Since 1970, the use of ocean resources has increased significantly. The sustainability of ocean resources therefore depends on our understanding of the potential and limitations of those resources.
A.3. New methods and technologies are being developed to utilize the ocean for mineral and biological resources, and as a source of energy (e.g., tidal power, wave power, and ocean thermal energy conversion).
A.6. New habitats and species continue to be discovered throughout the ocean.
A.7. Current exploration of ocean organisms is leading to new discoveries for human health and our interconnectedness to the ocean.
A.4. Data gathered from advanced technology enable scientists to make better estimations and predictions of physical and biological phenomena.
A.8. There are many ways that humans benefit from discoveries about the ocean (e.g., cancer research, new medicines, energy, etc.).
A.9. There are many ways that human activities negatively impact the ocean that are not fully understood.
A.5. Looking at data over time allows us to better understand the complexity and changing patterns in the ocean (e.g., noise pollution, weather, sea surface temperatures, and dead zones).
B. Ocean exploration involves collaboration of people in different careers, disciplines, countries, and organizations, which include universities, research institutes, government agencies, and private industries.
B.1. People in different countries with knowledge and skills in a diverse range of careers and disciplines propose ideas and develop methods for exploring and understanding the ocean.
B.4. Understanding the ocean requires the use of data and technologies from many domains of knowledge, such as computer science, engineering, biology, geology, chemistry, and physics.
B.5. Political, social, and scientific engagement on both national and international levels can affect the opportunity for, awareness of, and future directions of ocean exploration.
B.2. Careers in ocean exploration require personal interest and commitment, and years of study and apprenticeships, which may include education and training in vocational schools, colleges, and/or universities.
B.3. The communication of accurate and timely information allows the public to make informed decisions that promote sustainability of the ocean.
B.6. Exploring the ocean involves global participation because there is only one ocean that connects and sustains all life.
C. The ocean covers 70% of Earth, but less than 20% of it has been mapped, observed, and explored. This is due to extreme physical properties of the ocean that make exploration difficult, e.g., temperature, light, salinity, depth, vastness, and pressure. The ability to explore and observe the ocean depends on the development and use of new technologies, all of which have strengths and limitations.
C.1. Scientific models and simulations are used to describe, manipulate, and experiment with ocean systems, in order to better understand these systems and their interactions, interconnections, and interdependence.
C.2. Scientific models are physical, mathematical, or logical representations of entities, processes, and phenomena that make them comprehensible (e.g., computer rendering of ocean circulation patterns).
C.5. Simulations are the implementation of these models over time to test, analyze, and experiment with the representations of these real-world ocean systems.
C.3. Scientific models are limited by the accuracy of their representation of the complexity of ocean systems, which in turn is limited by: our scientific knowledge of the systems; our ability to transform our knowledge into accurate 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.
C.4. Advances in technology, such as satellites, sea floor and sea surface observatories, and digital media, have facilitated improvements in scientific models and simulations because they offer scientists extensive real-time data over time and space.
C.6. 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.
C.7. Submersibles allow scientists to observe and collect data below the ocean's surface. These include Human-Occupied Vehicles (HOVs), Remotely-Operated Vehicles (ROVs), and Autonomous Underwater Vehicles (AUVs).
C.8. HOVs allow scientists to go down to great depths to observe and collect samples. HOVs are compact and dependent on surface-support vessels.
C.10. ROVs are underwater robots tethered (i.e., linked by a cable) to a ship and operated by a pilot on that ship. The cables carry electrical power, video, and other data signals back and forth between the pilot and the vehicle.
C.12. AUVs are undersea computer-controlled systems. There is no physical connection to their operator, who may be onshore or aboard a ship. They are self-guiding and self-powered, are safe from bad weather, and can reach shallower water than human divers or ROVs.
C.9. Groundbreaking research, such as the discovery of life at hydrothermal vents, has been done in HOVs. However, they are not capable of reaching the deepest regions in the ocean, are costly to operate, and lack the versatility and endurance of ROVs and AUVs.
C.11. ROVs can be outfitted with additional sensors and equipment, such as sonars, magnetometers, robotic arms and water samplers, so scientists can collect data and specimens, and conduct experiments deep under the surface of the ocean.
C.13. AUVs can be outfitted with oceanographic sensors to measure numerous physical and biological features of the ocean. The geographic coverage and length of deployment time to collect data by AUVs is not limited by a cable or human occupant.
C.14. Scientists and natural resource managers use this data to understand the ocean and climate processes, as well as to monitor water quality and other activity around protected areas.
C.22. Advancements in technology to conduct molecular analysis (e.g., DNA technology and isotope analysis) provide scientists with more detailed information on organisms in large-scale systems (e.g., population structures, food webs, and migrations).
C.15. Satellites collect and transmit large-scale data from sensors (e.g., satellite imagery), or transmitters on buoys placed in fixed locations in the ocean, or on AUVs and living organisms that move throughout the ocean.
C.16. Scientists, and citizens alike, use satellite data from buoys in fixed locations to obtain information about local and regional places to understand daily, seasonal or annual patterns of change at these locations.
C.17. AUVs, such as gliders, can be programmed to collect data from specific depths along pre-determined paths. Satellites receive the data from the AUVs to obtain information about the ocean surface and water column for a geographic region.
C.18. Satellite data from living organisms (e.g., from transmitters attached to elephant seals, tuna, and/or sea turtles) provide information such as where these organisms travel. Scientists use this data to understand the geographic range and distribution, habitats, and migratory patterns of these organisms.
C.19. Satellites with cameras and radiometers provide extensive images of the ocean surface. For example, data from NOAA and NASA satellites are used to map sea surface temperatures and productivity.
C.20. Ocean-observing systems (OOS) are newer approaches to studying the ocean. They provide scientists with extensive and continuous data about the Earth, ocean, and atmosphere, so they can investigate the interactions and interconnections of ocean and climate processes, and the impacts from human activities.
C.21. An OOS employs both remote and *in situ* sensing methods to gather data. Remote sensing includes satellite-, aircraft- and land-based sensors, power sources, and transmitters. *In situ* sensing includes platforms (ships, buoys, gliders), sampling devices, power sources, and transmitters. These devices and sensors collect a variety of data, such as salinity, sea surface temperature, and cloud cover, which are transmitted to computers in labs onshore.
See Principle 1: A1
See Principle 6: E7
See Principle 6: A4 & A6
See Principle 6: B2
See Principle 6: E

Principle 7: The ocean is largely unexplored.

People Explore the Ocean — A

Exploration leads to a better understanding of ocean systems.

A1 There are many opportunities for ocean exploration, which can lead to hypothesis-generated science.

A2 Since 1970, the use of ocean resources has increased significantly. The sustainability of ocean resources therefore depends on our understanding of the potential and limitations of those resources

A3 New methods and technologies are being developed to utilize the ocean for mineral and biological resources, and as a source of energy (e.g., tidal power, wave power, and ocean thermal energy conversion).

- **A4** Data gathered from advanced technology enable scientists to make better estimations and predictions of physical and biological phenomena.
  - **A5** Looking at data over time allows us to better understand the complexity and changing patterns in the ocean (e.g., noise pollution, weather, sea surface temperatures, and dead zones).

A6 New habitats and species continue to be discovered throughout the ocean.

- **A4** Data gathered from advanced technology enable scientists to make better estimations and predictions of physical and biological phenomena.
  - **A5** Looking at data over time allows us to better understand the complexity and changing patterns in the ocean (e.g., noise pollution, weather, sea surface temperatures, and dead zones).

A7 Current exploration of ocean organisms is leading to new discoveries for human health and our interconnectedness to the ocean.

- **A8** There are many ways that humans benefit from discoveries about the ocean (e.g., cancer research, new medicines, energy, etc.).
- **A9** There are many ways that human activities negatively impact the ocean that are not fully understood.

Ocean Exploration Requires Collaboration — B

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

B1 People in different countries with knowledge and skills in a diverse range of careers and disciplines propose ideas and develop methods for exploring and understanding the ocean.

- **B2** Careers in ocean exploration require personal interest and commitment, and years of study and apprenticeships, which may include education and training in vocational schools, colleges, and/or universities.
- **B3** The communication of accurate and timely information allows the public to make informed decisions that promote sustainability of the ocean.

B4 Understanding the ocean requires the use of data and technologies from many domains of knowledge, such as computer science, engineering, biology, geology, chemistry, and physics.

- **B3** The communication of accurate and timely information allows the public to make informed decisions that promote sustainability of the ocean.

B5 Political, social, and scientific engagement on both national and international levels can affect the opportunity for, awareness of, and future directions of ocean exploration.

- **B3** The communication of accurate and timely information allows the public to make informed decisions that promote sustainability of the ocean.
- **B6** Exploring the ocean involves global participation because there is only one ocean that connects and sustains all life.

Ocean Exploration Requires Technological Innovations — C

The ocean covers 70% of Earth, but less than 20% of it has been mapped, observed, and explored. This is due to extreme physical properties of the ocean that make exploration difficult, e.g., temperature, light, salinity, depth, vastness, and pressure. The ability to explore and observe the ocean depends on the development and use of new technologies, all of which have strengths and limitations.

C1 Scientific models and simulations are used to describe, manipulate, and experiment with ocean systems, in order to better understand these systems and their interactions, interconnections, and interdependence.

C2 Scientific models are physical, mathematical, or logical representations of entities, processes, and phenomena that make them comprehendible (e.g., computer rendering of ocean circulation patterns).

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  - **C9** Groundbreaking research, such as the discovery of life at hydrothermal vents, has been done in HOVs. However, they are not capable of reaching the deepest regions in the ocean, are costly to operate, and lack the versatility and endurance of ROVs and AUVs.
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