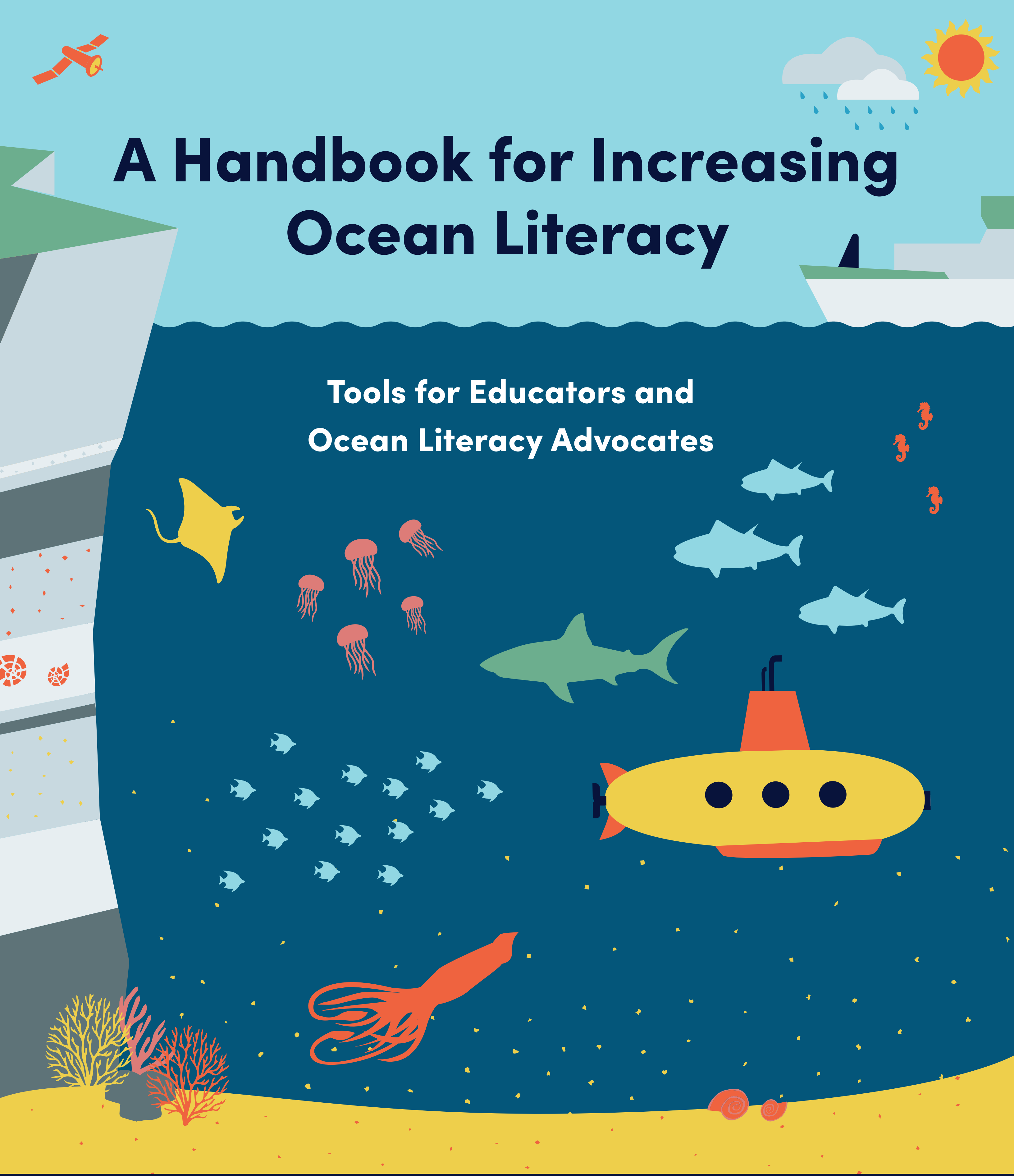
A Handbook for Increasing Ocean Literacy

Tools for Educators and Ocean Literacy Advocates



National Oceanic and Atmospheric Administration
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2021 2030 United Nations Decade of Ocean Science for Sustainable Development

National Marine Educators Association
making known the world of water

Acknowledgments

A Handbook for Increasing Ocean Literacy would not have been possible without the long-ago contributions of hundreds of ocean scientists and educators and the support of several organizations that have provided backbone support to the initial development, continual updates, and ongoing dissemination of core documents. The editors thank Craig Strang, Kathy DiRanna, and Jo Topps for allowing us to update and include the article on conceptual flow diagrams in this publication. Additionally, the many individuals who contributed to the development and refinement of 28 conceptual flow diagrams deserve acknowledgement once more for their contributions; these diagrams are still as useful today as they were more than a decade ago and have served ocean educators, curriculum developers, and others well in the intervening years. Finally, we also must acknowledge the work of 17 dedicated ocean literacy experts who gave many hours to the development of the NGSS-ocean literacy alignment. Individual and organizational contributors are included on NMEA's Honor Roll for Ocean Literacy at **www.marine-ed.org/ocean-literacy/honor-roll**.

The editors also thank Bill Andrake, Lyndsey Manzo, Sarah Pedemonte, Pete Tebeau, Lynn Tran, and Lynn Whitley for assisting the editors with the creation of alternatives to the conceptual flow diagrams that will be accessible to those who rely on screen reader assistance—no small task!

Finally, a special thanks belongs to the following organizations and networks for their past and ongoing support and promotion of the tools contained in this handbook:

- The NSF-funded Centers for Ocean Science Education Excellence
- The Lawrence Hall of Science
- National Marine Educators Association (NMEA)
- National Oceanic and Atmospheric Administration (NOAA)
- NOAA Sea Grant
- The College of Exploration

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Fellow Ocean Enthusiasts,

Marine educators participating in a pre-conference workshop, Designing Professional Development to Support Ocean Literacy. June 29, 2009 (Photo credit: Craig Strang)

Our one global ocean is the defining feature of our planet. It makes Earth habitable, influences our weather and climate, and supports a great diversity of life and ecosystems. While largely unexplored, the connection between the ocean and humans is undeniable. These ideas are the foundation of what has become an international effort to increase ocean literacy—to help each of us understand the ocean's influence on us and our influence on the ocean.

A Handbook for Increasing Ocean Literacy is a resource for you to help teach, learn, and communicate about the ocean. While originally intended for classroom teachers and informal educators for educational materials, programs, exhibits, and activity development in the United States, ***these resources can be used by anyone, anywhere, who seeks to increase ocean literacy****. In 2021, the United Nations launched the Decade of Ocean Science for Sustainable Development 2021–2030. Ocean literacy has been integrated into the goals of and plans for the Decade and this handbook has been recognized as a contribution toward achieving "…the ocean we want" now and in the future.*

In 2004, the National Oceanic and Atmospheric Association (NOAA), the National Science Foundation-funded Centers of Ocean Sciences Education Excellence (COSEE), National Geographic Society, National Marine Educators Association (NMEA), the College of Exploration, and the Lawrence Hall of Science, University of California Berkeley convened a series of meetings to define the most important ideas that the public should understand about the ocean. These meetings resulted in the publication of the seminal document, *Ocean Literacy: The Essential Principles of Ocean Sciences K–12*, originally published in 2005.[1] Upon publication of this guide, there was broad recognition of the potential power of a consensus document describing what every person should know about the ocean to be considered science literate. There was also recognition of the limitations of such a document that describes the ideal end state yet provides no road map for how to get there. The stage was set for the development and publication of the derivative document, *The Ocean Literacy Scope and Sequence for Grades K–12*, which provides just such a road map. These two documents ensured the inclusion of ocean science concepts in *A Framework for K–12 Science Education*, and ultimately the Disciplinary Core Ideas of the Next Generation Science Standards (NGSS). While our community of ocean

1 This guide has been updated several times, most recently in 2021 and is now titled, Ocean Literacy: The Essential Principles and Fundamental Concepts for Learners of All Ages (NOAA 2021)

scientists and educators didn't get all the desired changes to the final Framework and NGSS, there are without a doubt more ocean concepts in the final Framework report and NGSS than in the initial drafts.

The handbook includes the 28 conceptual flow diagrams of *The Ocean Literacy Scope and Sequence for Grades K–12*, an article explaining the theoretical basis for the Scope and Sequence, the *Ocean Literacy Alignment to Next Generation Science Standards*, as well as brief explanations about how to use these tools, their origins, and purposes. It is meant to be used in conjunction with the *Ocean Literacy: The Essential Principles and Fundamental Concepts for Learners of All Ages* (NOAA, 2021). It replaces the seminal publication (now out of print), *Ocean Literacy Campaign Special Report #3* (NMEA, 2010).

This handbook is intended to foster the conversation on Ocean Literacy and bring us closer to our collective goal of global ocean literacy.

Ocean-literately yours,
Diana Payne, Catherine Halversen, and Sarah Schoedinger
Editors

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National Oceanic and Atmospheric Administration. (2021). *Ocean Literacy: The Essential Principles and Fundamental Concepts of Ocean Science for Learners of All Ages.* Washington, DC. Retrieved from: **www.oceanliteracynmea.org/guide**

National Marine Educators Association

National Marine Educators Association (NMEA) is a dedicated, influential member-based organization of classroom teachers, informal educators, university professors, scientists, and more from around the world working together to advance the understanding and protection of our freshwater and marine ecosystems. From scientists working in the deep sea to students studying underwater archeology in the Great Lakes, NMEA members are dedicated to making known the world of water, both fresh and salt. For more information, please visit **www.marine-ed.org**.

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Marine educators discussing characteristics of effective professional development at a pre-conference workshop, Designing Professional Development to Support Ocean Literacy. June 29, 2009 (Photo credit: Craig Strang).

Organizing the essential components of effective professional development for educators at a pre-conference workshop, Designing Professional Development to Support Ocean Literacy. June 29, 2009 (Photo credit: Craig Strang)

Developing the Ideas of Ocean Literacy Using Conceptual Flow Diagrams

By Craig Strang, Kathy DiRanna, Jo Topps

Upon publication of *Ocean Literacy: The Essential Principles of Ocean Sciences K–12*,[1] there was broad recognition of the potential power of a consensus document describing what every person should know about the ocean to be considered science literate. There was also recognition of the limitations of such a document that describes the ideal end state, yet provides no road map for how to get there. We knew that ultimately we would need to craft a road map to provide an answer to the question, "If students are to understand the Ocean Literacy Principles by the end of grade 12, what would we need to teach them in grades K through 2, in grades 3 through 5, in grades 6 through 8, and in grades 9 through 12 to help them reach that goal?" The answer to that question—a scope and sequence—would be of great interest to teachers and informal science educators, but also to national and state standards committees, curriculum developers, textbook writers, and assessment specialists. But what would be an effective way to represent this complex information so that it would be comprehensive, understandable and accessible for these different end users? For this answer, we turned to literature in learning, teaching, and teacher professional development.

Research in the learning sciences (National Academies, 2018) reveal that to develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application. Thus to facilitate the development of students' conceptual understanding and organization of ocean sciences ideas, the scope and sequence should have a logical and coherent approach to building the complex ideas of the Ocean Literacy Principles from one grade band to the

1 Since the publication of *Ocean Literacy: The Essential Principles of Ocean Sciences for Grades K–12* in 2005, there have been two major updates to the Ocean Literacy Guide, one in 2013 and one in 2020. The title changed to *Ocean Literacy: The Essential Principles of Ocean Sciences for Learners of All Ages* in recognition that the concepts contained in the guide were important for informal as well as formal K through 12 education.

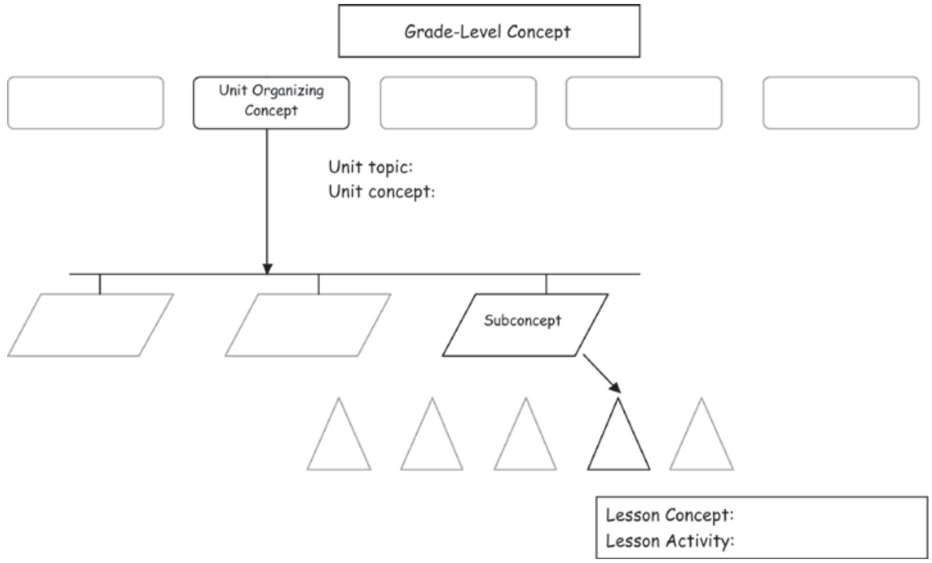
next. Conceptual flow diagrams (as shown on pages 16 to 74) offer a way to present and organize such a progression of ideas, and can be a versatile tool for several reasons: they describe the developmentally appropriate concepts at each grade band, as well as the relationships among the concepts, in a graphical format; they provide a research-based example of a sequence in which the concepts can be taught, beginning at the earliest grades; and the diagrams balance the need for clarity and utility with fidelity to learning theory and cognitive science. Additionally, we have developed a way to organize these concepts in a tabular format. This helps convey the connections and relationships between concepts, without relying on visual cues. As in the conceptual flow diagrams, strands of connected ideas are organized under a topic title and brief description. Instead of using arrows to convey connections between individual concepts, the tabular format stacks the concepts and subconcepts in rows and columns in the order in which they should be presented (i.e., top row to bottom row within a column, then left to right). This means some concepts are repeated under each higher-level concept to convey the connections among them.

Figure 1

Shows the generic layout of conceptual flow diagrams developed by teachers to describe an instructional sequence.

Concept Maps versus Conceptual Flows

Conceptual flow diagrams (using arrows or a tabular format) are a specialized and distinct form of concept maps. Concept maps are graphical tools for organizing and representing knowledge that were developed in 1972 in the course of Joseph Novak's research program at Cornell University where he sought to follow and understand changes in children's knowledge and understanding of science (Novak & Musonda, 1991). The data from Novak's study indicated "the lasting impact of early instruction in science and the value of concept maps as a representational tool for cognitive developmental changes." Novak's concept maps include concepts, usually enclosed in circles or boxes, and relationships between concepts indicated by a connecting line linking two concepts. Text on the connecting line, referred to as linking words or linking phrases, specify the relationship between the two concepts. Concepts are generally represented in a hierarchical fashion with the most inclusive, most general concepts at the top of the map, and more specific concepts arranged below. The hierarchical structure for a domain of knowledge may be somewhat relative as it often depends on the context in which that knowledge is being applied or considered (Novak & Cañas, 2008; Novak & Gowin, 1984). The use of concept maps generally represents a constructivist approach to learning and teaching, as it assists the learner in developing and displaying the trajectory of their understanding of new concepts and ideas.



Conceptual flow diagrams were first developed by the K–12 Alliance/WestEd in California in 1989, for use with teachers during professional development institutes conducted for an NSF-funded statewide systemic initiative.[2] Hundreds of teachers have used this model to develop conceptual flow diagrams to improve their content knowledge, their curriculum planning, and their instruction of complex science concepts. As a product, a conceptual flow diagram resembles a map of nested concepts. The biggest ideas are supported by small ideas, and those small ideas are maintained by even smaller ideas that become learning sequence concepts (**see Figure 1**). The conceptual flow diagram differs from a concept map in that it addresses concepts in a unit of instruction, and has both a hierarchy of ideas (indicating the relationship between and among the ideas) and a direction, i.e., the sequence for instruction of the unit. Conceptual flow diagrams are intended to be read and taught from top to bottom and from left to right. Concepts nested beneath other concepts, either connected by arrows or in an individual column in the tabular format, serve to elucidate and support the concepts above. Concepts to the right, i.e., in another strand, or in the next column, build on those to the left, and often move in a developmental sequence, especially in the early grades, from more concrete to more abstract.

The process of guiding teachers through the development of conceptual flow diagrams is described at length in the book, *Assessment Centered Teaching: A Reflective Practice* (DiRanna *et al*., 2008). The process of making conceptual flow diagrams has also been adapted for a variety of purposes, including planning for classroom instruction and assessment simultaneously, assisting in school district analysis, selection and adoption of instructional materials, and helping curriculum developers to design instructional materials. Given these versatile uses of conceptual flow diagrams to display and organize big ideas and concepts in a well-thought-out progression of learning and teaching for different educational purposes, we decided to use conceptual flow diagrams to represent the scope and sequence.

Purpose of Conceptual Flow Diagrams

The conceptual flow diagram is a "backward-planning" tool. Starting with the end in mind and planning backwards (Wiggins & McTighe, 2005) is a means for setting comprehensible goals and designing better instruction. Teachers can array the big ideas that are important for students to know, the standards they are responsible for teaching, and the content presented in the instructional materials into one comprehensive, sequential chart. As teachers identify and integrate these three elements, the process of constructing a conceptual flow diagram enables teachers to clearly identify specific goals for student learning and progress. The conceptual flow diagram assists learners by making them aware of the links in the concepts they are addressing. Too often it is a mystery to students why they are learning what they are learning. As one teacher put it,

The conceptual flow diagram is a determination of where you are going in your teaching and what you're going to reflect on. You have to know what concepts are important and the order in which they go to conceptualize the whole learning. I put my conceptual flow on the wall for the kids so they learn where they're going, too.

—Teacher Leader 1, NSF Center for Assessment & Evaluation of Student Learning

Developing conceptual flow diagrams helps teachers build foundational knowledge about the importance of helping students to construct conceptual frameworks rather than "learn" factual information. When a conceptual flow is displayed in the classroom, it allows both teachers and students to connect new ideas and information, providing opportunities to learn with deeper understanding.

2 Since the time that the Ocean Literacy Scope and Sequence was developed, conceptual flow diagrams have evolved to include an emphasis on 3-dimensional instruction articulated in *A Framework for K–12 Science Education*, i.e., Scientific and Engineering Practices (SEPs), Disciplinary Core Ideas (DCIs), and Crosscutting Concepts (CCCs) (National Research Council, 2012).

A completed conceptual flow diagram serves the following four purposes:

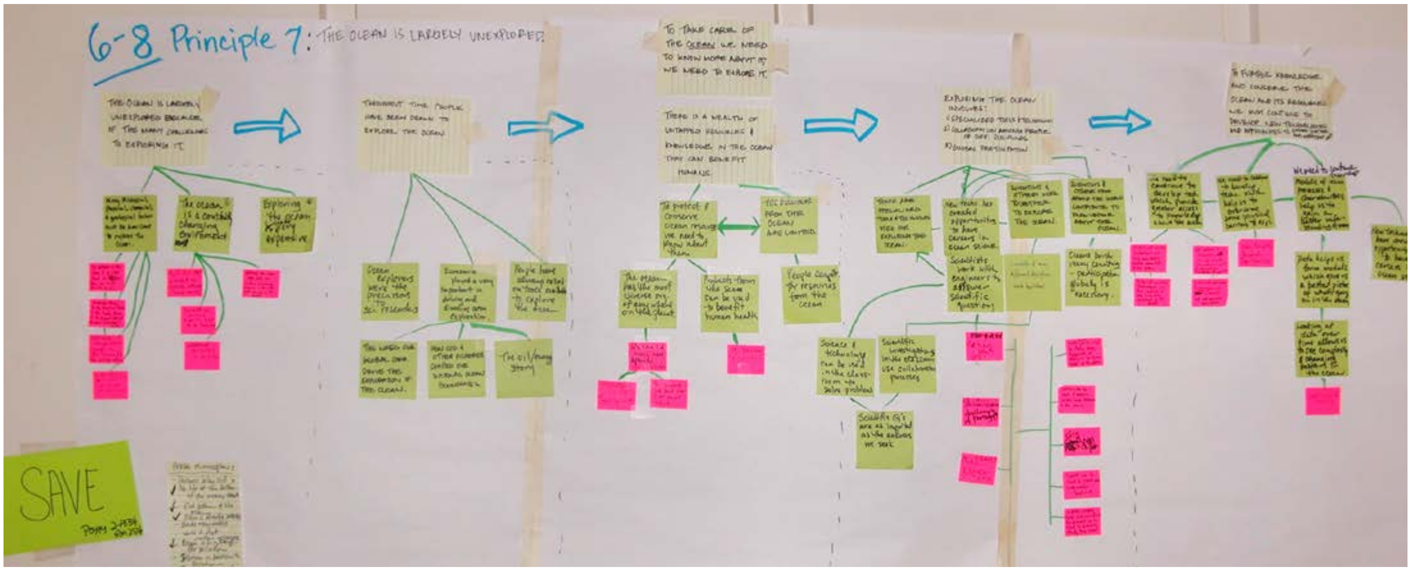
1. Details the important concepts and linkages to other ideas;
2. Identifies an instructional sequence for which resources (e.g., textbooks, instructional materials) can be used to support teaching;
3. Identifies important concepts for assessment of student understanding; and
4. Eventually serves as the foundation of an assessment plan for the unit of instruction.

Construction of Conceptual Flow Diagrams

Conceptual flow diagrams are designed by a team, often led by a facilitator knowledgeable of the process. The process for a team of 2 to 5 people to build a conceptual flow diagram for a unit of instruction includes these five steps:

1. Individuals write a narrative response to the question, "What should students be able to demonstrate their understanding about by the time they leave grade (blank)?
2. Individuals re-write and transfer each concept statement in complete sentences from their narrative responses onto separate post-it notes of three different sizes using the larger size for the larger, more important concepts.
3. Team members share their concepts on post-it notes with one another. They arrange the notes into a collaborative draft conceptual flow diagram with larger concepts at the top, and smaller, nested, supporting concepts below. This step can take several hours.
4. Team members match their collaborative, draft conceptual flow diagram to the concepts addressed in the instructional materials and to the science content standards and pedagogy used by team members.
5. Team members review the progression of concept clusters (each cluster is comprised of a large concept and the nested, smaller concepts below it) and place them in an instructional sequence that provides strong links for student understanding (see Figure 2).

Figure 2



Sample of a first draft of the conceptual flow diagram for Principle 7 grades 6 through 8 developed at the first Ocean Literacy Scope and Sequence working meeting in 2006.

Conceptual Flow and Teacher Change

In addition to aiding teachers in curriculum development, conceptual flow diagrams have been used as a foundational process for developing classroom assessment plans. A research study of teachers who received professional development on the building of conceptual flow diagrams found that most grade level teams shifted over time toward a *greater focus on big ideas* by removing, adding or reorganizing learning goals to focus on what was most important for students to learn. Another common shift was toward *more coordinated relationships among big ideas and smaller supporting concepts*. Most teams increasingly represented conceptual relationships among unit goals rather than as a list of sequential lesson topics. Paralleling organizational shifts in the conceptual flow diagrams, all of the teachers' assessment plans were more coherently organized in later portfolios. Assessment plans shifted from long lists of possible assessments toward judicious selection of a few key assessments for tracking student progress. Teachers indicated generally strong understandings of how to use conceptual flow diagrams to guide assessment decisions and to select their "juncture" assessments (Gearhart & Osmundson, 2009).

I think teachers need to understand the conceptual flow of their curriculum…what concepts they want students to learn; what concepts to assess with their students… then they can plan for teaching.

[Developing the Conceptual Flow] moved us from a list of topics to…nesting of important ideas. Identifying what really matters for student understanding drives decisions about…questions in the assessment.

—Teacher Leader 2, NSF Center for Assessment & Evaluation of Student Learning

In a political climate that often stresses coverage of material in preparation for state testing, teachers appreciate the process that building conceptual flow diagrams provides because it focuses on conceptual understanding of big ideas. One teacher explained,

My district is into curriculum mapping and… I'm trying to cover the standards, but (by using conceptual flow diagrams) you have to go deeper into the standards to assess the concepts that are actually behind the understanding, instead of just checking off standards.

—Teacher Leader 3, NSF Center for Assessment & Evaluation of Student Learning

Based on the findings of Gearhart and Osmundson, the benefits of conceptual flow diagrams appear to go beyond assessment planning: teachers *take ownership* of their instruction by becoming better consumers of instructional materials. As they grapple with important concepts and how they should be arranged in a meaningful sequence, teachers gain insight into how instructional materials are organized, which materials are designed to support students' understanding of the big ideas, and which lessons, resources, and assessments need to be revised. Teachers can then modify their instruction and assessment practice to address any gaps or weaknesses.

With a new focus on the concepts in the conceptual flow diagram, I was able to really see my instructional materials. I mean, I knew that our instructional materials were not often perfect, but this really brought out where the holes are, where I need to revise and what I need to put in there to make sure the students understand the concept that I'm trying to teach.

—Teacher Leader 4, NSF Center for Assessment & Evaluation of Student Learning

I always look at a unit now and make sure that it does flow conceptually. If not, then I rearrange to make sure I include ideas that build upon one another. I always make that a part of my science teaching and I want to incorporate conceptual flow diagrams into other content areas.

—Teacher Leader 5, NSF Center for Assessment & Evaluation of Student Learning

While collaborative development of working versions of conceptual flow diagrams has been demonstrated as an effective teacher professional development activity, involving hundreds of people in the development of a set of 28 completed conceptual flow diagrams has, to say the least, never been accomplished before. *The Ocean Literacy Scope and Sequence for Grades K–12* represents a new use of conceptual flow diagrams. In 2006, the authors and several other colleagues led a group of 46 ocean scientists and educators through the development of the first Ocean Literacy conceptual flow diagrams. The process was uplifting and invaluable. Achieving a final product, however, took considerable revision, iteration, and review before consensus was reached on all 28 diagrams. In 2015, the *Alignment of Ocean Literacy to the Next Generation Science Standards* was completed to detail the correlations between the Next Generation Science Standards (NGSS)—specifically the Disciplinary Core Ideas (DCI) and Performance Expectations (PE)—and the concepts included in the *Ocean Literacy: The Essential Principles of Ocean Sciences for Learners of All Ages* and the *Ocean Literacy Scope and Sequence for Grades K–12 (Scope and Sequence)*. The alignment documents are organized by grade band and provide a 4-point scale with a description and explanation for each rating. Providing coherence across the Ocean Literacy Framework and NGSS helps to leverage our community's work and make it more valuable and useful. (**See page 75 for the Alignment documents.**) The Scope and Sequence has become a catalyst for research about how students form and revise their understanding of complex ocean sciences concepts. Further, the Scope and Sequence is a driving force in defining the content that students will encounter in textbooks, curriculum materials, and assessments.

Editors' Note: This article was updated to reflect changes since the original 2010 publication. Any errors are the responsibility of the editors.

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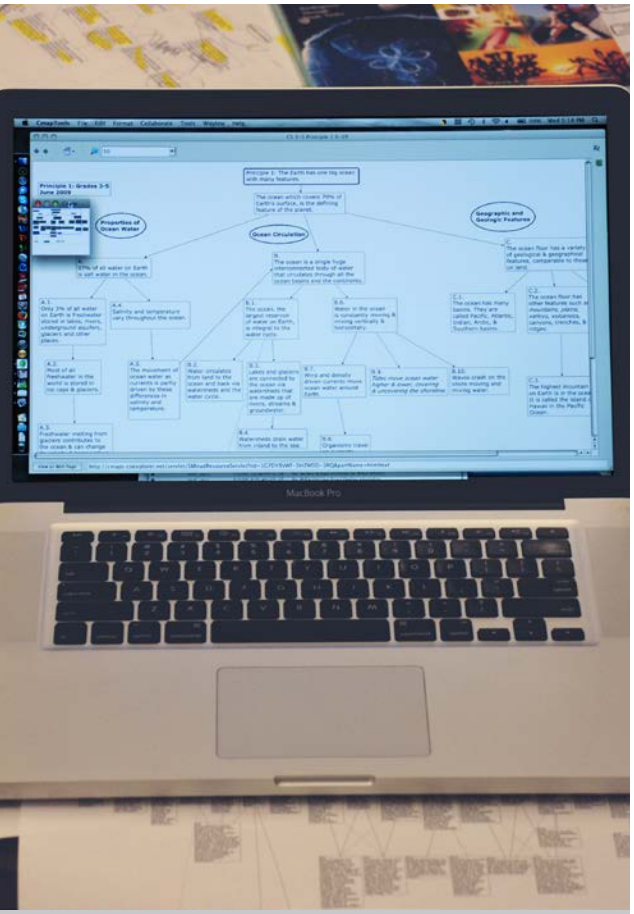


The freeware **CmapTools** was used in developing the conceptual flow diagrams (Photo credit: Craig Strang)

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.

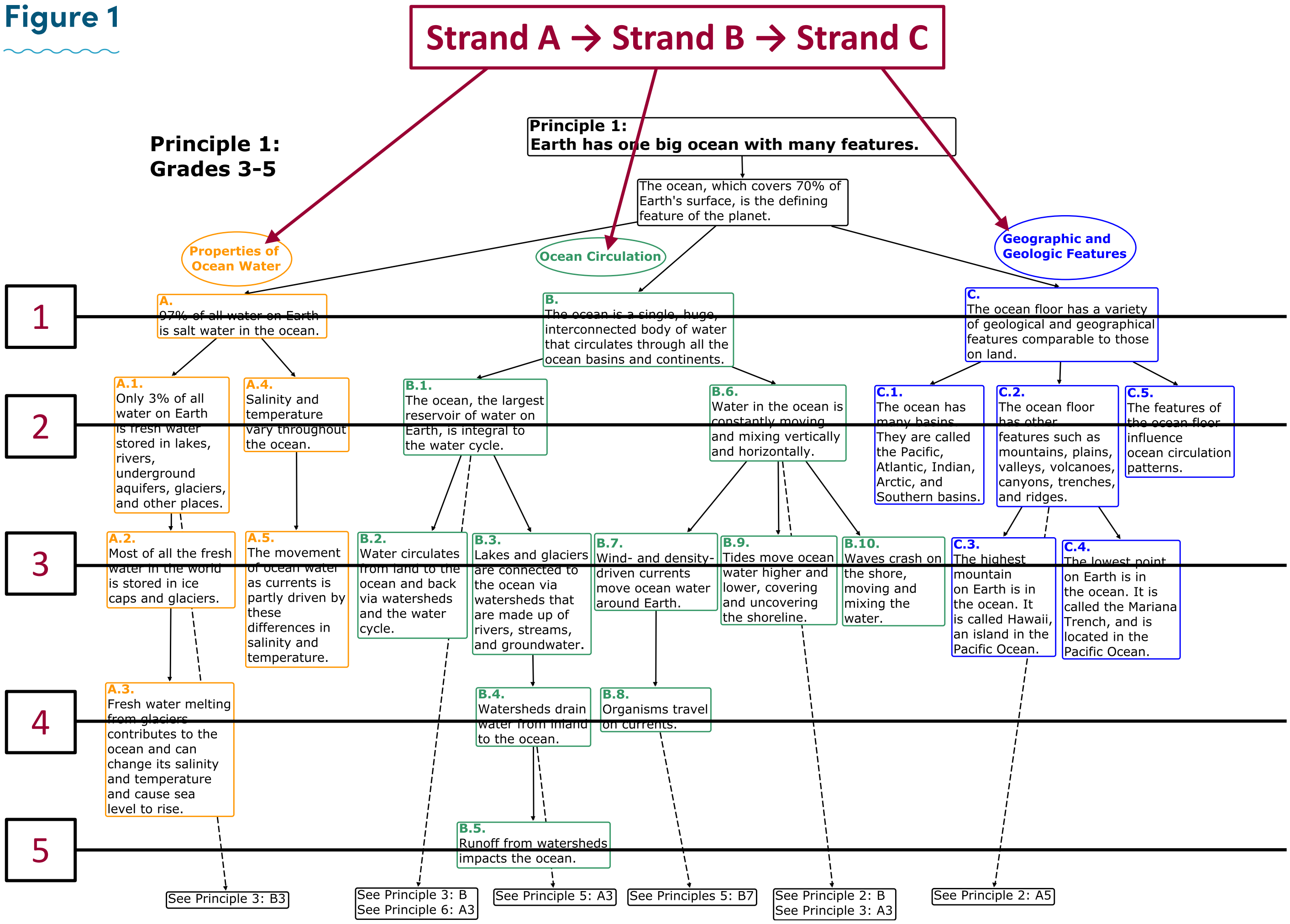
4 A more complete history is provided in the introduction to this handbook.

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.

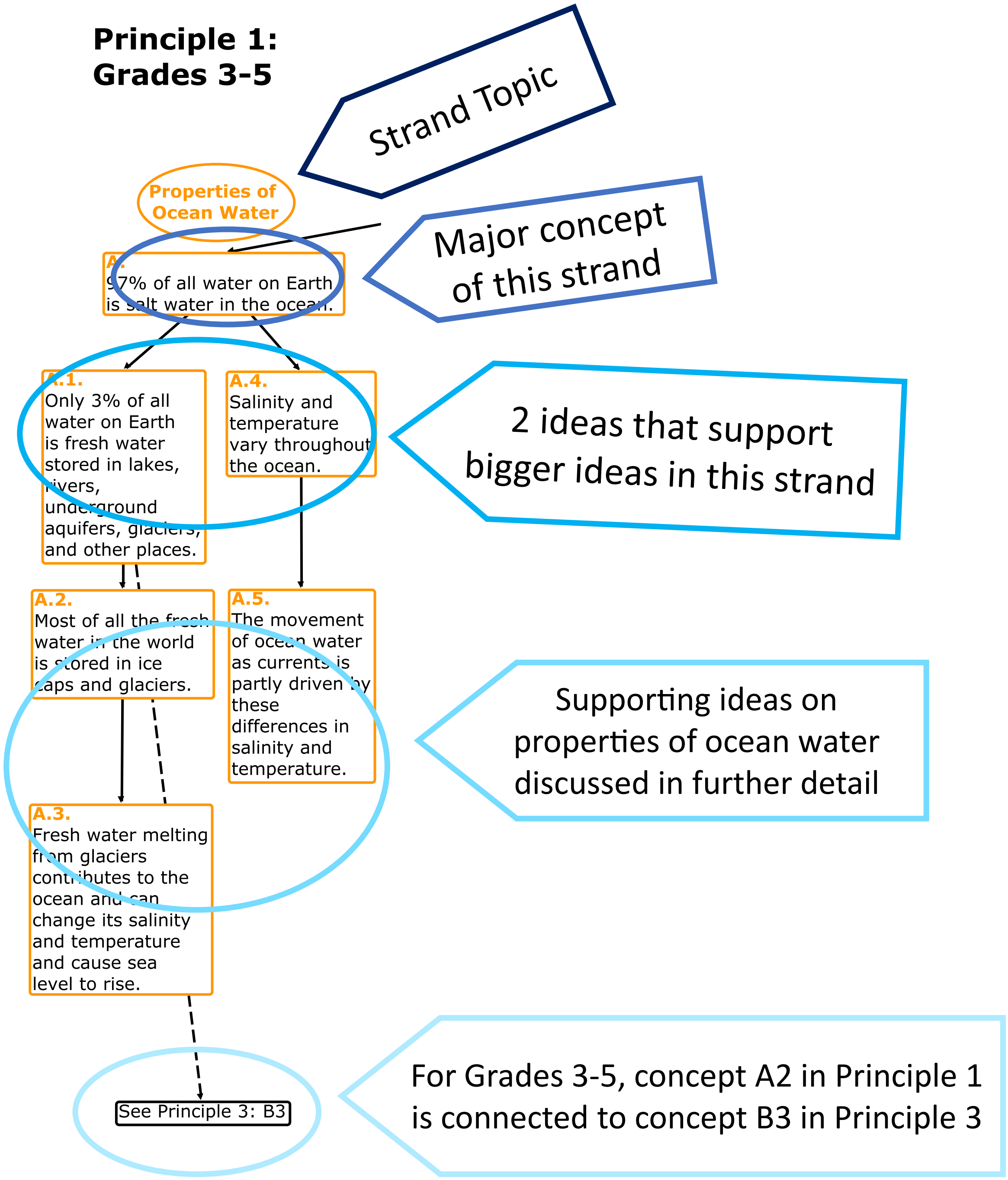
Figure 1



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

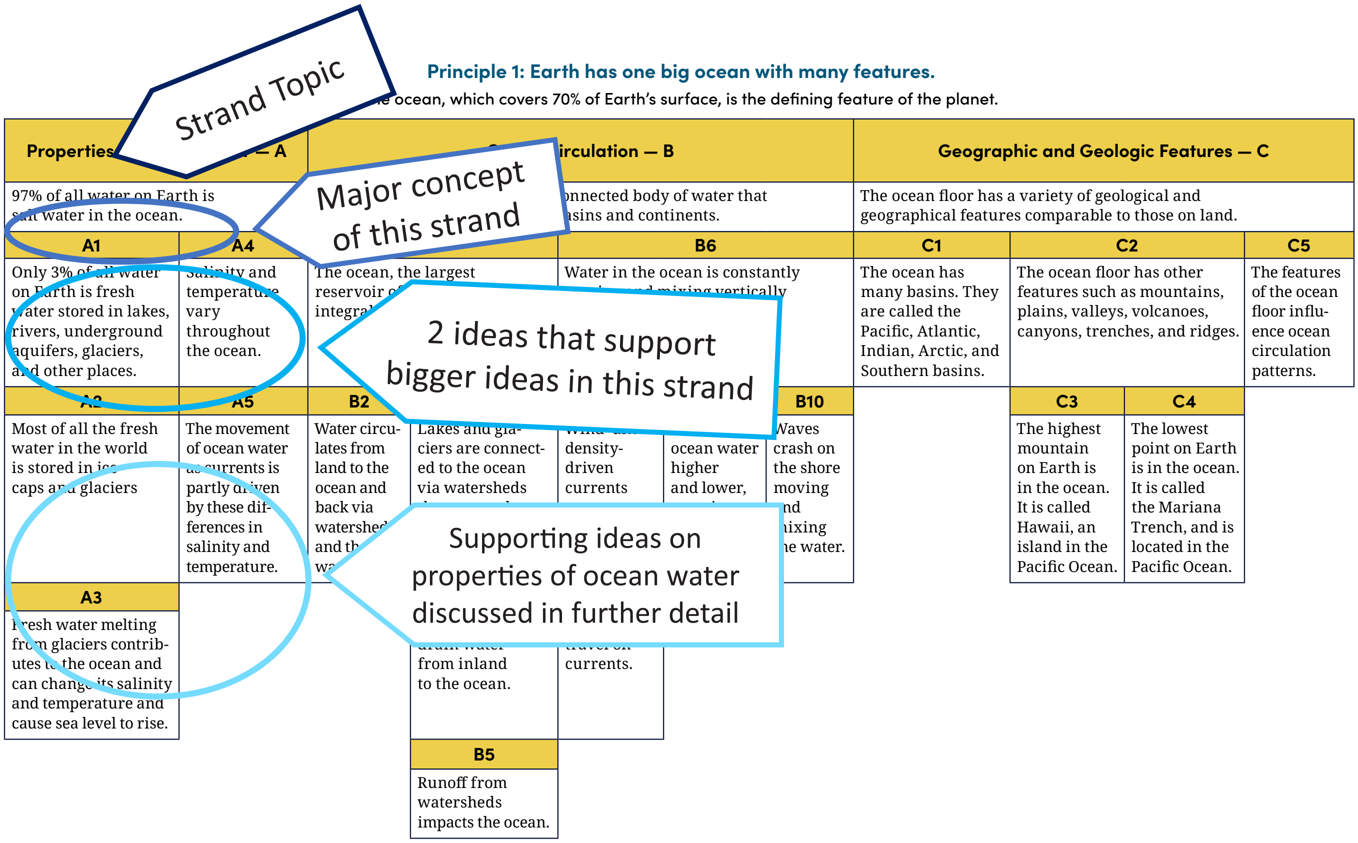


Strand A of conceptual flow diagram of Principle 1 for Grades 3 to 5. Here is a breakdown of the components in a strand. The strand is identified by topic for easy reference. The strand begins with a major concept and then nested below are two levels of ideas that support the bigger idea. Supporting 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

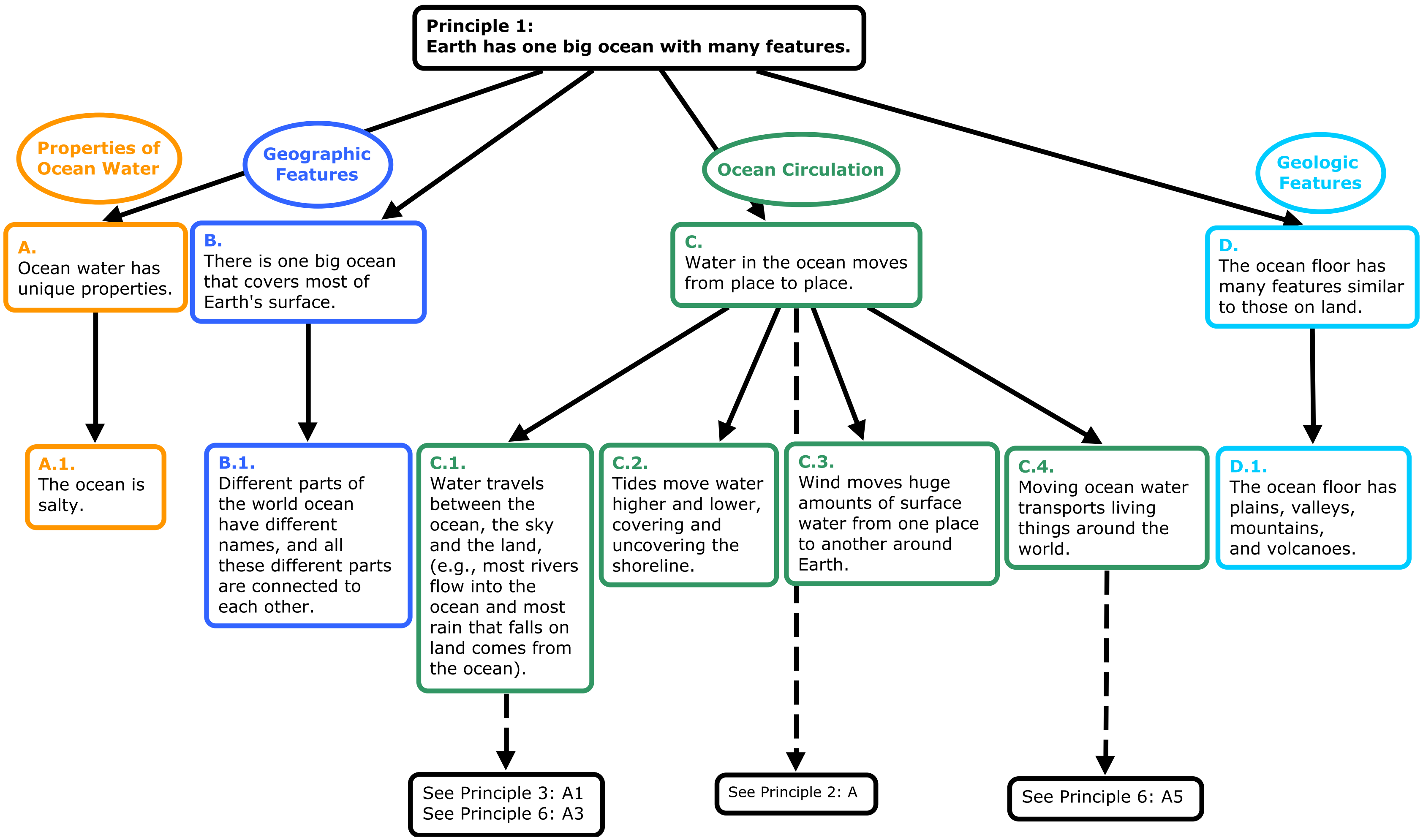
Principle 3

Principle 4

Principle 5

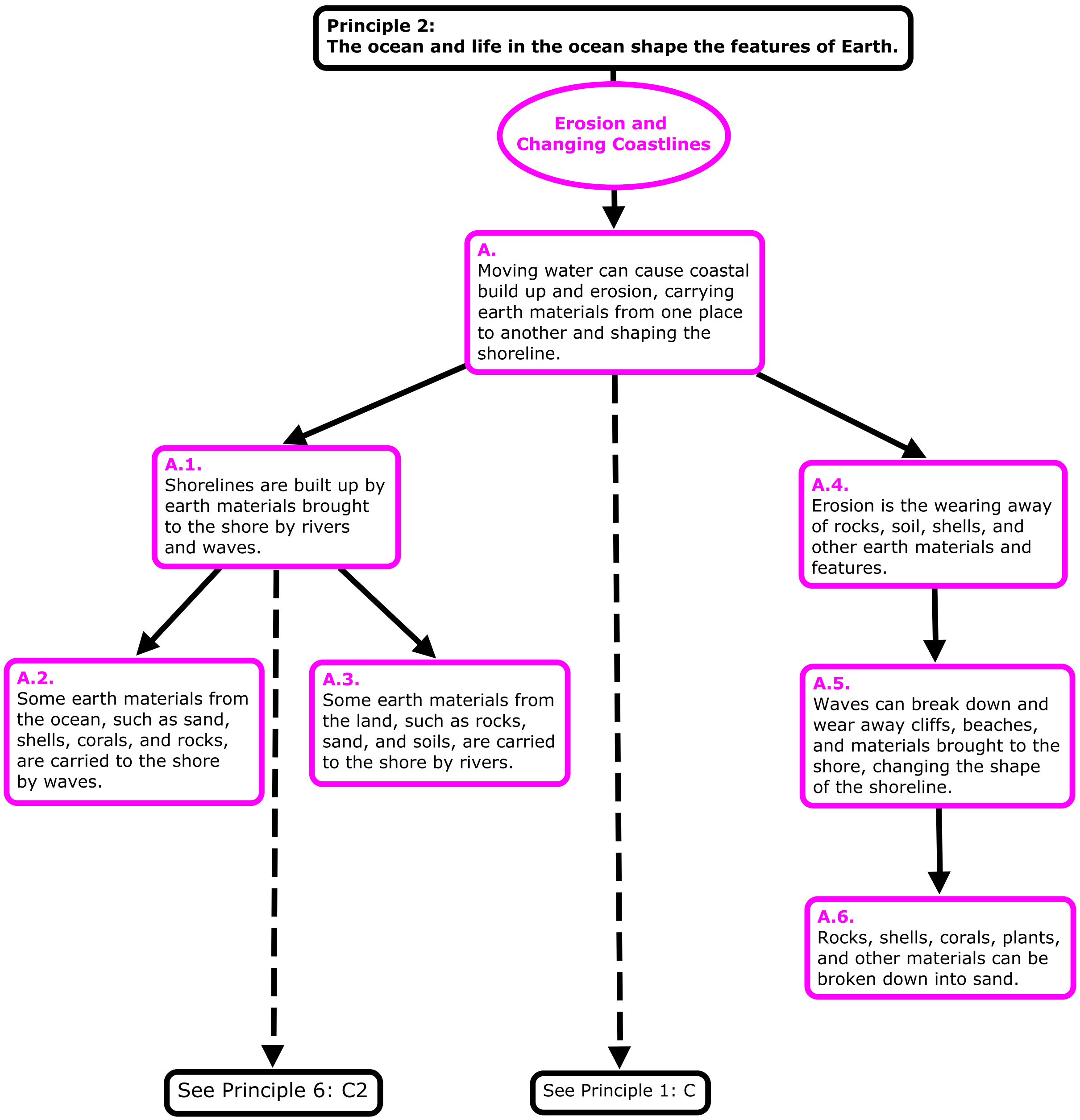
Principle 6

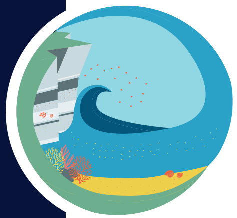
Principle 7


Principle 1:
Earth has one big ocean with many features.
Properties of Ocean Water
Geographic Features
Ocean Circulation
Geologic Features
A.
Ocean water has unique properties.
B.
There is one big ocean that covers most of Earth's surface.
C.
Water in the ocean moves from place to place.
D.
The ocean floor has many features similar to those on land.
A.1.
The ocean is salty.
B.1.
Different parts of the world ocean have different names, and all these different parts are connected to each other.
C.1.
Water travels between the ocean, the sky and the land, (e.g., most rivers flow into the ocean and most rain that falls on land comes from the ocean).
C.2.
Tides move water higher and lower, covering and uncovering the shoreline.
C.3.
Wind moves huge amounts of surface water from one place to another around Earth.
C.4.
Moving ocean water transports living things around the world.
D.1.
The ocean floor has plains, valleys, mountains, and volcanoes.
See Principle 3: A1
See Principle 6: A3
See Principle 2: A
See Principle 6: A5

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

Properties of Ocean Water — A	Geographic Features — B	Ocean Circulation — C				Geologic Features — D
Ocean water has unique properties.	There is one big ocean that covers most of Earth's surface.	Water in the ocean moves from place to place.				The ocean floor has many features similar to those on land.
A1	**B1**	**C1**	**C2**	**C3**	**C4**	**D1**
The ocean is salty.	Different parts of the world ocean have different names, and all these different parts are connected to each other.	Water travels between the ocean, the sky and the land, (e.g., most rivers flow into the ocean and most rain that falls on land comes from the ocean).	Tides move water higher and lower, covering and uncovering the shoreline.	Wind moves huge amounts of surface water from one place to another around Earth.	Moving ocean water transports living things around the world.	The ocean floor has plains, valleys, mountains, and volcanoes.


Principle 2:
The ocean and life in the ocean shape the features of Earth.
Erosion and Changing Coastlines
A.
Moving water can cause coastal build up and erosion, carrying earth materials from one place to another and shaping the shoreline.
A.1.
Shorelines are built up by earth materials brought to the shore by rivers and waves.
A.2.
Some earth materials from the ocean, such as sand, shells, corals, and rocks, are carried to the shore by waves.
A.3.
Some earth materials from the land, such as rocks, sand, and soils, are carried to the shore by rivers.
A.4.
Erosion is the wearing away of rocks, soil, shells, and other earth materials and features.
A.5.
Waves can break down and wear away cliffs, beaches, and materials brought to the shore, changing the shape of the shoreline.
A.6.
Rocks, shells, corals, plants, and other materials can be broken down into sand.
See Principle 6: C2
See Principle 1: C



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

<table>
<tr><th colspan="3">Erosion and Changing Coastlines — A</th></tr>
<tr><td colspan="3">Moving water can cause coastal build up and erosion, carrying earth materials from one place to another and shaping the shoreline.</td></tr>
<tr><th colspan="2">A1</th><th>A4</th></tr>
<tr><td colspan="2">Shorelines are built up by earth materials brought to the shore by rivers and waves.</td><td>Erosion is the wearing away of rocks, soil, shells, and other earth materials and features.</td></tr>
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<tr><td></td><td></td><td>Rocks, shells, corals, plants, and other materials can be broken down into sand.</td></tr>
</table>

Principle 3:
The ocean is a major influence on weather and climate.

Weather and Water Cycle

A.
Local weather, including precipitation, fog, and wind, can be caused by the ocean—no matter where you live.

A.1.
Most precipitation on Earth comes from water that evaporated from the ocean.

A.2.
When water evaporates and condenses, clouds form, which can lead to precipitation.

A.3.
Most of the water in lakes, ponds, rivers, and the ground comes from water that evaporated from the ocean and fell to the land as precipitation.

A.4.
Most of the water from land and in the atmosphere eventually returns to the ocean as runoff from rivers or precipitation.

See Principle 1: C1
See Principle 6: A6

See Principle 6: A3

Principle 3: The ocean is a major influence on weather and climate.

<table>
<tr><th colspan="3">Weather and Water Cycle — A</th></tr>
<tr><td colspan="3">Local weather, including precipitation, fog, and wind, can be caused by the ocean — no matter where you live.</td></tr>
<tr><th colspan="3">A1</th></tr>
<tr><td colspan="3">Most precipitation on Earth comes from water that evaporated from the ocean.</td></tr>
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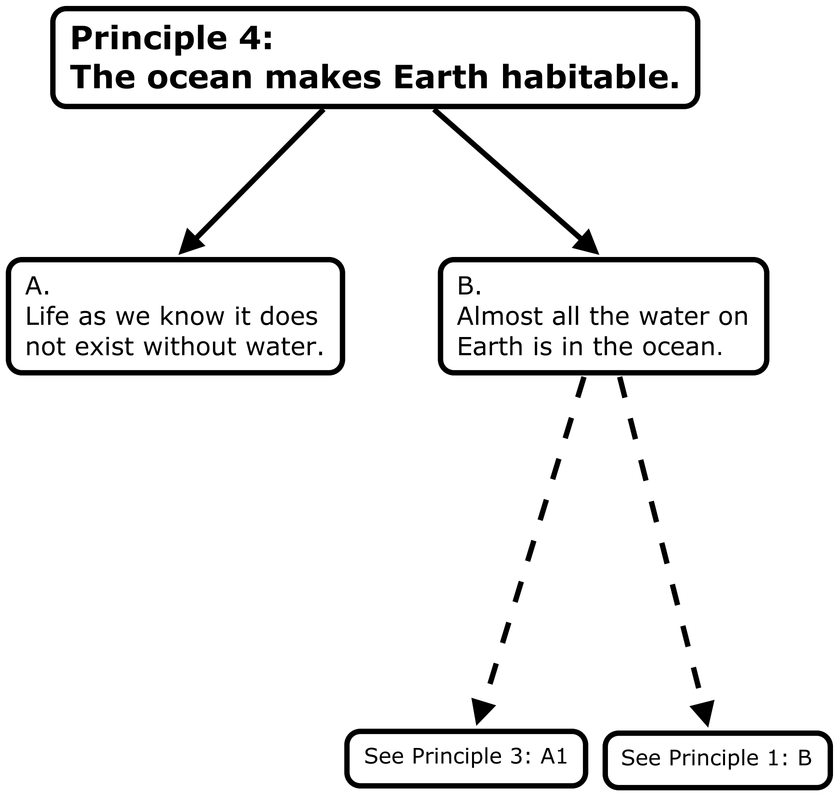
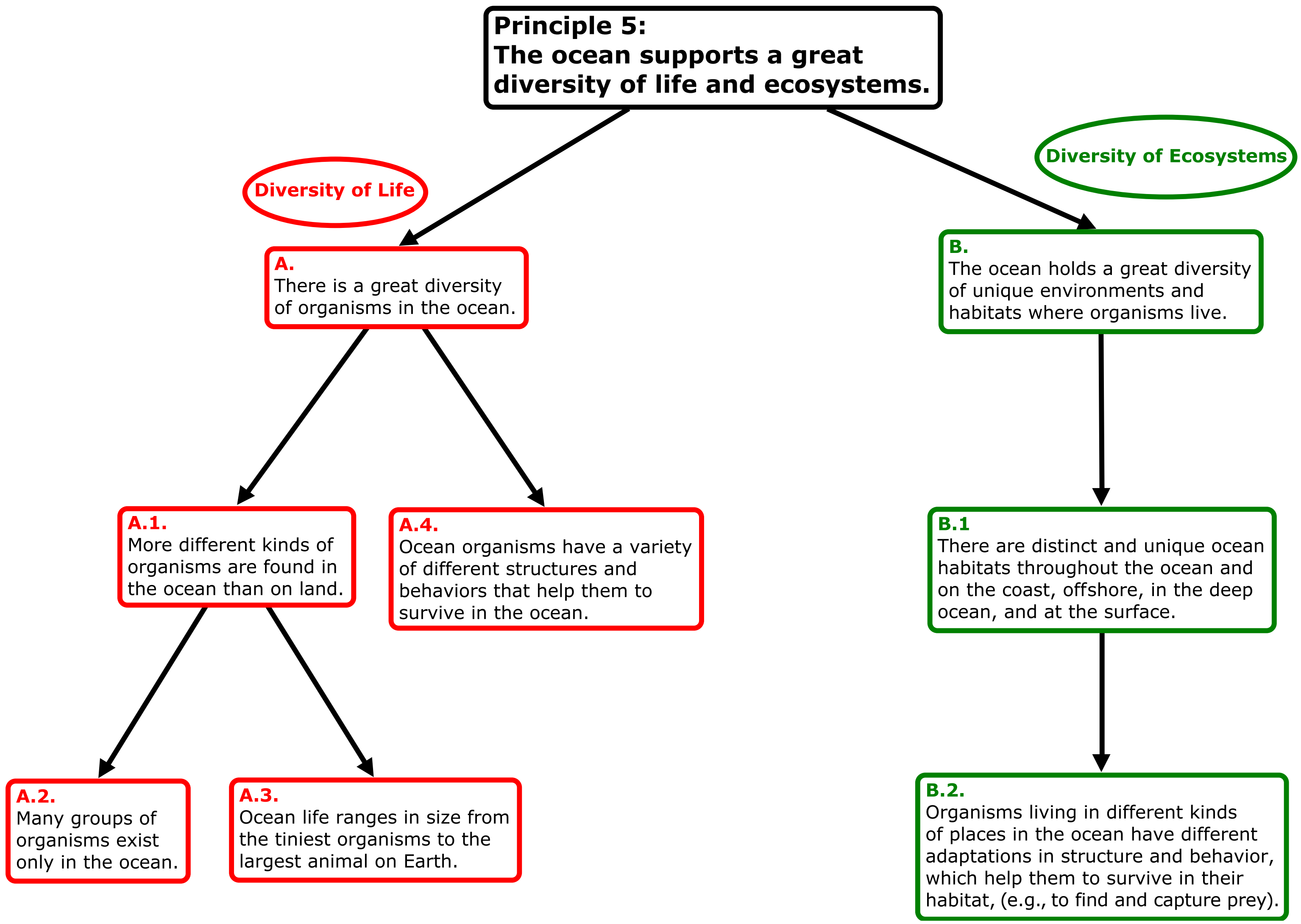

Principle 4:
The ocean makes Earth habitable.
A.
Life as we know it does not exist without water.
B.
Almost all the water on Earth is in the ocean.
See Principle 3: A1
See Principle 1: B

Principle 4: The ocean makes Earth habitable.

A	B
Life as we know it does not exist without water.	Almost all the water on Earth is in the ocean.


Principle 5:
The ocean supports a great diversity of life and ecosystems.
Diversity of Life
Diversity of Ecosystems
A.
There is a great diversity of organisms in the ocean.
B.
The ocean holds a great diversity of unique environments and habitats where organisms live.
A.1.
More different kinds of organisms are found in the ocean than on land.
A.4.
Ocean organisms have a variety of different structures and behaviors that help them to survive in the ocean.
B.1
There are distinct and unique ocean habitats throughout the ocean and on the coast, offshore, in the deep ocean, and at the surface.
A.2.
Many groups of organisms exist only in the ocean.
A.3.
Ocean life ranges in size from the tiniest organisms to the largest animal on Earth.
B.2.
Organisms living in different kinds of places in the ocean have different adaptations in structure and behavior, which help them to survive in their habitat, (e.g., to find and capture prey).

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

<table>
<tr><th colspan="3">Diversity of Life — A</th><th>Diversity of Ecosystems — B</th></tr>
<tr><td colspan="3">There is a great diversity of organisms in the ocean.</td><td>The ocean holds a great diversity of unique environments and habitats where organisms live.</td></tr>
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<tr><td colspan="2">More different kinds of organisms are found in the ocean than on land.</td><td>Ocean organisms have a variety of different structures and behaviors that help them to survive in the ocean.</td><td>There are distinct and unique ocean habitats throughout the ocean and on the coast, offshore, in the deep ocean, and at the surface.</td></tr>
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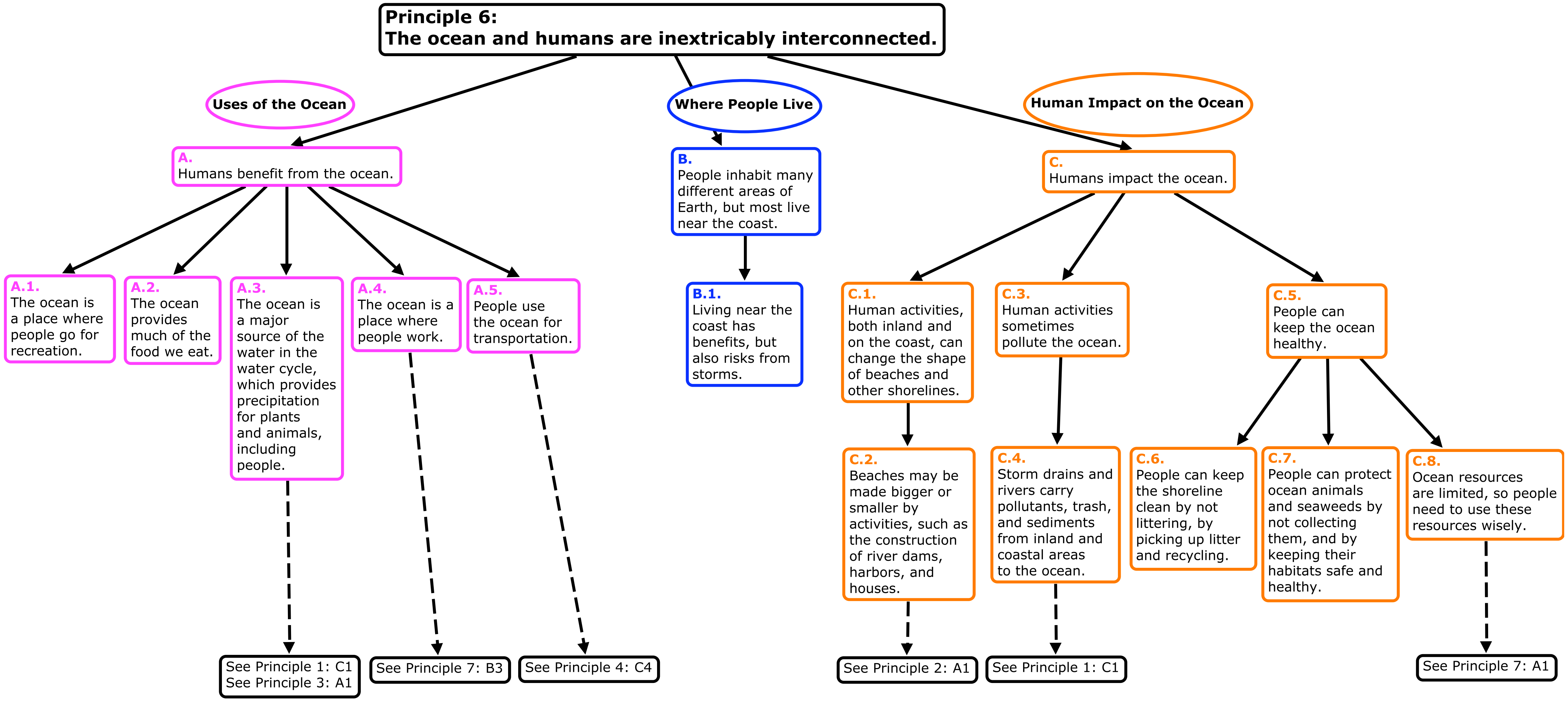
Principle 6:
The ocean and humans are inextricably interconnected.
Uses of the Ocean
Where People Live
Human Impact on the Ocean
A.
Humans benefit from the ocean.
B.
People inhabit many different areas of Earth, but most live near the coast.
C.
Humans impact the ocean.
A.1.
The ocean is a place where people go for recreation.
A.2.
The ocean provides much of the food we eat.
A.3.
The ocean is a major source of the water in the water cycle, which provides precipitation for plants and animals, including people.
A.4.
The ocean is a place where people work.
A.5.
People use the ocean for transportation.
B.1.
Living near the coast has benefits, but also risks from storms.
C.1.
Human activities, both inland and on the coast, can change the shape of beaches and other shorelines.
C.3.
Human activities sometimes pollute the ocean.
C.5.
People can keep the ocean healthy.
C.2.
Beaches may be made bigger or smaller by activities, such as the construction of river dams, harbors, and houses.
C.4.
Storm drains and rivers carry pollutants, trash, and sediments from inland and coastal areas to the ocean.
C.6.
People can keep the shoreline clean by not littering, by picking up litter and recycling.
C.7.
People can protect ocean animals and seaweeds by not collecting them, and by keeping their habitats safe and healthy.
C.8.
Ocean resources are limited, so people need to use these resources wisely.
See Principle 1: C1
See Principle 3: A1
See Principle 7: B3
See Principle 4: C4
See Principle 2: A1
See Principle 1: C1
See Principle 7: A1

Principle 6: The ocean and humans are inextricably interconnected.

<table>
<tr><th colspan="5">Uses of the Ocean — A</th><th>Where People Live — B</th><th colspan="5">Human Impact on the Ocean — C</th></tr>
<tr><td colspan="5">Humans benefit from the ocean.</td><td>People inhabit many different areas of Earth, but most live near the coast.</td><td colspan="5">Humans impact the ocean.</td></tr>
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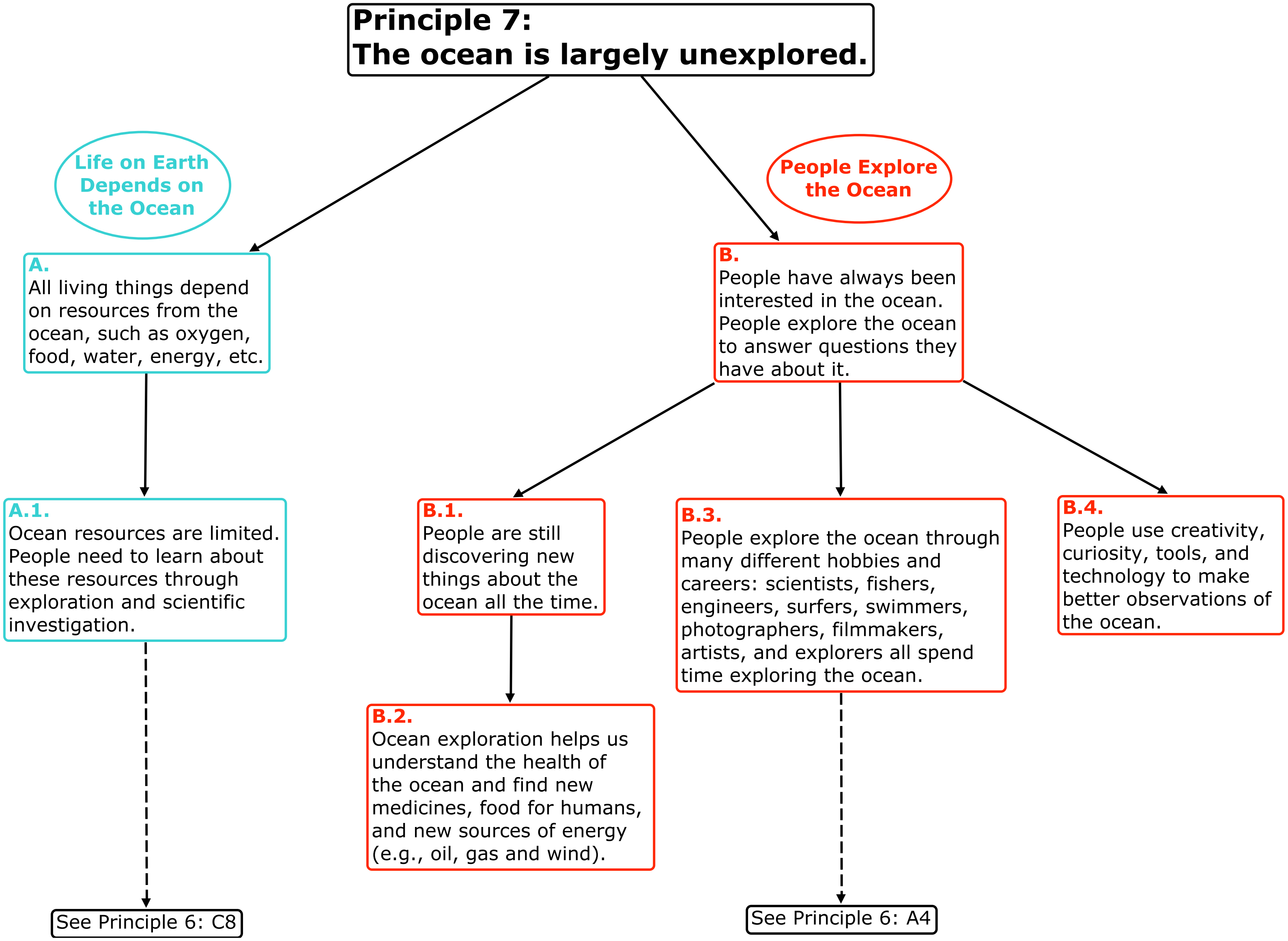
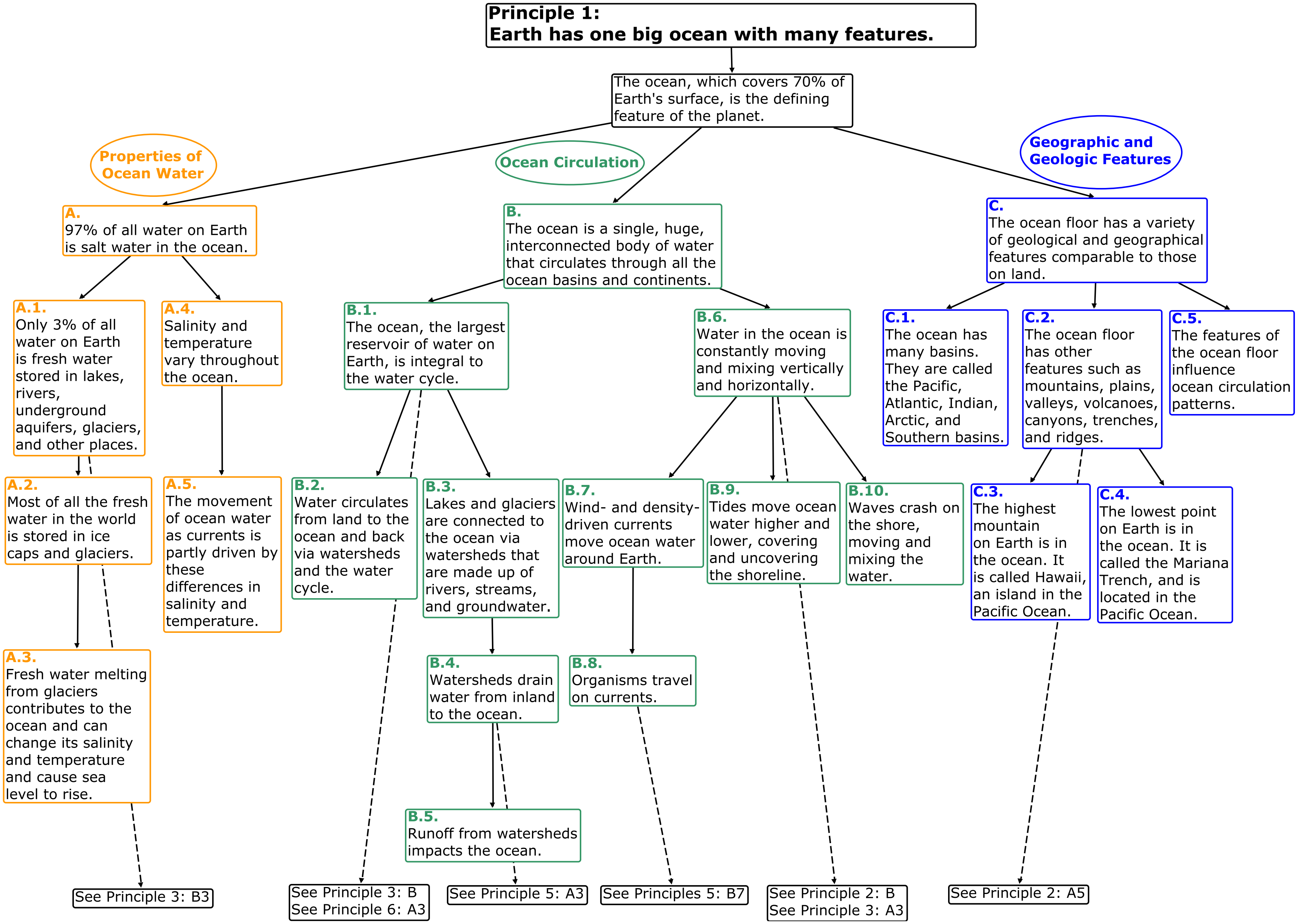

Principle 7:
The ocean is largely unexplored.
Life on Earth Depends on the Ocean
People Explore the Ocean
A.
All living things depend on resources from the ocean, such as oxygen, food, water, energy, etc.
B.
People have always been interested in the ocean. People explore the ocean to answer questions they have about it.
A.1.
Ocean resources are limited. People need to learn about these resources through exploration and scientific investigation.
B.1.
People are still discovering new things about the ocean all the time.
B.3.
People explore the ocean through many different hobbies and careers: scientists, fishers, engineers, surfers, swimmers, photographers, filmmakers, artists, and explorers all spend time exploring the ocean.
B.4.
People use creativity, curiosity, tools, and technology to make better observations of the ocean.
B.2.
Ocean exploration helps us understand the health of the ocean and find new medicines, food for humans, and new sources of energy (e.g., oil, gas and wind).
See Principle 6: C8
See Principle 6: A4

Principle 7: The ocean is largely unexplored.

Life on Earth Depends on the Ocean — A	People Explore the Ocean — B		
All living things depend on resources from the ocean, such as oxygen, food, water, energy, etc.	People have always been interested in the ocean. People explore the ocean to answer questions they have about it.		
A1	**B1**	**B3**	**B4**
Ocean resources are limited. People need to learn about these resources through exploration and scientific investigation.	People are still discovering new things about the ocean all the time.	People explore the ocean through many different hobbies and careers: scientists, fishers, engineers, surfers, swimmers, photographers, filmmakers, artists, and explorers all spend time exploring the ocean.	People use creativity, curiosity, tools, and technology to make better observations of the ocean.
	B2		
	Ocean exploration helps us understand the health of the ocean and find new medicines, food for humans, and new sources of energy (e.g., oil, gas, and wind).		


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.
Properties of Ocean Water
Ocean Circulation
Geographic and Geologic Features
A. 97% of all water on Earth is salt water in the ocean.
A.1. Only 3% of all water on Earth is fresh water stored in lakes, rivers, underground aquifers, glaciers, and other places.
A.4. Salinity and temperature vary throughout the ocean.
A.2. Most of all the fresh water in the world is stored in ice caps and glaciers.
A.5. The movement of ocean water as currents is partly driven by these differences in salinity and temperature.
A.3. Fresh water melting from glaciers contributes to the ocean and can change its salinity and temperature and cause sea level to rise.
B. The ocean is a single, huge, interconnected body of water that circulates through all the ocean basins and continents.
B.1. The ocean, the largest reservoir of water on Earth, is integral to the water cycle.
B.6. Water in the ocean is constantly moving and mixing vertically and horizontally.
B.2. Water circulates from land to the ocean and back via watersheds and the water cycle.
B.3. Lakes and glaciers are connected to the ocean via watersheds that are made up of rivers, streams, and groundwater.
B.7. Wind- and density-driven currents move ocean water around Earth.
B.9. Tides move ocean water higher and lower, covering and uncovering the shoreline.
B.10. Waves crash on the shore, moving and mixing the water.
B.4. Watersheds drain water from inland to the ocean.
B.8. Organisms travel on currents.
B.5. Runoff from watersheds impacts the ocean.
C. The ocean floor has a variety of geological and geographical features comparable to those on land.
C.1. The ocean has many basins. They are called the Pacific, Atlantic, Indian, Arctic, and Southern basins.
C.2. The ocean floor has other features such as mountains, plains, valleys, volcanoes, canyons, trenches, and ridges.
C.5. The features of the ocean floor influence ocean circulation patterns.
C.3. The highest mountain on Earth is in the ocean. It is called Hawaii, an island in the Pacific Ocean.
C.4. The lowest point on Earth is in the ocean. It is called the Mariana Trench, and is located in the Pacific Ocean.
See Principle 3: B3
See Principle 3: B
See Principle 6: A3
See Principle 5: A3
See Principles 5: B7
See Principle 2: B
See Principle 3: A3
See Principle 2: A5

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.

Properties of Ocean Water — A

97% of all water on Earth is salt water in the ocean.

- **A1** Only 3% of all water on Earth is fresh water stored in lakes, rivers, underground aquifers, glaciers, and other places.
- **A2** Most of all the fresh water in the world is stored in ice caps and glaciers
- **A3** Fresh water melting from glaciers contributes to the ocean and can change its salinity and temperature and cause sea level to rise.
- **A4** Salinity and temperature vary throughout the ocean.
- **A5** The movement of ocean water as currents is partly driven by these differences in salinity and temperature.

Ocean Circulation — B

The ocean is a single, huge, interconnected body of water that circulates through all the ocean basins and continents.

- **B1** The ocean, the largest reservoir of water on Earth, is integral to the water cycle.
- **B2** Water circulates from land to the ocean and back via watersheds and the water cycle.
- **B3** Lakes and glaciers are connected to the ocean via watersheds that are made up of rivers, streams, and groundwater.
- **B4** Watersheds drain water from inland to the ocean.
- **B5** Runoff from watersheds impacts the ocean.
- **B6** Water in the ocean is constantly moving and mixing vertically and horizontally.
- **B7** Wind- and density-driven currents move ocean water around Earth.
- **B8** Organisms travel on currents.
- **B9** Tides move ocean water higher and lower, covering and uncovering the shoreline.
- **B10** Waves crash on the shore moving and mixing the water.

Geographic and Geologic Features — C

The ocean floor has a variety of geological and geographical features comparable to those on land.

- **C1** The ocean has many basins. They are called the Pacific, Atlantic, Indian, Arctic, and Southern basins.
- **C2** The ocean floor has other features such as mountains, plains, valleys, volcanoes, canyons, trenches, and ridges.
- **C3** The highest mountain on Earth is in the ocean. It is called Hawaii, an island in the Pacific Ocean.
- **C4** The lowest point on Earth is in the ocean. It is called the Mariana Trench, and is located in the Pacific Ocean.
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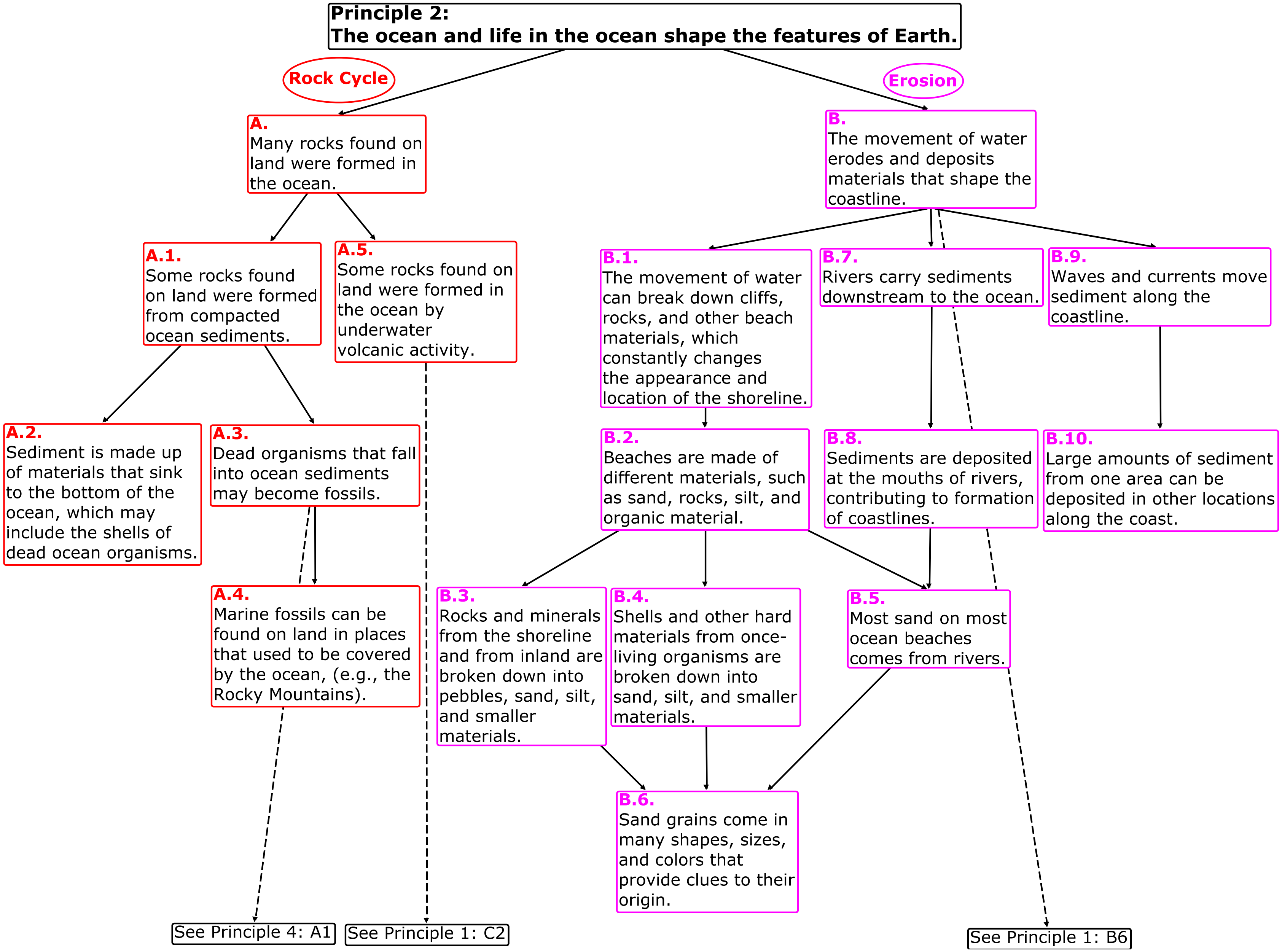
Principle 2:
The ocean and life in the ocean shape the features of Earth.
Rock Cycle
Erosion
A.
Many rocks found on land were formed in the ocean.
A.1.
Some rocks found on land were formed from compacted ocean sediments.
A.5.
Some rocks found on land were formed in the ocean by underwater volcanic activity.
A.2.
Sediment is made up of materials that sink to the bottom of the ocean, which may include the shells of dead ocean organisms.
A.3.
Dead organisms that fall into ocean sediments may become fossils.
A.4.
Marine fossils can be found on land in places that used to be covered by the ocean, (e.g., the Rocky Mountains).
See Principle 4: A1
See Principle 1: C2
B.
The movement of water erodes and deposits materials that shape the coastline.
B.1.
The movement of water can break down cliffs, rocks, and other beach materials, which constantly changes the appearance and location of the shoreline.
B.7.
Rivers carry sediments downstream to the ocean.
B.9.
Waves and currents move sediment along the coastline.
B.2.
Beaches are made of different materials, such as sand, rocks, silt, and organic material.
B.8.
Sediments are deposited at the mouths of rivers, contributing to formation of coastlines.
B.10.
Large amounts of sediment from one area can be deposited in other locations along the coast.
B.3.
Rocks and minerals from the shoreline and from inland are broken down into pebbles, sand, silt, and smaller materials.
B.4.
Shells and other hard materials from once-living organisms are broken down into sand, silt, and smaller materials.
B.5.
Most sand on most ocean beaches comes from rivers.
B.6.
Sand grains come in many shapes, sizes, and colors that provide clues to their origin.
See Principle 1: B6

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

<table>
<tr><th colspan="3">Rock Cycle — A</th><th colspan="5">Erosion — B</th></tr>
<tr><td colspan="3">Many rocks found on land were formed in the ocean.</td><td colspan="5">The movement of water erodes and deposits materials that shape the coastline.</td></tr>
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<tr><th>A2</th><th>A3</th><td></td><th colspan="3">B2</th><th>B8</th><th>B10</th></tr>
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<tr><td></td><th>A4</th><td></td><th>B3</th><th>B4</th><th>B5</th><th>B5</th><td></td></tr>
<tr><td></td><td>Marine fossils can be found on land in places that used to be covered by the ocean, (e.g., the Rocky Mountains).</td><td></td><td>Rocks and minerals from the shoreline and from inland are broken down into pebbles, sand, silt, and smaller materials.</td><td>Shells and other hard materials from once-living organisms are broken down into sand, silt, and smaller materials.</td><td>Most sand on most ocean beaches comes from rivers.</td><td>Most sand on most ocean beaches comes from rivers.</td><td></td></tr>
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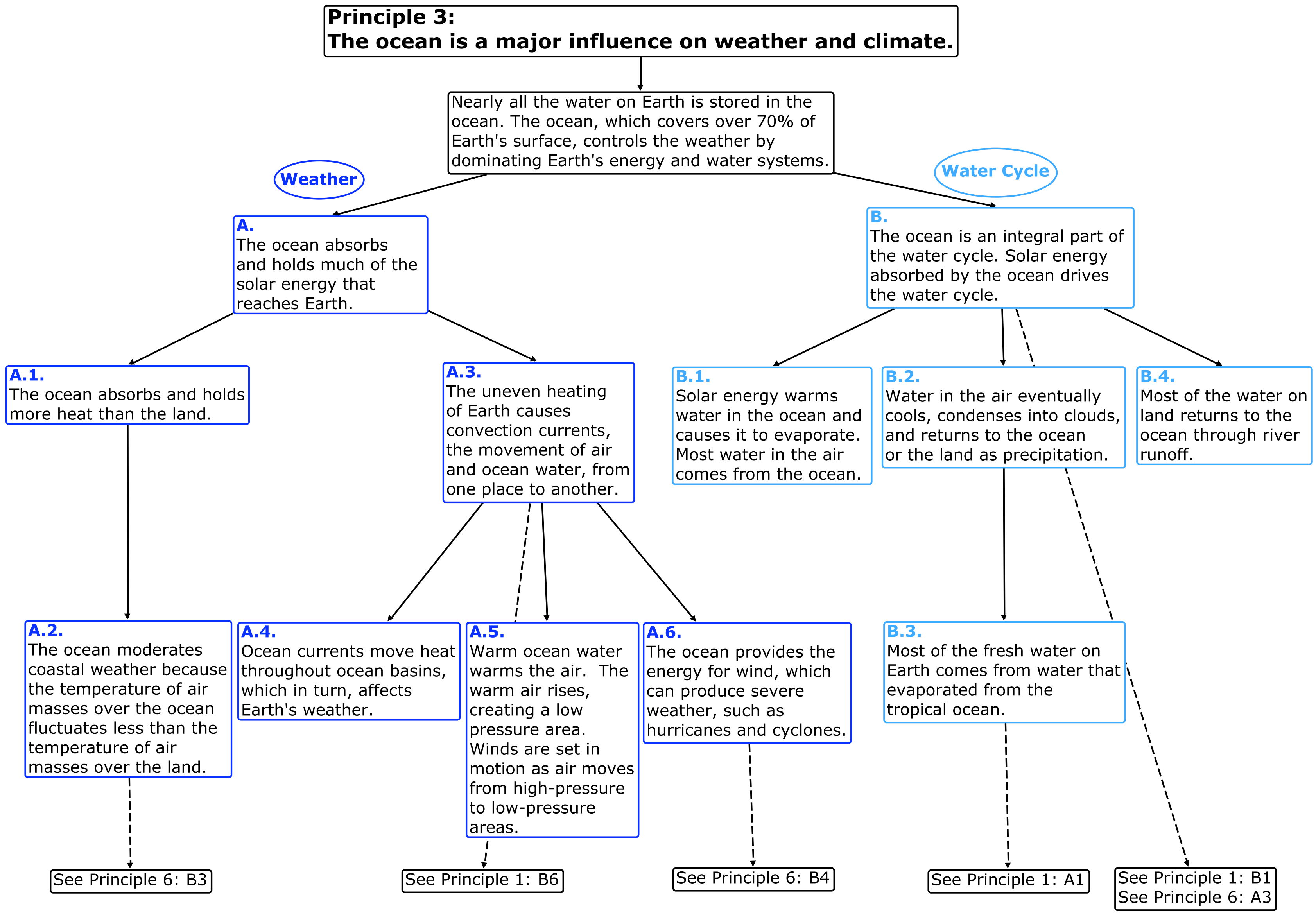
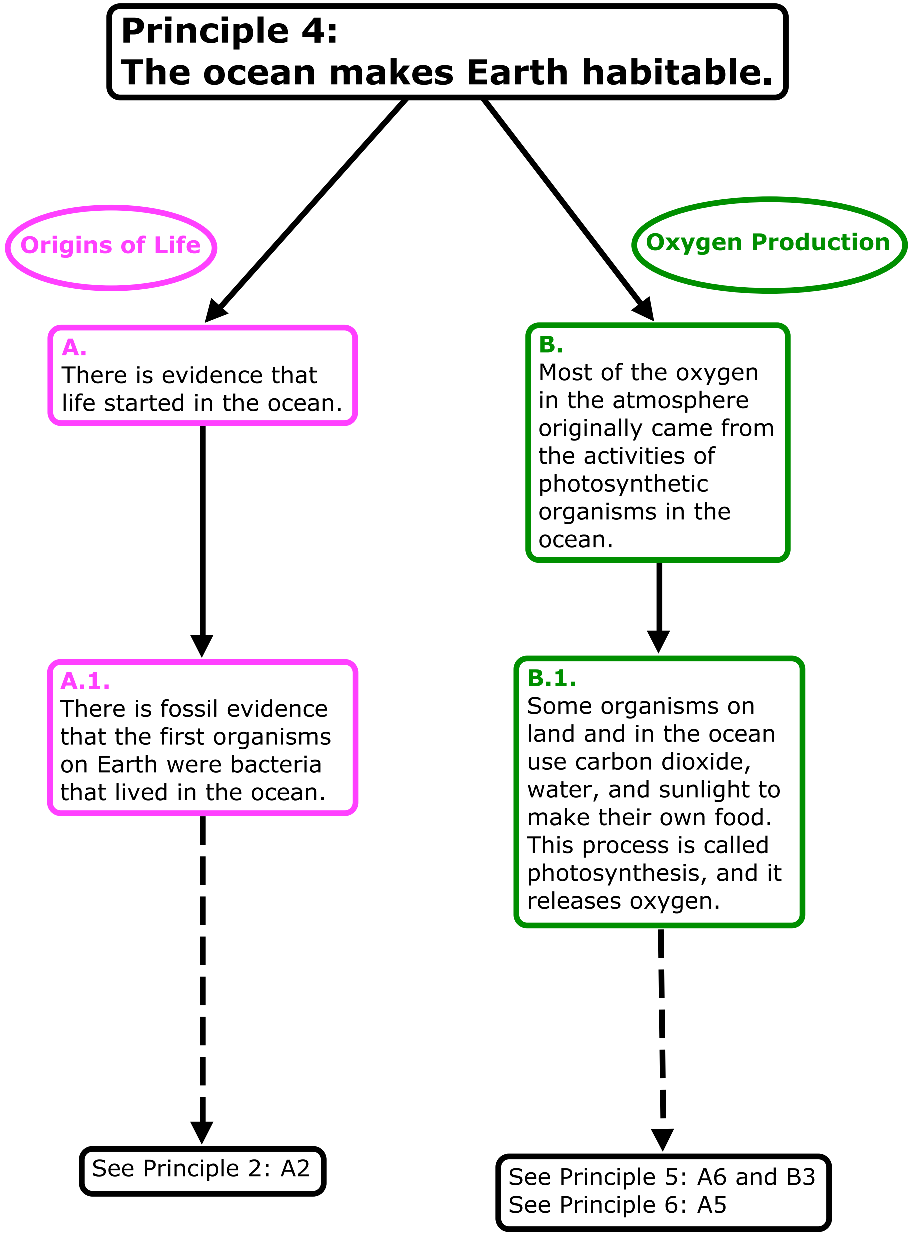

Principle 3:
The ocean is a major influence on weather and climate.
Nearly all the water on Earth is stored in the ocean. The ocean, which covers over 70% of Earth's surface, controls the weather by dominating Earth's energy and water systems.
Weather
Water Cycle
A. The ocean absorbs and holds much of the solar energy that reaches Earth.
B. The ocean is an integral part of the water cycle. Solar energy absorbed by the ocean drives the water cycle.
A.1. The ocean absorbs and holds more heat than the land.
A.3. The uneven heating of Earth causes convection currents, the movement of air and ocean water, from one place to another.
B.1. Solar energy warms water in the ocean and causes it to evaporate. Most water in the air comes from the ocean.
B.2. Water in the air eventually cools, condenses into clouds, and returns to the ocean or the land as precipitation.
B.4. Most of the water on land returns to the ocean through river runoff.
A.2. The ocean moderates coastal weather because the temperature of air masses over the ocean fluctuates less than the temperature of air masses over the land.
A.4. Ocean currents move heat throughout ocean basins, which in turn, affects Earth's weather.
A.5. Warm ocean water warms the air. The warm air rises, creating a low pressure area. Winds are set in motion as air moves from high-pressure to low-pressure areas.
A.6. The ocean provides the energy for wind, which can produce severe weather, such as hurricanes and cyclones.
B.3. Most of the fresh water on Earth comes from water that evaporated from the tropical ocean.
See Principle 6: B3
See Principle 1: B6
See Principle 6: B4
See Principle 1: A1
See Principle 1: B1
See Principle 6: A3

Principle 3: The ocean is a major influence on weather and climate.

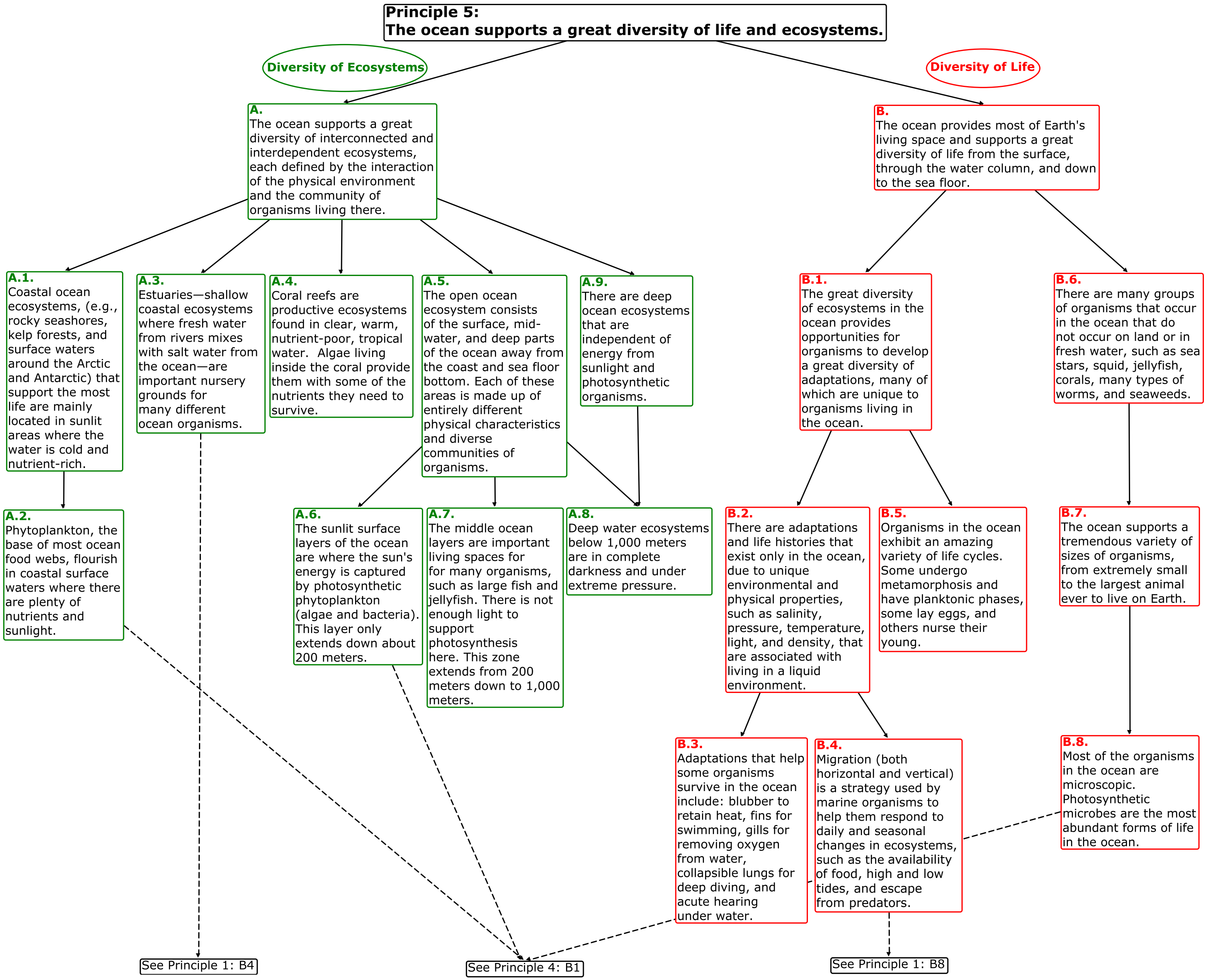
Nearly all the water on Earth is stored in the ocean. The ocean, which covers over 70% of Earth's surface, controls the weather by dominating Earth's energy and water systems.

Weather — A				Water Cycle — B		
The ocean absorbs and holds much of the solar energy that reaches Earth.				The ocean is an integral part of the water cycle. Solar energy absorbed by the ocean drives the water cycle.		
A1	**A3**			**B1**	**B2**	**B4**
The ocean absorbs and holds more heat than the land.	The uneven heating of Earth causes convection currents, the movement of air and ocean water, from one place to another.			Solar energy warms water in the ocean and causes it to evaporate. Most water in the air comes from the ocean.	Water in the air eventually cools, condenses into clouds, and returns to the ocean or the land as precipitation.	Most of the water on land returns to the ocean through river runoff.
A2	**A4**	**A5**	**A6**		**B3**	
The ocean moderates coastal weather because the temperature of air masses over the ocean fluctuates less than the temperature of air masses over the land.	Ocean currents move heat throughout ocean basins, which in turn, affects Earth's weather.	Warm ocean water warms the air. The warm air rises, creating a low pressure area. Winds are set in motion as air moves from high-pressure to low-pressure areas.	The ocean provides the energy for wind, which can produce severe weather, such as hurricanes and cyclones.		Most of the fresh water on Earth comes from water that evaporated from the tropical ocean.	


Principle 4:
The ocean makes Earth habitable.
Origins of Life
Oxygen Production
A.
There is evidence that life started in the ocean.
B.
Most of the oxygen in the atmosphere originally came from the activities of photosynthetic organisms in the ocean.
A.1.
There is fossil evidence that the first organisms on Earth were bacteria that lived in the ocean.
B.1.
Some organisms on land and in the ocean use carbon dioxide, water, and sunlight to make their own food. This process is called photosynthesis, and it releases oxygen.
See Principle 2: A2
See Principle 5: A6 and B3
See Principle 6: A5

Principle 4: The ocean makes Earth habitable.

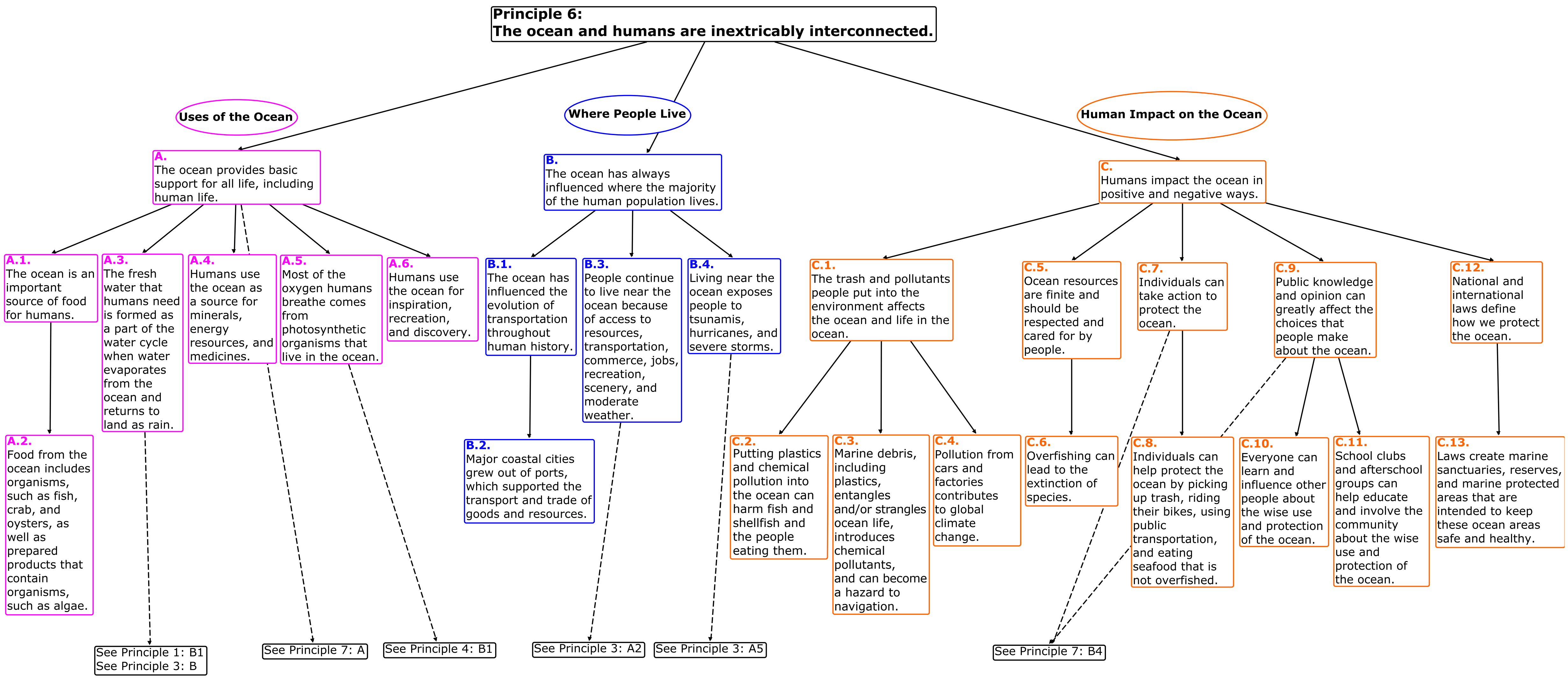
Origins of Life — A	Oxygen Production — B
There is evidence that life started in the ocean.	Most of the oxygen in the atmosphere originally came from the activities of photosynthetic organisms in the ocean.
A1	**B1**
There is fossil evidence that the first organisms on Earth were bacteria that lived in the ocean.	Some organisms on land and in the ocean use carbon dioxide, water, and sunlight to make their own food. This process is called photosynthesis, and it releases oxygen.


Principle 5:
The ocean supports a great diversity of life and ecosystems.
Diversity of Ecosystems
Diversity of Life
A.
The ocean supports a great diversity of interconnected and interdependent ecosystems, each defined by the interaction of the physical environment and the community of organisms living there.
B.
The ocean provides most of Earth's living space and supports a great diversity of life from the surface, through the water column, and down to the sea floor.
A.1.
Coastal ocean ecosystems, (e.g., rocky seashores, kelp forests, and surface waters around the Arctic and Antarctic) that support the most life are mainly located in sunlit areas where the water is cold and nutrient-rich.
A.3.
Estuaries—shallow coastal ecosystems where fresh water from rivers mixes with salt water from the ocean—are important nursery grounds for many different ocean organisms.
A.4.
Coral reefs are productive ecosystems found in clear, warm, nutrient-poor, tropical water. Algae living inside the coral provide them with some of the nutrients they need to survive.
A.5.
The open ocean ecosystem consists of the surface, mid-water, and deep parts of the ocean away from the coast and sea floor bottom. Each of these areas is made up of entirely different physical characteristics and diverse communities of organisms.
A.9.
There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms.
B.1.
The great diversity of ecosystems in the ocean provides opportunities for organisms to develop a great diversity of adaptations, many of which are unique to organisms living in the ocean.
B.6.
There are many groups of organisms that occur in the ocean that do not occur on land or in fresh water, such as sea stars, squid, jellyfish, corals, many types of worms, and seaweeds.
A.2.
Phytoplankton, the base of most ocean food webs, flourish in coastal surface waters where there are plenty of nutrients and sunlight.
A.6.
The sunlit surface layers of the ocean are where the sun's energy is captured by photosynthetic phytoplankton (algae and bacteria). This layer only extends down about 200 meters.
A.7.
The middle ocean layers are important living spaces for for many organisms, such as large fish and jellyfish. There is not enough light to support photosynthesis here. This zone extends from 200 meters down to 1,000 meters.
A.8.
Deep water ecosystems below 1,000 meters are in complete darkness and under extreme pressure.
B.2.
There are adaptations and life histories that exist only in the ocean, due to unique environmental and physical properties, such as salinity, pressure, temperature, light, and density, that are associated with living in a liquid environment.
B.5.
Organisms in the ocean exhibit an amazing variety of life cycles. Some undergo metamorphosis and have planktonic phases, some lay eggs, and others nurse their young.
B.7.
The ocean supports a tremendous variety of sizes of organisms, from extremely small to the largest animal ever to live on Earth.
B.3.
Adaptations that help some organisms survive in the ocean include: blubber to retain heat, fins for swimming, gills for removing oxygen from water, collapsible lungs for deep diving, and acute hearing under water.
B.4.
Migration (both horizontal and vertical) is a strategy used by marine organisms to help them respond to daily and seasonal changes in ecosystems, such as the availability of food, high and low tides, and escape from predators.
B.8.
Most of the organisms in the ocean are microscopic. Photosynthetic microbes are the most abundant forms of life in the ocean.
See Principle 1: B4
See Principle 4: B1
See Principle 1: B8

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

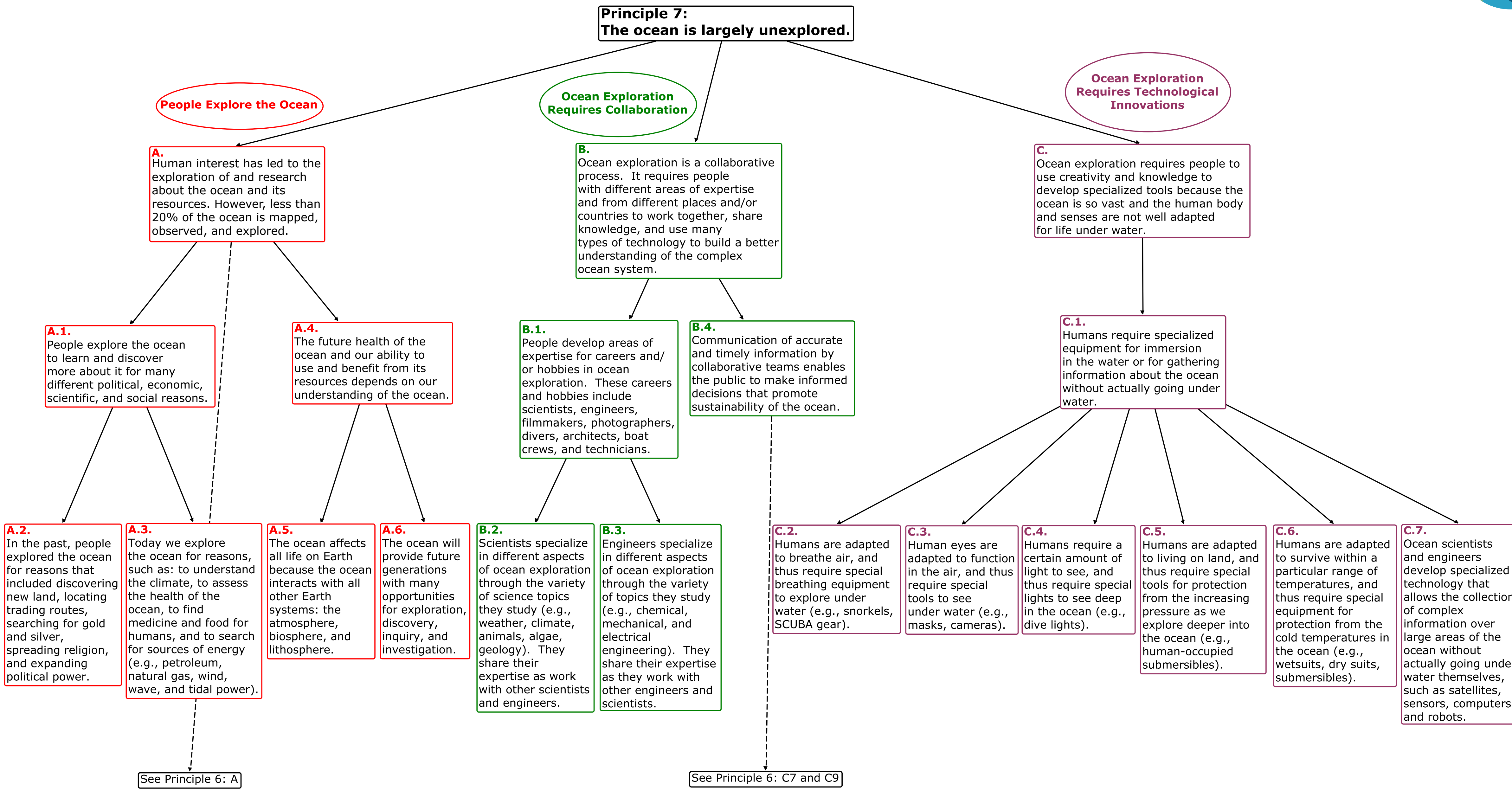
Diversity of Ecosystems — A	
	The ocean supports a great diversity of interconnected and interdependent ecosystems, each defined by the interaction of the physical environment and the community of organisms living there.
A1	Coastal ocean ecosystems, (e.g., rocky seashores, kelp forests, and surface waters around the Arctic and Antarctic) that support the most life are mainly located in sunlit areas where the water is cold and nutrient-rich.
A2	Phytoplankton, the base of most ocean food webs, flourish in coastal surface waters where there are plenty of nutrients and sunlight.
A3	Estuaries — shallow coastal ecosystems where fresh water from rivers mixes with salt water from the ocean — are important nursery grounds for many different ocean organisms.
A4	Coral reefs are productive ecosystems found in clear, warm, nutrient-poor, tropical water. Algae living inside the coral provide them with some of the nutrients that they need to survive.
A5	The open ocean ecosystem consists of the surface, mid-water, and deep parts of the ocean away from the coast and sea floor bottom. Each of these areas is made up of entirely different physical characteristics and diverse communities of organisms.
A6	The sunlit surface layers of the ocean are where the sun's energy is captured by photosynthetic phytoplankton (algae and bacteria). This layer only extends down about 200 meters.
A7	The middle ocean layers are important living spaces for many organisms, such as large fish and jellyfish. There is not enough light to support photosynthesis here. This zone extends from 200 meters down to 1,000 meters.
A8	Deep water ecosystems below 1,000 meters are in complete darkness and under extreme pressure.
A9	There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms.
A8	Deep water ecosystems below 1,000 meters are in complete darkness and under extreme pressure.

Diversity of Life — B	
	The ocean provides most of Earth's living space and supports a great diversity of life from the surface, through the water column, and down to the sea floor.
B1	The great diversity of ecosystems in the ocean provides opportunities for organisms to develop a great diversity of adaptations, many of which are unique to organisms living in the ocean.
B2	There are adaptations and life histories that exist only in the ocean, due to unique environmental and physical properties, such as salinity, pressure, temperature, light, and density, that are associated with living in a liquid environment.
B3	Adaptations that help some organisms survive in the ocean include: blubber to retain heat, fins for swimming, gills for removing oxygen from water, collapsible lungs for deep diving, and acute hearing under water.
B4	Migration (both horizontal and vertical) is a strategy used by marine organisms to help them respond to daily and seasonal changes in ecosystems, such as the availability of food, high and low tides, and escape from predators.
B5	Organisms in the ocean exhibit an amazing variety of life cycles. Some undergo metamorphosis and have planktonic phases, some lay eggs, and others nurse their young.
B6	There are many groups of organisms that occur in the ocean that do not occur on land or in fresh water, such as sea stars, squid, jellyfish, corals, many types of worms, and seaweeds.
B7	The ocean supports a tremendous variety of sizes of organisms, from extremely small to the largest animal ever to live on Earth.
B8	Most of the organisms in the ocean are microscopic. Photosynthetic microbes are the most abundant forms of life in the ocean.


Principle 6:
The ocean and humans are inextricably interconnected.
Uses of the Ocean
Where People Live
Human Impact on the Ocean
A. The ocean provides basic support for all life, including human life.
B. The ocean has always influenced where the majority of the human population lives.
C. Humans impact the ocean in positive and negative ways.
A.1. The ocean is an important source of food for humans.
A.3. The fresh water that humans need is formed as a part of the water cycle when water evaporates from the ocean and returns to land as rain.
A.4. Humans use the ocean as a source for minerals, energy resources, and medicines.
A.5. Most of the oxygen humans breathe comes from photosynthetic organisms that live in the ocean.
A.6. Humans use the ocean for inspiration, recreation, and discovery.
B.1. The ocean has influenced the evolution of transportation throughout human history.
B.3. People continue to live near the ocean because of access to resources, transportation, commerce, jobs, recreation, scenery, and moderate weather.
B.4. Living near the ocean exposes people to tsunamis, hurricanes, and severe storms.
C.1. The trash and pollutants people put into the environment affects the ocean and life in the ocean.
C.5. Ocean resources are finite and should be respected and cared for by people.
C.7. Individuals can take action to protect the ocean.
C.9. Public knowledge and opinion can greatly affect the choices that people make about the ocean.
C.12. National and international laws define how we protect the ocean.
A.2. Food from the ocean includes organisms, such as fish, crab, and oysters, as well as prepared products that contain organisms, such as algae.
B.2. Major coastal cities grew out of ports, which supported the transport and trade of goods and resources.
C.2. Putting plastics and chemical pollution into the ocean can harm fish and shellfish and the people eating them.
C.3. Marine debris, including plastics, entangles and/or strangles ocean life, introduces chemical pollutants, and can become a hazard to navigation.
C.4. Pollution from cars and factories contributes to global climate change.
C.6. Overfishing can lead to the extinction of species.
C.8. Individuals can help protect the ocean by picking up trash, riding their bikes, using public transportation, and eating seafood that is not overfished.
C.10. Everyone can learn and influence other people about the wise use and protection of the ocean.
C.11. School clubs and afterschool groups can help educate and involve the community about the wise use and protection of the ocean.
C.13. Laws create marine sanctuaries, reserves, and marine protected areas that are intended to keep these ocean areas safe and healthy.
See Principle 1: B1
See Principle 3: B
See Principle 7: A
See Principle 4: B1
See Principle 3: A2
See Principle 3: A5
See Principle 7: B4

Principle 6: The ocean and humans are inextricably connected.

Uses of the Ocean — A					Where People Live- B			Human Impact on the Ocean — C							
The ocean provides basic support for all life, including human life.					The ocean has always influenced where the majority of the human population lives.			Humans impact the ocean in positive and negative ways.							
A1	**A3**	**A4**	**A5**	**A6**	**B1**	**B3**	**B4**	**C1**			**C5**	**C7**	**C9**		**C12**
The ocean is an important source of food for humans.	The freshwater that humans need is formed as a part of the water cycle when water evaporates from the ocean and returns to land as rain.	Humans use the ocean as a source for minerals, energy resources, and medicines.	Most of the oxygen humans breathe comes from photosynthetic organisms that live in the ocean.	Humans use the ocean for inspiration, recreation, and discovery.	The ocean has influenced the evolution of transportation throughout human history.	People continue to live near the ocean because of access to resources, transportation, commerce, jobs, recreation, scenery, and moderate weather.	Living near the ocean exposes people to tsunamis, hurricanes, and severe storms.	The trash and pollutants people put into the environment affects the ocean and life in the ocean.			Ocean resources are finite and should be respected and cared for by people.	Individuals can take action to protect the ocean.	Public knowledge and opinion can greatly affect the choices that people make about the ocean.		National and international laws define how we protect the ocean.
A2					**B2**			**C2**	**C3**	**C4**	**C6**	**C8**	**C10**	**C11**	**C13**
Food from the ocean includes organisms, such as fish, crab, and oysters, as well as prepared products that contain organisms, such as algae.					Major coastal cities grow out of ports, which supported the transport and trade of goods and resources.			Putting plastics and chemical pollution into the ocean can harm fish and shellfish and the people eating them.	Marine debris, including plastics, entangles and/or strangles ocean life, introduces chemical pollutants, and can become a hazard to navigation.	Pollution from cars and factories contributes to global climate change.	Overfishing can lead to the extinction of species.	Individuals can help protect the ocean by picking up trash, riding their bikes,using public transportation, and eating seafood that is not overfished.	Everyone can learn and influence other people about the wise use and protection of the ocean.	School clubs and afterschool groups can help educate and involve the community about the wise use and protection of the ocean.	Laws create marine sanctuaries, reserves, and marine protected areas that are intended to keep these ocean areas safe and healthy.

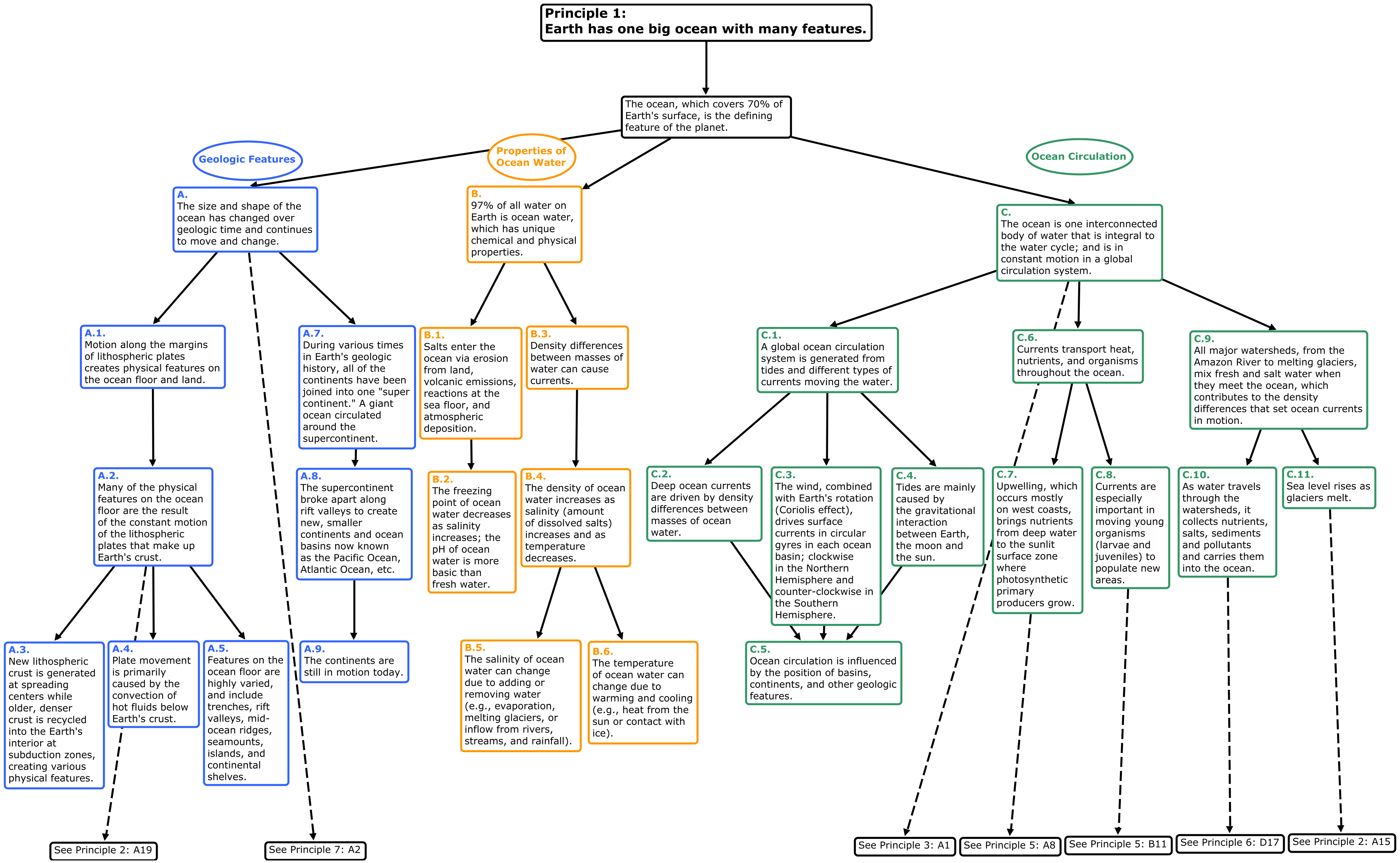

Principle 7:
The ocean is largely unexplored.
People Explore the Ocean
Ocean Exploration Requires Collaboration
Ocean Exploration Requires Technological Innovations
A.
Human interest has led to the exploration of and research about the ocean and its resources. However, less than 20% of the ocean is mapped, observed, and explored.
B.
Ocean exploration is a collaborative process. It requires people with different areas of expertise and from different places and/or countries to work together, share knowledge, and use many types of technology to build a better understanding of the complex ocean system.
C.
Ocean exploration requires people to use creativity and knowledge to develop specialized tools because the ocean is so vast and the human body and senses are not well adapted for life under water.
A.1.
People explore the ocean to learn and discover more about it for many different political, economic, scientific, and social reasons.
A.4.
The future health of the ocean and our ability to use and benefit from its resources depends on our understanding of the ocean.
B.1.
People develop areas of expertise for careers and/or hobbies in ocean exploration. These careers and hobbies include scientists, engineers, filmmakers, photographers, divers, architects, boat crews, and technicians.
B.4.
Communication of accurate and timely information by collaborative teams enables the public to make informed decisions that promote sustainability of the ocean.
C.1.
Humans require specialized equipment for immersion in the water or for gathering information about the ocean without actually going under water.
A.2.
In the past, people explored the ocean for reasons that included discovering new land, locating trading routes, searching for gold and silver, spreading religion, and expanding political power.
A.3.
Today we explore the ocean for reasons, such as: to understand the climate, to assess the health of the ocean, to find medicine and food for humans, and to search for sources of energy (e.g., petroleum, natural gas, wind, wave, and tidal power).
A.5.
The ocean affects all life on Earth because the ocean interacts with all other Earth systems: the atmosphere, biosphere, and lithosphere.
A.6.
The ocean will provide future generations with many opportunities for exploration, discovery, inquiry, and investigation.
B.2.
Scientists specialize in different aspects of ocean exploration through the variety of science topics they study (e.g., weather, climate, animals, algae, geology). They share their expertise as work with other scientists and engineers.
B.3.
Engineers specialize in different aspects of ocean exploration through the variety of topics they study (e.g., chemical, mechanical, and electrical engineering). They share their expertise as they work with other engineers and scientists.
C.2.
Humans are adapted to breathe air, and thus require special breathing equipment to explore under water (e.g., snorkels, SCUBA gear).
C.3.
Human eyes are adapted to function in the air, and thus require special tools to see under water (e.g., masks, cameras).
C.4.
Humans require a certain amount of light to see, and thus require special lights to see deep in the ocean (e.g., dive lights).
C.5.
Humans are adapted to living on land, and thus require special tools for protection from the increasing pressure as we explore deeper into the ocean (e.g., human-occupied submersibles).
C.6.
Humans are adapted to survive within a particular range of temperatures, and thus require special equipment for protection from the cold temperatures in the ocean (e.g., wetsuits, dry suits, submersibles).
C.7.
Ocean scientists and engineers develop specialized technology that allows the collection of complex information over large areas of the ocean without actually going under water themselves, such as satellites, sensors, computers, and robots.
See Principle 6: A
See Principle 6: C7 and C9

Principle 7: The ocean is largely unexplored.

People Explore the Ocean — A			
Human interest has led to the exploration of and research about the ocean and its resources. However, less than 20% of the ocean has been mapped, observed, and explored.			
A1		**A4**	
People explore the ocean to learn and discover more about it for many different political, economic, scientific, and social reasons.		The future health of the ocean and our ability to use it and benefit from its resources depends on our understanding of the ocean.	
A2	**A3**	**A5**	**A6**
In the past, people explored the ocean for reasons that included discovering new land, locating trading routes, searching for gold and silver, spreading religion, and expanding political power.	Today we explore the ocean for reasons, such as: to understand the climate, to assess the health of the ocean, to find medicine and food for humans, and to search for sources of energy (e.g., petroleum, natural gas, wind, wave and tidal power).	The ocean affects all life on Earth because the ocean interacts with all other Earth systems: the atmosphere, biosphere and lithosphere.	The ocean will provide future generations with many opportunities for exploration, discovery, inquiry, and investigation.

Ocean Exploration Requires Collaboration — B		
Ocean exploration is a collaborative process. It requires people with different areas of expertise and from different places and/or countries to work together, share knowledge, and use many types of technology to build a better understanding of the complex ocean system.		
B1		**B4**
People develop areas of expertise for careers and/or hobbies in ocean exploration. These careers and hobbies include scientists, engineers, filmmakers, photographers, divers, architects, boat crews, and technicians.		Communication of accurate and timely information by collaborative teams enables the public to make informed decisions that promote sustainability of the ocean.
B2	**B3**	
Scientists specialize in different aspects of ocean exploration through the variety of science topics they study (e.g., weather, climate, animals, algae, geology). They share their expertise as they work with other scientists and engineers.	Engineers specialize in different aspects of ocean exploration through the variety of topics they study (e.g., chemical, mechanical, and electrical engineering). They share their expertise as they work with other engineers and scientists.	

Ocean Exploration Requires Technological Innovations — C					
Ocean exploration requires people to use creativity and knowledge to develop specialized tools because the ocean is so vast and the human body and senses are not well adapted for life under water.					
C1					
Humans require specialized equipment for immersion in the water or for gathering information about the ocean without actually going under water.					
C2	**C3**	**C4**	**C5**	**C6**	**C7**
Humans are adapted to breathe air, and thus require special breathing equipment to explore under water (e.g., snorkels, SCUBA gear).	Human eyes are adapted to function in the air, and thus require special tools to see under water (e.g., masks, cameras).	Humans require a certain amount of light to see, and thus require special lights to see deep in the ocean (e.g., dive lights).	Humans are adapted to living on land, and thus require special tools for protection from increasing pressure as we explore deeper into the ocean (e.g., human-occupied submersibles).	Humans are adapted to survive within a particular range of temperatures, and thus require special equipment for protection from the cold temperatures in the ocean (e.g., wetsuits, dry suits, submersibles).	Ocean scientists and engineers develop specialized technology that allows the collection of complex information over large areas of the ocean without actually going under water themselves, such as satellites, sensors, computers, and robots.


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
A. The size and shape of the ocean has changed over geologic time and continues to move and change.
A.1. Motion along the margins of lithospheric plates creates physical features on the ocean floor and land.
A.2. Many of the physical features on the ocean floor are the result of the constant motion of the lithospheric plates that make up Earth's crust.
A.3. New lithospheric crust is generated at spreading centers while older, denser crust is recycled into the Earth's interior at subduction zones, creating various physical features.
A.4. Plate movement is primarily caused by the convection of hot fluids below Earth's crust.
A.5. Features on the ocean floor are highly varied, and include trenches, rift valleys, mid-ocean ridges, seamounts, islands, and continental shelves.
A.7. During various times in Earth's geologic history, all of the continents have been joined into one "super continent." A giant ocean circulated around the supercontinent.
A.8. The supercontinent broke apart along rift valleys to create new, smaller continents and ocean basins now known as the Pacific Ocean, Atlantic Ocean, etc.
A.9. The continents are still in motion today.
See Principle 2: A19
See Principle 7: A2
B. 97% of all water on Earth is ocean water, which has unique chemical and physical properties.
B.1. Salts enter the ocean via erosion from land, volcanic emissions, reactions at the sea floor, and atmospheric deposition.
B.2. The freezing point of ocean water decreases as salinity increases; the pH of ocean water is more basic than fresh water.
B.3. Density differences between masses of water can cause currents.
B.4. The density of ocean water increases as salinity (amount of dissolved salts) increases and as temperature decreases.
B.5. The salinity of ocean water can change due to adding or removing water (e.g., evaporation, melting glaciers, or inflow from rivers, streams, and rainfall).
B.6. The temperature of ocean water can change due to warming and cooling (e.g., heat from the sun or contact with ice).
C. The ocean is one interconnected body of water that is integral to the water cycle; and is in constant motion in a global circulation system.
C.1. A global ocean circulation system is generated from tides and different types of currents moving the water.
C.2. Deep ocean currents are driven by density differences between masses of ocean water.
C.3. The wind, combined with Earth's rotation (Coriolis effect), drives surface currents in circular gyres in each ocean basin; clockwise in the Northern Hemisphere and counter-clockwise in the Southern Hemisphere.
C.4. Tides are mainly caused by the gravitational interaction between Earth, the moon and the sun.
C.5. Ocean circulation is influenced by the position of basins, continents, and other geologic features.
C.6. Currents transport heat, nutrients, and organisms throughout the ocean.
C.7. Upwelling, which occurs mostly on west coasts, brings nutrients from deep water to the sunlit surface zone where photosynthetic primary producers grow.
C.8. Currents are especially important in moving young organisms (larvae and juveniles) to populate new areas.
C.9. All major watersheds, from the Amazon River to melting glaciers, mix fresh and salt water when they meet the ocean, which contributes to the density differences that set ocean currents in motion.
C.10. As water travels through the watersheds, it collects nutrients, salts, sediments and pollutants and carries them into the ocean.
C.11. Sea level rises as glaciers melt.
See Principle 3: A1
See Principle 5: A8
See Principle 5: B11
See Principle 6: D17
See Principle 2: A15

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

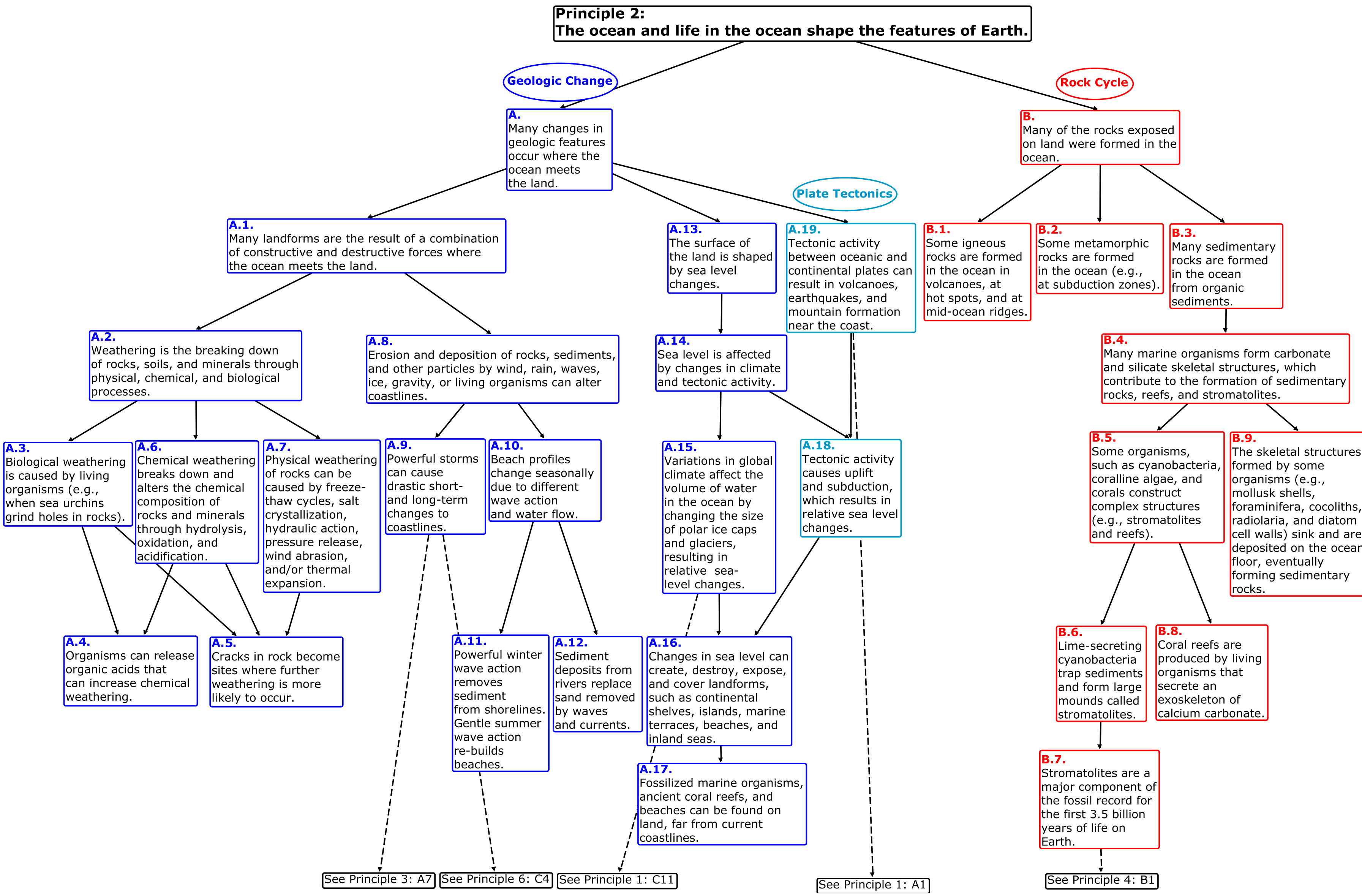
The ocean, which covers 70% of Earth's surface, is the defining feature of the planet.

Geologic Features — A	Properties of Ocean Water — B	Ocean Circulation — C
The size and shape of the ocean has changed over geologic time and continues to move and change.	97% of all water on Earth is ocean water, which has unique chemical and physical properties.	The ocean is one interconnected body of water that is integral to the water cycle; and is in constant motion in a global circulation system.

A1	A7	B1	B3	C1	C6	C9
Motion along the margins of lithospheric plates creates physical features on the ocean floor and land.	During various times in Earth's geologic history, all of the continents have been joined into one supercontinent. A giant ocean circulated around the supercontinent.	Salts enter the ocean via erosion from land, volcanic emissions, reactions at the sea floor, and atmospheric deposition.	Density differences between masses of water can cause currents.	A global ocean circulation system is generated from tides and different types of currents moving the water.	Currents transport heat, nutrients, and organisms throughout the ocean.	All major watersheds, from the Amazon River to melting glaciers, mix fresh and salt water when they meet the ocean, which contributes to the density differences that set ocean currents in motion.

A2	A8	B2	B4	C2	C3	C4	C7	C8	C10	C11
Many of the physical features on the ocean floor are the result of the constant motion of the lithospheric plates that make up Earth's crust.	The supercontinent broke apart along rift valleys to create new, smaller continents and ocean basins now known as the Pacific Ocean, Atlantic Ocean, etc.	The freezing point of ocean water decreases as salinity increases; the pH of ocean water is more basic than fresh water.	The density of ocean water increases as salinity (amount of dissolved salts) increases and as temperature decreases.	Deep ocean currents are driven by density differences between masses of ocean water.	The wind, combined with Earth's rotation (Coriolis effect), drives surface currents in circular gyres in each ocean basin; clockwise in the Northern Hemisphere and counter-clockwise in the Southern Hemisphere.	Tides are mainly caused by the gravitational interaction between Earth, the moon and the sun.	Upwelling, which occurs mostly on west coasts, brings nutrients from deep water to the sunlit surface zone where photosynthetic primary producers grow.	Currents are especially important in moving young organisms (larvae and juveniles) to populate new areas.	As water travels through the watersheds, it collects nutrients, salts, sediments and pollutants and carries them into the ocean.	Sea level rises as glaciers melt.

A3	A4	A5	A9		B5	B6	C5	C5	C5
New lithospheric crust is generated at spreading centers while older, denser crust is recycled into the Earth's interior at subduction zones, creating various physical features.	Plate movement is primarily caused by the convection of hot fluids below Earth's crust.	Features on the ocean floor are highly varied, and include trenches, rift valleys, mid-ocean ridges, seamounts, islands, and continental shelves.	The continents are still in motion today.		The salinity of ocean water can change due to adding or removing water (e.g., evaporation, melting glaciers, or inflow from rivers, streams, and rainfall).	The temperature of ocean water can change due to warming and cooling (e.g., heat from the sun or contact with ice).	Ocean circulation is influenced by the position of basins, continents, and other geologic features.	Ocean circulation is influenced by the position of basins, continents, and other geologic features.	Ocean circulation is influenced by the position of basins, continents, and other geologic features.


Principle 2:
The ocean and life in the ocean shape the features of Earth.
Geologic Change
Rock Cycle
Plate Tectonics
A.
Many changes in geologic features occur where the ocean meets the land.
B.
Many of the rocks exposed on land were formed in the ocean.
A.1.
Many landforms are the result of a combination of constructive and destructive forces where the ocean meets the land.
A.13.
The surface of the land is shaped by sea level changes.
A.19.
Tectonic activity between oceanic and continental plates can result in volcanoes, earthquakes, and mountain formation near the coast.
B.1.
Some igneous rocks are formed in the ocean in volcanoes, at hot spots, and at mid-ocean ridges.
B.2.
Some metamorphic rocks are formed in the ocean (e.g., at subduction zones).
B.3.
Many sedimentary rocks are formed in the ocean from organic sediments.
A.2.
Weathering is the breaking down of rocks, soils, and minerals through physical, chemical, and biological processes.
A.8.
Erosion and deposition of rocks, sediments, and other particles by wind, rain, waves, ice, gravity, or living organisms can alter coastlines.
A.14.
Sea level is affected by changes in climate and tectonic activity.
B.4.
Many marine organisms form carbonate and silicate skeletal structures, which contribute to the formation of sedimentary rocks, reefs, and stromatolites.
A.3.
Biological weathering is caused by living organisms (e.g., when sea urchins grind holes in rocks).
A.6.
Chemical weathering breaks down and alters the chemical composition of rocks and minerals through hydrolysis, oxidation, and acidification.
A.7.
Physical weathering of rocks can be caused by freeze-thaw cycles, salt crystallization, hydraulic action, pressure release, wind abrasion, and/or thermal expansion.
A.9.
Powerful storms can cause drastic short- and long-term changes to coastlines.
A.10.
Beach profiles change seasonally due to different wave action and water flow.
A.15.
Variations in global climate affect the volume of water in the ocean by changing the size of polar ice caps and glaciers, resulting in relative sea-level changes.
A.18.
Tectonic activity causes uplift and subduction, which results in relative sea level changes.
B.5.
Some organisms, such as cyanobacteria, coralline algae, and corals construct complex structures (e.g., stromatolites and reefs).
B.9.
The skeletal structures formed by some organisms (e.g., mollusk shells, foraminifera, cocoliths, radiolaria, and diatom cell walls) sink and are deposited on the ocean floor, eventually forming sedimentary rocks.
A.4.
Organisms can release organic acids that can increase chemical weathering.
A.5.
Cracks in rock become sites where further weathering is more likely to occur.
A.11.
Powerful winter wave action removes sediment from shorelines. Gentle summer wave action re-builds beaches.
A.12.
Sediment deposits from rivers replace sand removed by waves and currents.
A.16.
Changes in sea level can create, destroy, expose, and cover landforms, such as continental shelves, islands, marine terraces, beaches, and inland seas.
B.6.
Lime-secreting cyanobacteria trap sediments and form large mounds called stromatolites.
B.8.
Coral reefs are produced by living organisms that secrete an exoskeleton of calcium carbonate.
A.17.
Fossilized marine organisms, ancient coral reefs, and beaches can be found on land, far from current coastlines.
B.7.
Stromatolites are a major component of the fossil record for the first 3.5 billion years of life on Earth.
See Principle 3: A7
See Principle 6: C4
See Principle 1: C11
See Principle 1: A1
See Principle 4: B1

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

Geologic Change — A

Many changes in geologic features occur where the ocean meets the land.

A1
Many landforms are the result of a combination of constructive and destructive forces where the ocean meets the land.

A2
Weathering is the breaking down of rocks, soils, and minerals through physical, chemical, and biological processes.

A3
Biological weathering is caused by living organisms (e.g., when sea urchins grind holes in rocks).

- **A4** Organisms can release organic acids that can increase chemical weathering.
- **A5** Cracks in rock become sites where further weathering is more likely to occur.

A6
Chemical weathering breaks down and alters the chemical composition of rocks and minerals through hydrolysis, oxidation, and acidification.

- **A4** Organisms can release organic acids that can increase chemical weathering.
- **A5** Cracks in rock become sites where further weathering is more likely to occur.

A7
Physical weathering of rocks can be caused by freeze-thaw cycles, salt crystallization, hydraulic action, pressure release, wind abrasion, and/or thermal expansion.

- **A5** Cracks in rock become sites where further weathering is more likely to occur.

A8
Erosion and deposition of rocks, sediments, and other particles by wind, rain, waves, ice, gravity, or living organisms can alter coastlines.

A9
Powerful storms can cause drastic short- and long-term changes to coastlines.

A10
Beach profiles change seasonally due to different wave action and water flow.

- **A11** Powerful winter wave action removes sediment from shorelines. Gentle summer wave action re-builds beaches.
- **A12** Sediment deposits from rivers replace sand removed by waves and currents.

A13
The surface of the land is shaped by sea level changes.

A14
Sea level is affected by changes in climate and tectonic activity.

A15
Variations in global climate affect the volume of water in the ocean by changing the size of polar ice caps and glaciers, resulting in relative sea-level changes.

- **A16** Changes in sea level can create, destroy, expose, and cover landforms, such as continental shelves, islands, marine terraces, beaches, and inland seas.
- **A17** Fossilized marine organisms, ancient coral reefs, and beaches can be found on land, far from current coastlines.

A18
Tectonic activity causes uplift and subduction, which results in relative sea level changes.

- **A16** Changes in sea level can create, destroy, expose, and cover landforms, such as continental shelves, islands, marine terraces, beaches, and inland seas.
- **A17** Fossilized marine organisms, ancient coral reefs, and beaches can be found on land, far from current coastlines.

Plate Tectonics — A19
Tectonic activity between oceanic and continental plates can result in volcanoes, earthquakes, and mountain formation near the coast.

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Tectonic activity causes uplift and subduction, which results in relative sea level changes.

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- **A17** Fossilized marine organisms, ancient coral reefs, and beaches can be found on land, far from current coastlines.

Rock Cycle — B

Many of the rocks exposed on land were formed in the ocean.

B1
Some igneous rocks are formed in the ocean in volcanoes, at hot spots, and at mid-ocean ridges.

B2
Some metamorphic rocks are formed in the ocean (e.g., at subduction zones).

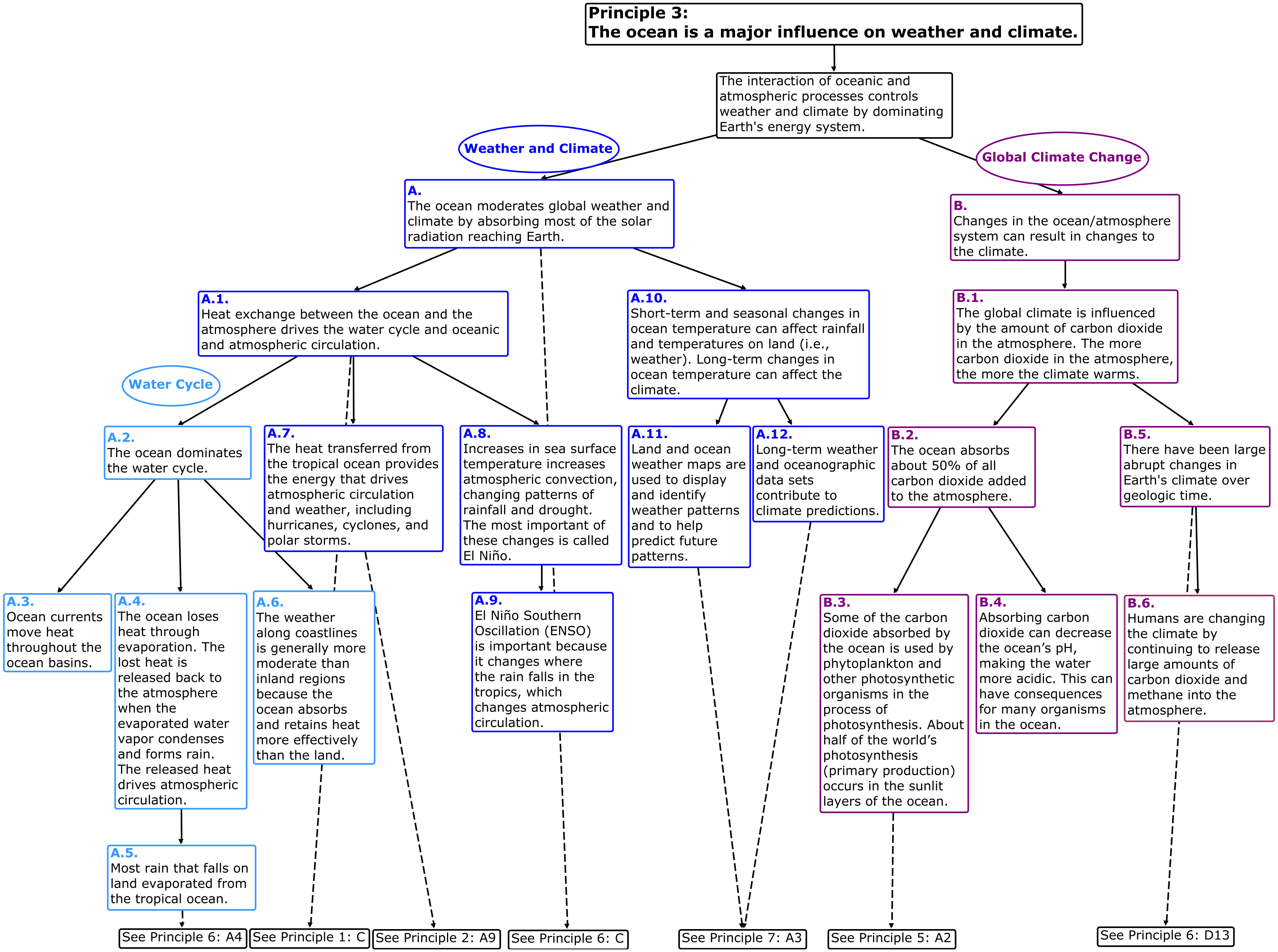
B3
Many sedimentary rocks are formed in the ocean from organic sediments.

B4
Many marine organisms form carbonate and silicate skeletal structures, which contribute to the formation of sedimentary rocks, reefs, and stromatolites.

B5
Some organisms, such as cyanobacteria, coralline algae, and corals construct complex structures (e.g., stromatolites and reefs).

- **B6** Lime-secreting cyanobacteria trap sediments and form large mounds called stromatolites.
  - **B7** Stromatolites are a major component of the fossil record for the first 3.5 billion years of life on Earth.
- **B8** Coral reefs are produced by living organisms that secrete an exoskeleton of calcium carbonate.

B9
The skeletal structures formed by some organisms (e.g., mollusk shells, foraminifera, cocoliths, radiolaria, and diatom cell walls) sink and are deposited on the ocean floor, eventually forming sedimentary rocks.


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
Global Climate Change
A.
The ocean moderates global weather and climate by absorbing most of the solar radiation reaching Earth.
B.
Changes in the ocean/atmosphere system can result in changes to the climate.
A.1.
Heat exchange between the ocean and the atmosphere drives the water cycle and oceanic and atmospheric circulation.
A.10.
Short-term and seasonal changes in ocean temperature can affect rainfall and temperatures on land (i.e., weather). Long-term changes in ocean temperature can affect the climate.
B.1.
The global climate is influenced by the amount of carbon dioxide in the atmosphere. The more carbon dioxide in the atmosphere, the more the climate warms.
Water Cycle
A.2.
The ocean dominates the water cycle.
A.7.
The heat transferred from the tropical ocean provides the energy that drives atmospheric circulation and weather, including hurricanes, cyclones, and polar storms.
A.8.
Increases in sea surface temperature increases atmospheric convection, changing patterns of rainfall and drought. The most important of these changes is called El Niño.
A.11.
Land and ocean weather maps are used to display and identify weather patterns and to help predict future patterns.
A.12.
Long-term weather and oceanographic data sets contribute to climate predictions.
B.2.
The ocean absorbs about 50% of all carbon dioxide added to the atmosphere.
B.5.
There have been large abrupt changes in Earth's climate over geologic time.
A.3.
Ocean currents move heat throughout the ocean basins.
A.4.
The ocean loses heat through evaporation. The lost heat is released back to the atmosphere when the evaporated water vapor condenses and forms rain. The released heat drives atmospheric circulation.
A.6.
The weather along coastlines is generally more moderate than inland regions because the ocean absorbs and retains heat more effectively than the land.
A.9.
El Niño Southern Oscillation (ENSO) is important because it changes where the rain falls in the tropics, which changes atmospheric circulation.
B.3.
Some of the carbon dioxide absorbed by the ocean is used by phytoplankton and other photosynthetic organisms in the process of photosynthesis. About half of the world's photosynthesis (primary production) occurs in the sunlit layers of the ocean.
B.4.
Absorbing carbon dioxide can decrease the ocean's pH, making the water more acidic. This can have consequences for many organisms in the ocean.
B.6.
Humans are changing the climate by continuing to release large amounts of carbon dioxide and methane into the atmosphere.
A.5.
Most rain that falls on land evaporated from the tropical ocean.
See Principle 6: A4
See Principle 1: C
See Principle 2: A9
See Principle 6: C
See Principle 7: A3
See Principle 5: A2
See Principle 6: D13

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

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Water Cycle — A2

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Global Climate Change — B

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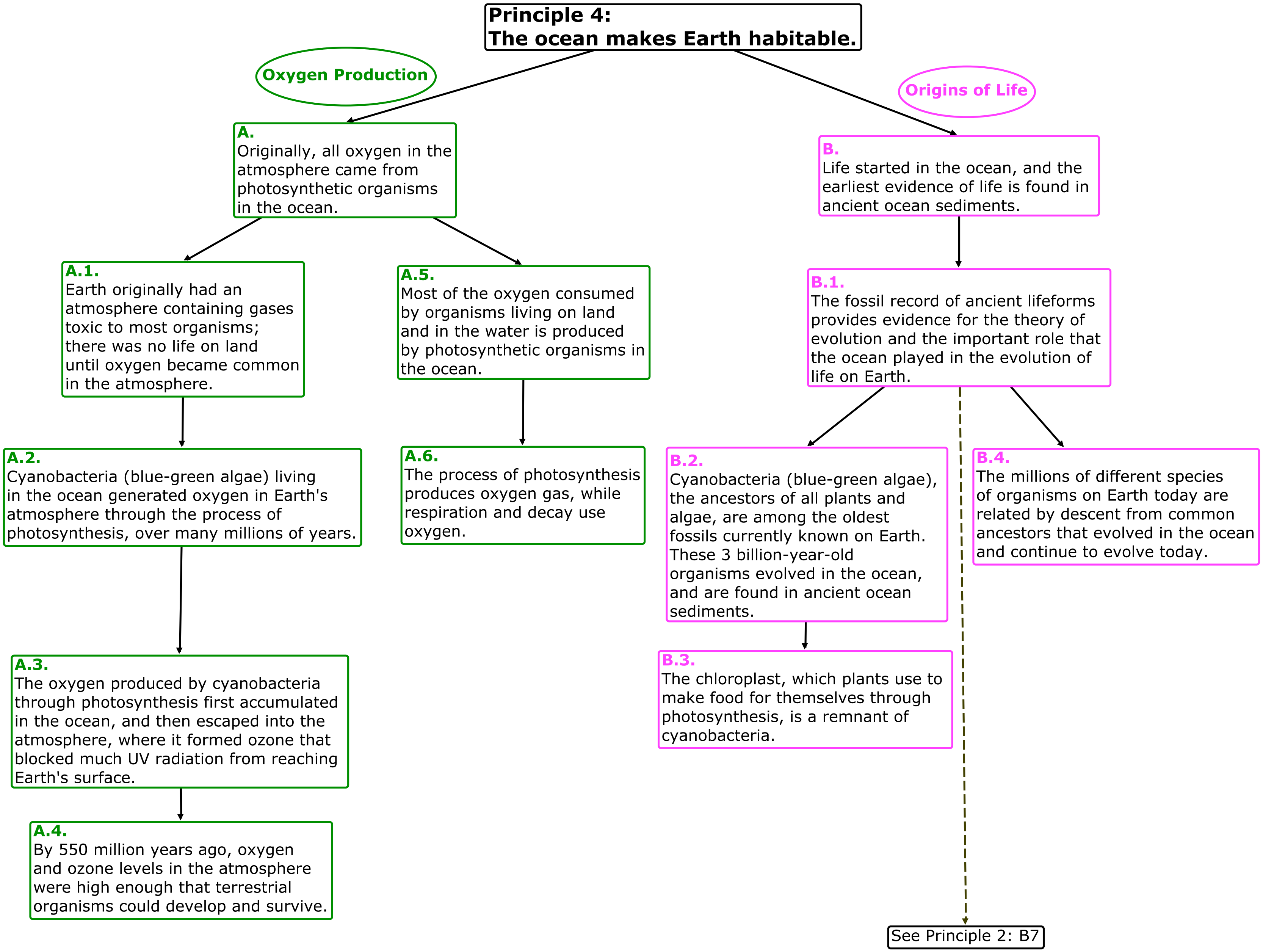
Humans are changing the climate by continuing to release large amounts of carbon dioxide and methane into the atmosphere.


Principle 4:
The ocean makes Earth habitable.
Oxygen Production
A.
Originally, all oxygen in the atmosphere came from photosynthetic organisms in the ocean.
A.1.
Earth originally had an atmosphere containing gases toxic to most organisms; there was no life on land until oxygen became common in the atmosphere.
A.2.
Cyanobacteria (blue-green algae) living in the ocean generated oxygen in Earth's atmosphere through the process of photosynthesis, over many millions of years.
A.3.
The oxygen produced by cyanobacteria through photosynthesis first accumulated in the ocean, and then escaped into the atmosphere, where it formed ozone that blocked much UV radiation from reaching Earth's surface.
A.4.
By 550 million years ago, oxygen and ozone levels in the atmosphere were high enough that terrestrial organisms could develop and survive.
A.5.
Most of the oxygen consumed by organisms living on land and in the water is produced by photosynthetic organisms in the ocean.
A.6.
The process of photosynthesis produces oxygen gas, while respiration and decay use oxygen.
Origins of Life
B.
Life started in the ocean, and the earliest evidence of life is found in ancient ocean sediments.
B.1.
The fossil record of ancient lifeforms provides evidence for the theory of evolution and the important role that the ocean played in the evolution of life on Earth.
B.2.
Cyanobacteria (blue-green algae), the ancestors of all plants and algae, are among the oldest fossils currently known on Earth. These 3 billion-year-old organisms evolved in the ocean, and are found in ancient ocean sediments.
B.3.
The chloroplast, which plants use to make food for themselves through photosynthesis, is a remnant of cyanobacteria.
B.4.
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.
See Principle 2: B7

Principle 4: The ocean makes Earth habitable.

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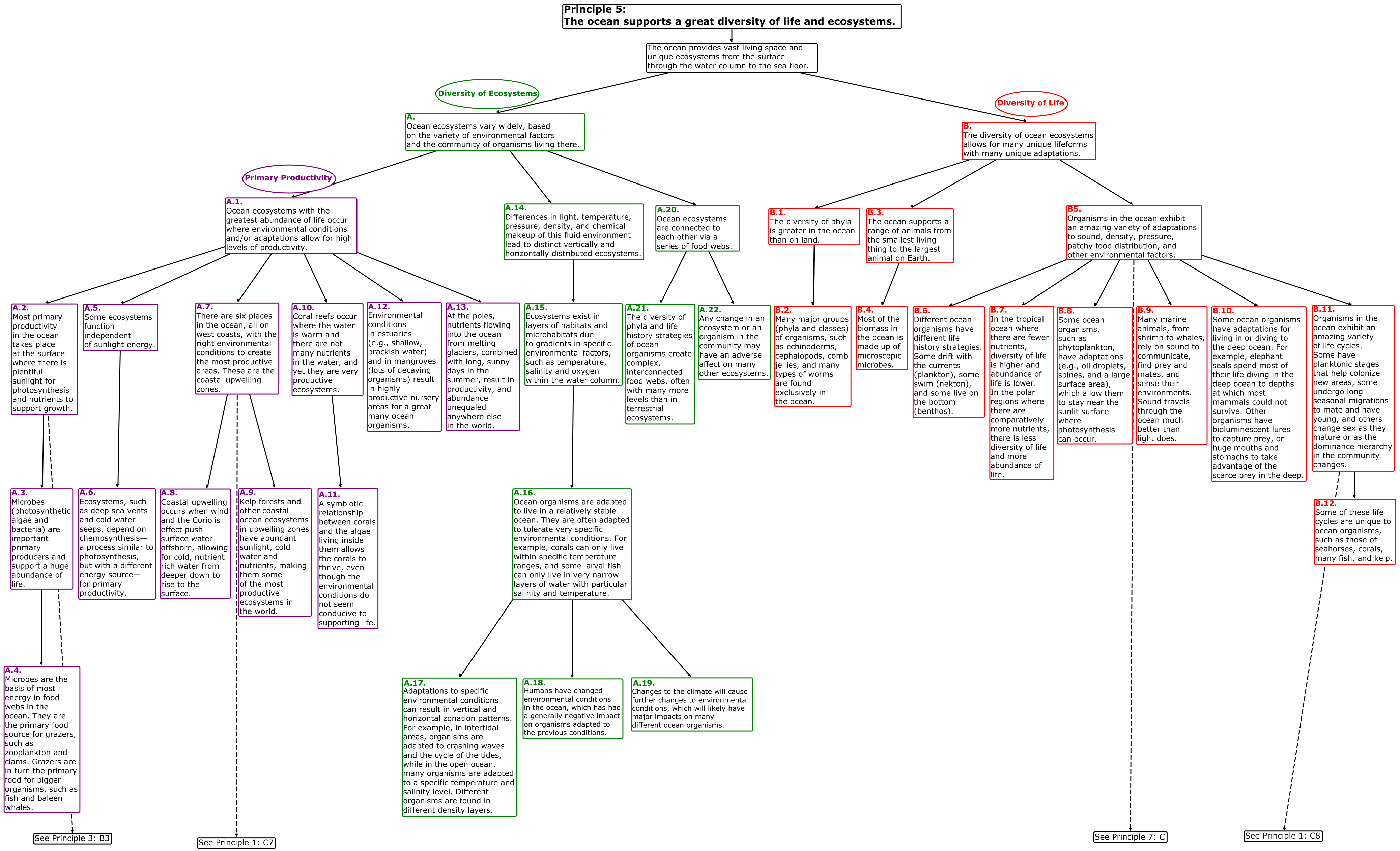
Principle 5:
The ocean supports a great diversity of life and ecosystems.
The ocean provides vast living space and unique ecosystems from the surface through the water column to the sea floor.
Diversity of Ecosystems
Diversity of Life
A. Ocean ecosystems vary widely, based on the variety of environmental factors and the community of organisms living there.
B. The diversity of ocean ecosystems allows for many unique lifeforms with many unique adaptations.
Primary Productivity
A.1. Ocean ecosystems with the greatest abundance of life occur where environmental conditions and/or adaptations allow for high levels of productivity.
A.14. Differences in light, temperature, pressure, density, and chemical makeup of this fluid environment lead to distinct vertically and horizontally distributed ecosystems.
A.20. Ocean ecosystems are connected to each other via a series of food webs.
B.1. The diversity of phyla is greater in the ocean than on land.
B.3. The ocean supports a range of animals from the smallest living thing to the largest animal on Earth.
B5. Organisms in the ocean exhibit an amazing variety of adaptations to sound, density, pressure, patchy food distribution, and other environmental factors.
A.2. Most primary productivity in the ocean takes place at the surface where there is plentiful sunlight for photosynthesis and nutrients to support growth.
A.5. Some ecosystems function independent of sunlight energy.
A.7. There are six places in the ocean, all on west coasts, with the right environmental conditions to create the most productive areas. These are the coastal upwelling zones.
A.10. Coral reefs occur where the water is warm and there are not many nutrients in the water, and yet they are very productive ecosystems.
A.12. Environmental conditions in estuaries (e.g., shallow, brackish water) and in mangroves (lots of decaying organisms) result in highly productive nursery areas for a great many ocean organisms.
A.13. At the poles, nutrients flowing into the ocean from melting glaciers, combined with long, sunny days in the summer, result in productivity, and abundance unequaled anywhere else in the world.
A.15. Ecosystems exist in layers of habitats and microhabitats due to gradients in specific environmental factors, such as temperature, salinity and oxygen within the water column.
A.21. The diversity of phyla and life history strategies of ocean organisms create complex, interconnected food webs, often with many more levels than in terrestrial ecosystems.
A.22. Any change in an ecosystem or an organism in the community may have an adverse affect on many other ecosystems.
B.2. Many major groups (phyla and classes) of organisms, such as echinoderms, cephalopods, comb jellies, and many types of worms are found exclusively in the ocean.
B.4. Most of the biomass in the ocean is made up of microscopic microbes.
B.6. Different ocean organisms have different life history strategies. Some drift with the currents (plankton), some swim (nekton), and some live on the bottom (benthos).
B.7. In the tropical ocean where there are fewer nutrients, diversity of life is higher and abundance of life is lower. In the polar regions where there are comparatively more nutrients, there is less diversity of life and more abundance of life.
B.8. Some ocean organisms, such as phytoplankton, have adaptations (e.g., oil droplets, spines, and a large surface area), which allow them to stay near the sunlit surface where photosynthesis can occur.
B.9. Many marine animals, from shrimp to whales, rely on sound to communicate, find prey and mates, and sense their environments. Sound travels through the ocean much better than light does.
B.10. Some ocean organisms have adaptations for living in or diving to the deep ocean. For example, elephant seals spend most of their life diving in the deep ocean to depths at which most mammals could not survive. Other organisms have bioluminescent lures to capture prey, or huge mouths and stomachs to take advantage of the scarce prey in the deep.
B.11. Organisms in the ocean exhibit an amazing variety of life cycles. Some have planktonic stages that help colonize new areas, some undergo long seasonal migrations to mate and have young, and others change sex as they mature or as the dominance hierarchy in the community changes.
A.3. Microbes (photosynthetic algae and bacteria) are important primary producers and support a huge abundance of life.
A.6. Ecosystems, such as deep sea vents and cold water seeps, depend on chemosynthesis—a process similar to photosynthesis, but with a different energy source—for primary productivity.
A.8. Coastal upwelling occurs when wind and the Coriolis effect push surface water offshore, allowing for cold, nutrient rich water from deeper down to rise to the surface.
A.9. Kelp forests and other coastal ocean ecosystems in upwelling zones have abundant sunlight, cold water and nutrients, making them some of the most productive ecosystems in the world.
A.11. A symbiotic relationship between corals and the algae living inside them allows the corals to thrive, even though the environmental conditions do not seem conducive to supporting life.
A.16. Ocean organisms are adapted to live in a relatively stable ocean. They are often adapted to tolerate very specific environmental conditions. For example, corals can only live within specific temperature ranges, and some larval fish can only live in very narrow layers of water with particular salinity and temperature.
B.12. Some of these life cycles are unique to ocean organisms, such as those of seahorses, corals, many fish, and kelp.
A.4. Microbes are the basis of most energy in food webs in the ocean. They are the primary food source for grazers, such as zooplankton and clams. Grazers are in turn the primary food for bigger organisms, such as fish and baleen whales.
A.17. Adaptations to specific environmental conditions can result in vertical and horizontal zonation patterns. For example, in intertidal areas, organisms are adapted to crashing waves and the cycle of the tides, while in the open ocean, many organisms are adapted to a specific temperature and salinity level. Different organisms are found in different density layers.
A.18. Humans have changed environmental conditions in the ocean, which has had a generally negative impact on organisms adapted to the previous conditions.
A.19. Changes to the climate will cause further changes to environmental conditions, which will likely have major impacts on many different ocean organisms.
See Principle 3: B3
See Principle 1: C7
See Principle 7: C
See Principle 1: C8

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

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

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A13	At the poles, nutrients flowing into the ocean from melting glaciers, combined with long, sunny days in the summer, result in productivity, and abundance unequaled anywhere else in the world.
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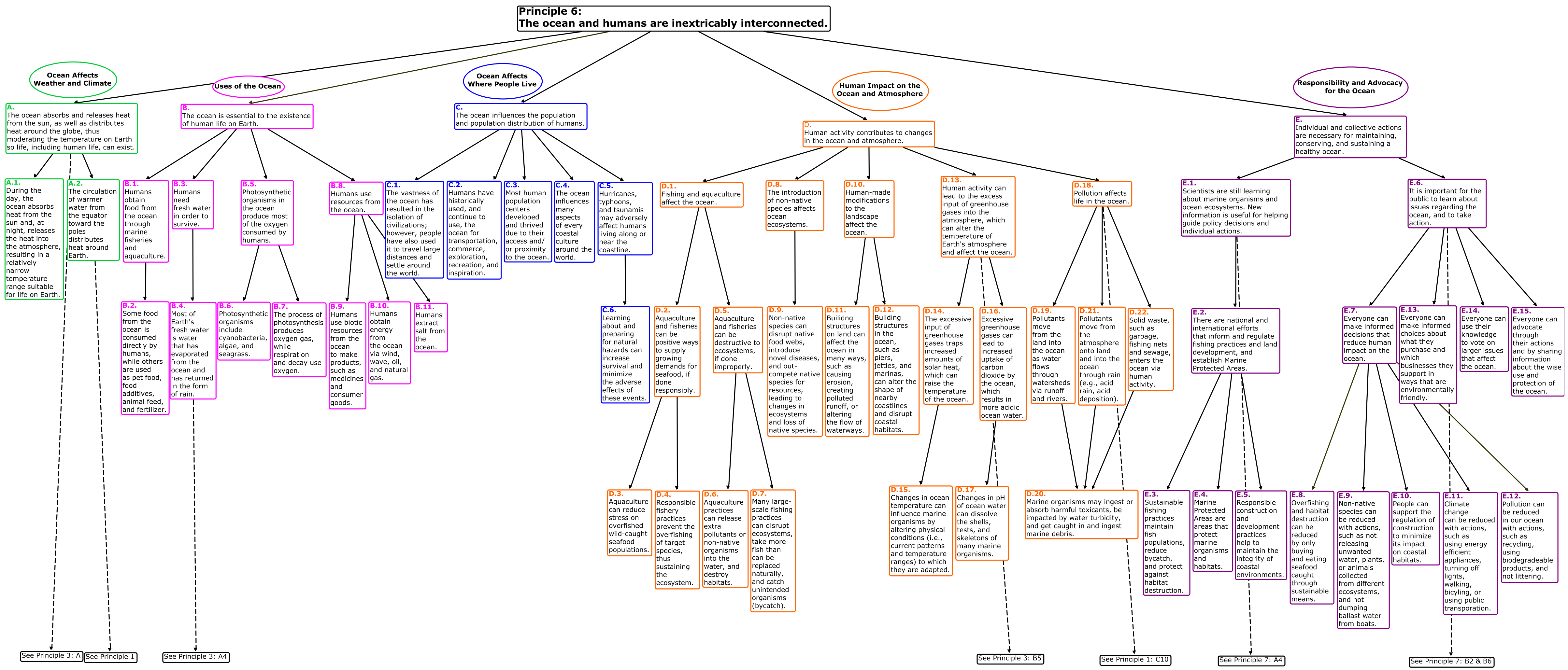
Principle 6:
The ocean and humans are inextricably interconnected.
Ocean Affects Weather and Climate
Uses of the Ocean
Ocean Affects Where People Live
Human Impact on the Ocean and Atmosphere
Responsibility and Advocacy for the Ocean
A. The ocean absorbs and releases heat from the sun, as well as distributes heat around the globe, thus moderating the temperature on Earth so life, including human life, can exist.
A.1. During the day, the ocean absorbs heat from the sun and, at night, releases the heat into the atmosphere, resulting in a relatively narrow temperature range suitable for life on Earth.
A.2. The circulation of warmer water from the equator toward the poles distributes heat around Earth.
B. The ocean is essential to the existence of human life on Earth.
B.1. Humans obtain food from the ocean through marine fisheries and aquaculture.
B.2. Some food from the ocean is consumed directly by humans, while others are used as pet food, food additives, animal feed, and fertilizer.
B.3. Humans need fresh water in order to survive.
B.4. Most of Earth's fresh water is water that has evaporated from the ocean and has returned in the form of rain.
B.5. Photosynthetic organisms in the ocean produce most of the oxygen consumed by humans.
B.6. Photosynthetic organisms include cyanobacteria, algae, and seagrass.
B.7. The process of photosynthesis produces oxygen gas, while respiration and decay use oxygen.
B.8. Humans use resources from the ocean.
B.9. Humans use biotic resources from the ocean to make products, such as medicines and consumer goods.
B.10. Humans obtain energy from the ocean via wind, wave, oil, and natural gas.
B.11. Humans extract salt from the ocean.
C. The ocean influences the population and population distribution of humans.
C.1. The vastness of the ocean has resulted in the isolation of civilizations; however, people have also used it to travel large distances and settle around the world.
C.2. Humans have historically used, and continue to use, the ocean for transportation, commerce, exploration, recreation, and inspiration.
C.3. Most human population centers developed and thrived due to their access and/ or proximity to the ocean.
C.4. The ocean influences many aspects of every coastal culture around the world.
C.5. Hurricanes, typhoons, and tsunamis may adversely affect humans living along or near the coastline.
C.6. Learning about and preparing for natural hazards can increase survival and minimize the adverse effects of these events.
D. Human activity contributes to changes in the ocean and atmosphere.
D.1. Fishing and aquaculture affect the ocean.
D.2. Aquaculture and fisheries can be positive ways to supply growing demands for seafood, if done responsibly.
D.3. Aquaculture can reduce stress on overfished wild-caught seafood populations.
D.4. Responsible fishery practices prevent the overfishing of target species, thus sustaining the ecosystem.
D.5. Aquaculture and fisheries can be destructive to ecosystems, if done improperly.
D.6. Aquaculture practices can release extra pollutants or non-native organisms into the water, and destroy habitats.
D.7. Many large-scale fishing practices can disrupt ecosystems, take more fish than can be replaced naturally, and catch unintended organisms (bycatch).
D.8. The introduction of non-native species affects ocean ecosystems.
D.9. Non-native species can disrupt native food webs, introduce novel diseases, and out-compete native species for resources, leading to changes in ecosystems and loss of native species.
D.10. Human-made modifications to the landscape affect the ocean.
D.11. Building structures on land can affect the ocean in many ways, such as causing erosion, creating polluted runoff, or altering the flow of waterways.
D.12. Building structures in the ocean, such as piers, jetties, and marinas, can alter the shape of nearby coastlines and disrupt coastal habitats.
D.13. Human activity can lead to the excess input of greenhouse gases into the atmosphere, which can alter the temperature of Earth's atmosphere and affect the ocean.
D.14. The excessive input of greenhouse gases traps increased amounts of solar heat, which can raise the temperature of the ocean.
D.15. Changes in ocean temperature can influence marine organisms by altering physical conditions (i.e., current patterns and temperature ranges) to which they are adapted.
D.16. Excessive greenhouse gases can lead to increased uptake of carbon dioxide by the ocean, which results in more acidic ocean water.
D.17. Changes in pH of ocean water can dissolve the shells, tests, and skeletons of many marine organisms.
D.18. Pollution affects life in the ocean.
D.19. Pollutants move from the land into the ocean as water flows through watersheds via runoff and rivers.
D.20. Marine organisms may ingest or absorb harmful toxicants, be impacted by water turbidity, and get caught in and ingest marine debris.
D.21. Pollutants move from the atmosphere onto land and into the ocean through rain (e.g., acid rain, acid deposition).
D.22. Solid waste, such as garbage, fishing nets and sewage, enters the ocean via human activity.
E. Individual and collective actions are necessary for maintaining, conserving, and sustaining a healthy ocean.
E.1. Scientists are still learning about marine organisms and ocean ecosystems. New information is useful for helping guide policy decisions and individual actions.
E.2. There are national and international efforts that inform and regulate fishing practices and land development, and establish Marine Protected Areas.
E.3. Sustainable fishing practices maintain fish populations, reduce bycatch, and protect against habitat destruction.
E.4. Marine Protected Areas are areas that protect marine organisms and habitats.
E.5. Responsible construction and development practices help to maintain the integrity of coastal environments.
E.6. It is important for the public to learn about issues regarding the ocean, and to take action.
E.7. Everyone can make informed decisions that reduce human impact on the ocean.
E.8. Overfishing and habitat destruction can be reduced by only buying and eating seafood caught through sustainable means.
E.9. Non-native species can be reduced with actions, such as not releasing unwanted water, plants, or animals collected from different ecosystems, and not dumping ballast water from boats.
E.10. People can support the regulation of construction to minimize its impact on coastal habitats.
E.11. Climate change can be reduced with actions, such as using energy efficient appliances, turning off lights, walking, bicyling, or using public transportation.
E.12. Pollution can be reduced in our ocean with actions, such as recycling, using biodegradeable products, and not littering.
E.13. Everyone can make informed choices about what they purchase and which businesses they support in ways that are environmentally friendly.
E.14. Everyone can use their knowledge to vote on larger issues that affect the ocean.
E.15. Everyone can advocate through their actions and by sharing information about the wise use and protection of the ocean.
See Principle 3: A
See Principle 1
See Principle 3: A4
See Principle 3: B5
See Principle 1: C10
See Principle 7: A4
See Principle 7: B2 & B6

Principle 6: The ocean and humans are inextricably interconnected.

Ocean Affects Weather and Climate — A

The ocean absorbs and releases heat from the sun, as well as distributes heat around the globe, thus moderating the temperature on Earth so life, including human life, can exist.

A1	During the day, the ocean absorbs heat from the sun and, at night, releases the heat into the atmosphere, resulting in a relatively narrow temperature range suitable for life on Earth.
A2	The circulation of warmer water from the equator toward the poles distributes heat around Earth.

Uses of the Ocean — B

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

B1	Humans obtain food from the ocean through marine fisheries and aquaculture.
B3	Humans need fresh water in order to survive.
B5	Photosynthetic organisms in the ocean produce most of the oxygen consumed by humans.
B8	Humans use resources from the ocean.
B2	Some food from the ocean is consumed directly by humans, while others are used as pet food, food additives, animal feed, and fertilizer.
B4	Most of Earth's fresh water is water that has evaporated from the ocean and has returned in the form of rain.
B6	Photosynthetic organisms include cyanobacteria, algae, and seagrass.
B7	The process of photosynthesis produces oxygen gas, while respiration and decay use oxygen.
B9	Humans use biotic resources from the ocean to make products, such as medicines and consumer goods.
B10	Humans obtain energy from the ocean via wind, wave, oil, and natural gas.
B11	Humans extract salt from the ocean.

Ocean Affects Where People Live — C

The ocean influences the population and population distribution of humans.

C1	The vastness of the ocean has resulted in the isolation of civilizations; however, people have also used it to travel large distances and settle around the world.
C2	Humans have historically used, and continue to use the ocean for transportation, commerce, exploration, recreation, and inspiration.
C3	Most human population centers developed and thrived due to their access and/or proximity to the ocean.
C4	The ocean influences many aspects of every coastal culture around the world.
C5	Hurricanes, typhoons, and tsunamis may adversely affect humans living along or near the coastline.
C6	Learning about and preparing for natural hazards can increase survival and minimize the adverse effects of these events.

Human Impact on the Ocean and Atmosphere — D

Human activity contributes to changes in the ocean and atmosphere.

D1	Fishing and aquaculture affect the ocean.
D8	The introduction of non-native species affects ocean ecosystems.
D10	Human-made modifications to the landscape affect the ocean.
D13	Human activity can lead to the excess input of greenhouse gases into the atmosphere which can alter the temperature of Earth's atmosphere and affect the ocean.
D18	Pollution affects life in the ocean.
D2	Aquaculture and fisheries can be positive ways to supply growing demands for seafood, if done responsibly.
D5	Aquaculture and fisheries can be destructive to ecosystems, if done improperly.
D9	Non-native species can disrupt native food webs, introduce novel diseases, and out-compete native species for resources, leading to changes in ecosystems and loss of native species.
D11	Building structures on land can affect the ocean in many ways, such as causing erosion, creating polluted runoff, or altering the flow of waterways.
D12	Building structures in the ocean, such as piers, jetties, and marinas, can alter the shape of nearby coastlines and disrupt coastal habitats.
D14	The excessive input of greenhouse gases traps increased amounts of solar heat, which can raise the temperature of the ocean.
D16	Excessive greenhouse gases can lead to increased uptake of carbon dioxide by the ocean, which results in more acidic ocean water.
D19	Pollutants move from the land into the ocean as water flows through watersheds via runoff and rivers.
D21	Pollutants move from the atmosphere onto land and into the ocean through rain (e.g., acid rain, acid deposition).
D22	Solid waste, such as garbage, fishing nets, and sewage enters the ocean via human activity.
D3	Aquaculture can reduce stress on overfished wild-caught seafood populations.
D4	Responsible fishery practices prevent the overfishing of target species, thus sustaining the ecosystem.
D6	Aquaculture practices can release extra pollutants or non-native organisms into the water, and destroy habitats.
D7	Many large-scale fishing practices can disrupt ecosystems, take more fish than can be replaced naturally and catch unintended organisms (bycatch).
D15	Changes in ocean temperature can influence marine organisms by altering physical conditions (i.e., current patterns and temperature ranges) to which they are adapted.
D17	Changes in pH of ocean water can dissolve the shells, tests, and skeletons of many marine organisms.
D20	Marine organisms may ingest or absorb harmful toxicants, be impacted by water turbidity, and get caught in and ingest marine debris.
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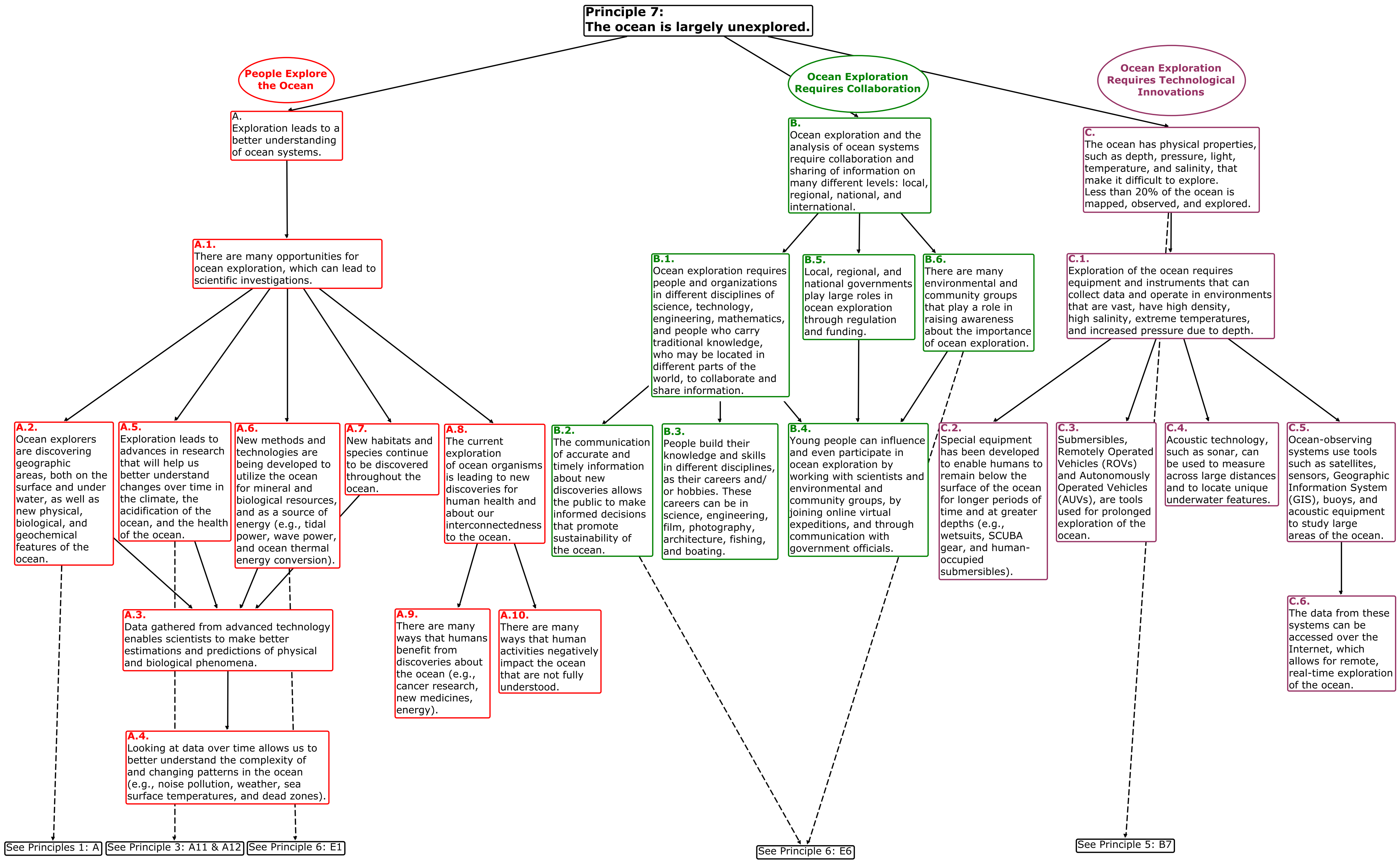
Responsibility and Advocacy for the Ocean — E

Individual and collective actions are necessary for maintaining, conserving, and sustaining a healthy ocean.

E1	Scientists are still learning about marine organisms and ocean ecosystems. New information is useful for helping guide policy decisions and individual actions.
E6	It is important for the public to learn about issues regarding the ocean, and to take action.
E2	There are national and international efforts that inform and regulate fishing practices and land development, and establish Marine Protected Areas.
E7	Everyone can make informed decisions that reduce human impact on the ocean.
E13	Everyone can make informed choices about what they purchase and which businesses they support in ways that are environmentally friendly.
E14	Everyone can use their knowledge to vote on larger issues that affect the ocean.
E15	Everyone can advocate through their actions and by sharing information about the wise use and protection of the ocean.
E3	Sustainable fishing practices maintain fish populations, reduce bycatch, and protect against habitat destruction.
E4	Marine Protected Areas are areas that protect marine organisms and habitats.
E5	Responsible construction and development practices help to maintain the integrity of coastal environments.
E8	Overfishing and habitat destruction can be reduced by only buying and eating seafood caught through sustainable means.
E9	Non-native species can be reduced with actions, such as not releasing unwanted water, plants, or animals collected from different ecosystems, and not dumping ballast water from boats.
E10	People can support the regulation of construction to minimize its impact on coastal habitats.
E11	Climate change can be reduced with actions, such as using energy efficient appliances, turning off lights, walking, bicycling, or using public transportation.
E12	Pollution can be reduced in our ocean with actions, such as recycling, using biodegradable products, and not littering.


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 scientific investigations.
A.2.
Ocean explorers are discovering geographic areas, both on the surface and under water, as well as new physical, biological, and geochemical features of the ocean.
A.5.
Exploration leads to advances in research that will help us better understand changes over time in the climate, the acidification of the ocean, and the health of the ocean.
A.6.
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.7.
New habitats and species continue to be discovered throughout the ocean.
A.8.
The current exploration of ocean organisms is leading to new discoveries for human health and about our interconnectedness to the ocean.
A.3.
Data gathered from advanced technology enables scientists to make better estimations and predictions of physical and biological phenomena.
A.4.
Looking at data over time allows us to better understand the complexity of and changing patterns in the ocean (e.g., noise pollution, weather, sea surface temperatures, and dead zones).
A.9.
There are many ways that humans benefit from discoveries about the ocean (e.g., cancer research, new medicines, energy).
A.10.
There are many ways that human activities negatively impact the ocean that are not fully understood.
B.
Ocean exploration and the analysis of ocean systems require collaboration and sharing of information on many different levels: local, regional, national, and international.
B.1.
Ocean exploration requires people and organizations in different disciplines of science, technology, engineering, mathematics, and people who carry traditional knowledge, who may be located in different parts of the world, to collaborate and share information.
B.5.
Local, regional, and national governments play large roles in ocean exploration through regulation and funding.
B.6.
There are many environmental and community groups that play a role in raising awareness about the importance of ocean exploration.
B.2.
The communication of accurate and timely information about new discoveries allows the public to make informed decisions that promote sustainability of the ocean.
B.3.
People build their knowledge and skills in different disciplines, as their careers and/ or hobbies. These careers can be in science, engineering, film, photography, architecture, fishing, and boating.
B.4.
Young people can influence and even participate in ocean exploration by working with scientists and environmental and community groups, by joining online virtual expeditions, and through communication with government officials.
C.
The ocean has physical properties, such as depth, pressure, light, temperature, and salinity, that make it difficult to explore.
Less than 20% of the ocean is mapped, observed, and explored.
C.1.
Exploration of the ocean requires equipment and instruments that can collect data and operate in environments that are vast, have high density, high salinity, extreme temperatures, and increased pressure due to depth.
C.2.
Special equipment has been developed to enable humans to remain below the surface of the ocean for longer periods of time and at greater depths (e.g., wetsuits, SCUBA gear, and human-occupied submersibles).
C.3.
Submersibles, Remotely Operated Vehicles (ROVs) and Autonomously Operated Vehicles (AUVs), are tools used for prolonged exploration of the ocean.
C.4.
Acoustic technology, such as sonar, can be used to measure across large distances and to locate unique underwater features.
C.5.
Ocean-observing systems use tools such as satellites, sensors, Geographic Information System (GIS), buoys, and acoustic equipment to study large areas of the ocean.
C.6.
The data from these systems can be accessed over the Internet, which allows for remote, real-time exploration of the ocean.
See Principles 1: A
See Principle 3: A11 & A12
See Principle 6: E1
See Principle 6: E6
See Principle 5: B7

Principle 7: The ocean is largely unexplored.

People Explore the Ocean — A

Exploration leads to a better understanding of systems.

A1
There are many opportunities for ocean exploration, which can lead to scientific investigations.

A2
Ocean explorers are discovering geographic areas, both on the surface and under water, as well as new physical, biological, and geochemical features of the ocean.

A3
Data gathered from advanced technology enables scientists to make better estimations and predictions of physical and biological phenomena.

A4
Looking at data over time allows us to better understand the complexity of and changing patterns in the ocean (e.g., noise pollution, weather, sea surface temperatures, and dead zones).

A5
Exploration leads to advances in research that will help us better understand changes over time in the climate, the acidification of the ocean, and the health of the ocean.

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Data gathered from advanced technology enables scientists to make better estimations and predictions of physical and biological phenomena.

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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).

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A9
There are many ways that humans benefit from discoveries about the ocean (e.g., cancer research, new medicines, energy).

A10
There are many ways that human activities negatively impact the ocean that are not fully understood.

Ocean Exploration Requires Collaboration — B

Ocean exploration and the analysis of ocean systems require collaboration and sharing of information on many different levels: local, regional, national, and international.

B1
Ocean exploration requires people and organizations in different disciplines of science, technology, engineering, mathematics, and people who carry traditional knowledge, who may be located in different parts of the world, to collaborate and share information.

B2
The communication of accurate and timely information about new discoveries allows the public to make informed decisions that promote sustainability of the ocean.

B3
People build their knowledge and skills in different disciplines, as their careers and/or hobbies. These careers can be in science, engineering, film, photography, architecture, fishing, and boating.

B4
Young people can influence and even participate in ocean exploration by working with scientists and environmental and community groups, by joining online virtual expeditions, and through communication with government officials.

B5
Local, regional, and national governments play large roles in ocean exploration through regulation and funding.

B4
Young people can influence and even participate in ocean exploration by working with scientists and environmental and community groups, by joining online virtual expeditions, and through communication with government officials.

B6
There are many environmental and community groups that play a role in raising awareness about the importance of ocean exploration.

B4
Young people can influence and even participate in ocean exploration by working with scientists and environmental and community groups, by joining online virtual expeditions, and through communication with government officials.

Ocean Exploration Requires Technological Innovations — C

The ocean has physical properties, such as depth, pressure, light, temperature, and salinity, that make it difficult to explore. Less than 20% of the ocean is mapped, observed, and explored.

C1
Exploration of the ocean requires equipment and instruments that can collect data and operate in environments that are vast, have high density, high salinity, extreme temperatures, and increased pressure due to depth.

C2
Special equipment has been developed to enable humans to remain below the surface of the ocean for longer periods of time and at greater depths (e.g., wetsuits, SCUBA gear, and human-occupied submersibles).

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Submersibles, Remotely Operated Vehicles (ROVs) and Autonomously Operated Vehicles (AUVs), are tools used for prolonged exploration of the ocean.

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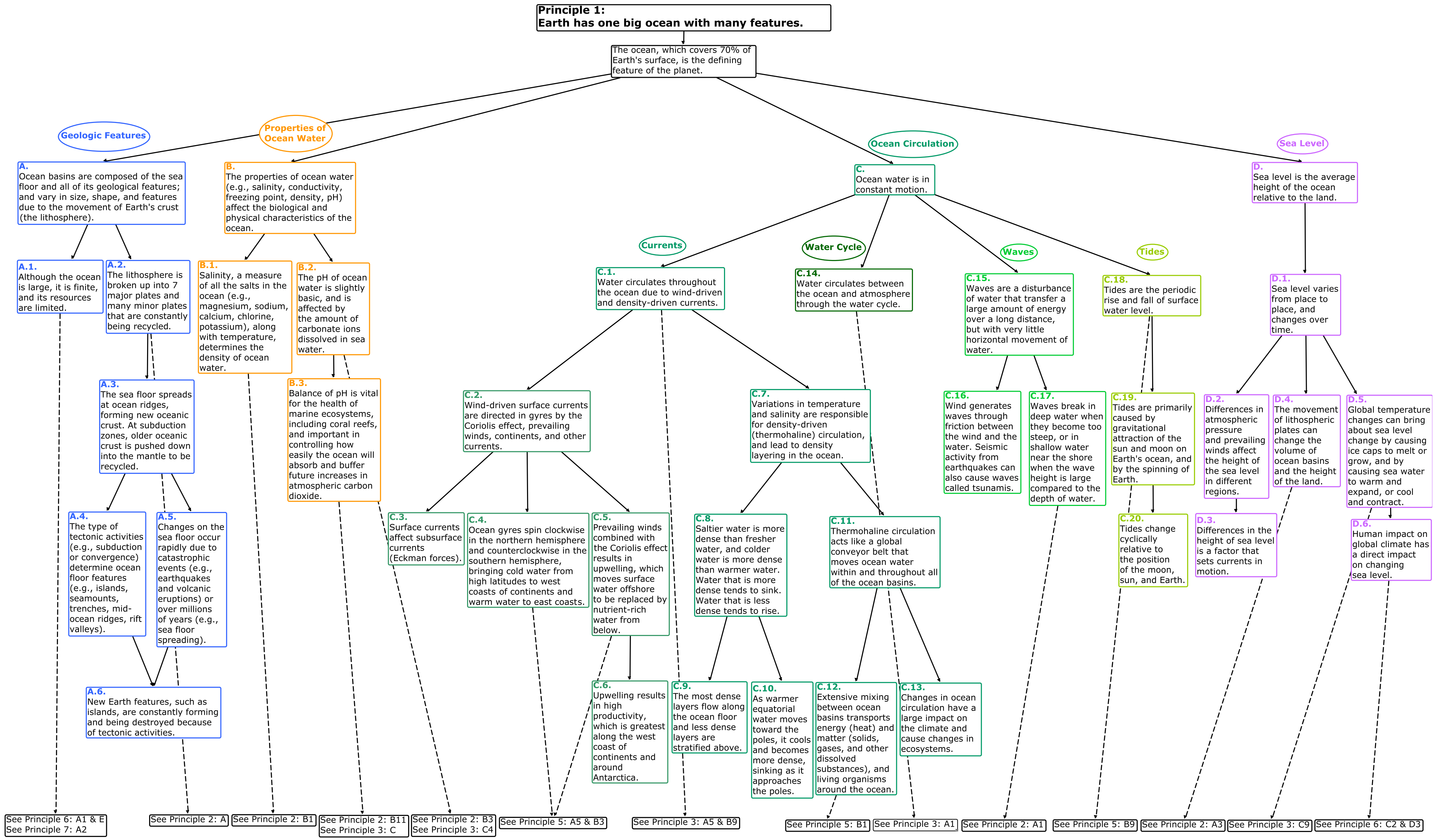
Principle 1:
Earth has one big ocean with many features.
The ocean, which covers 70% of Earth's surface, is the defining feature of the planet.
Geologic Features
Properties of Ocean Water
Ocean Circulation
Sea Level
A. Ocean basins are composed of the sea floor and all of its geological features; and 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.

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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.

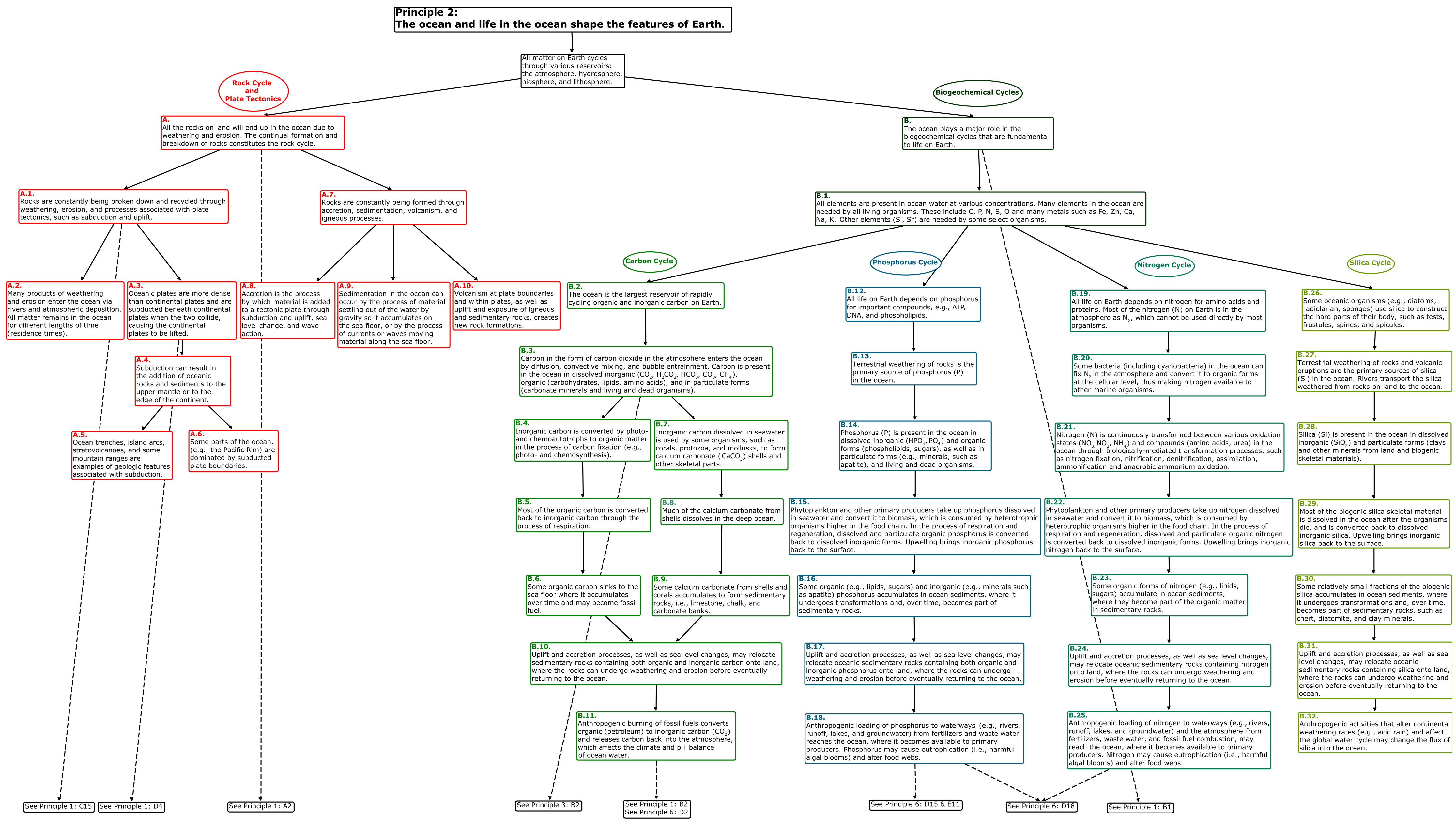
D2
Differences in atmospheric pressure and prevailing winds affect the height of the sea level in different regions.

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

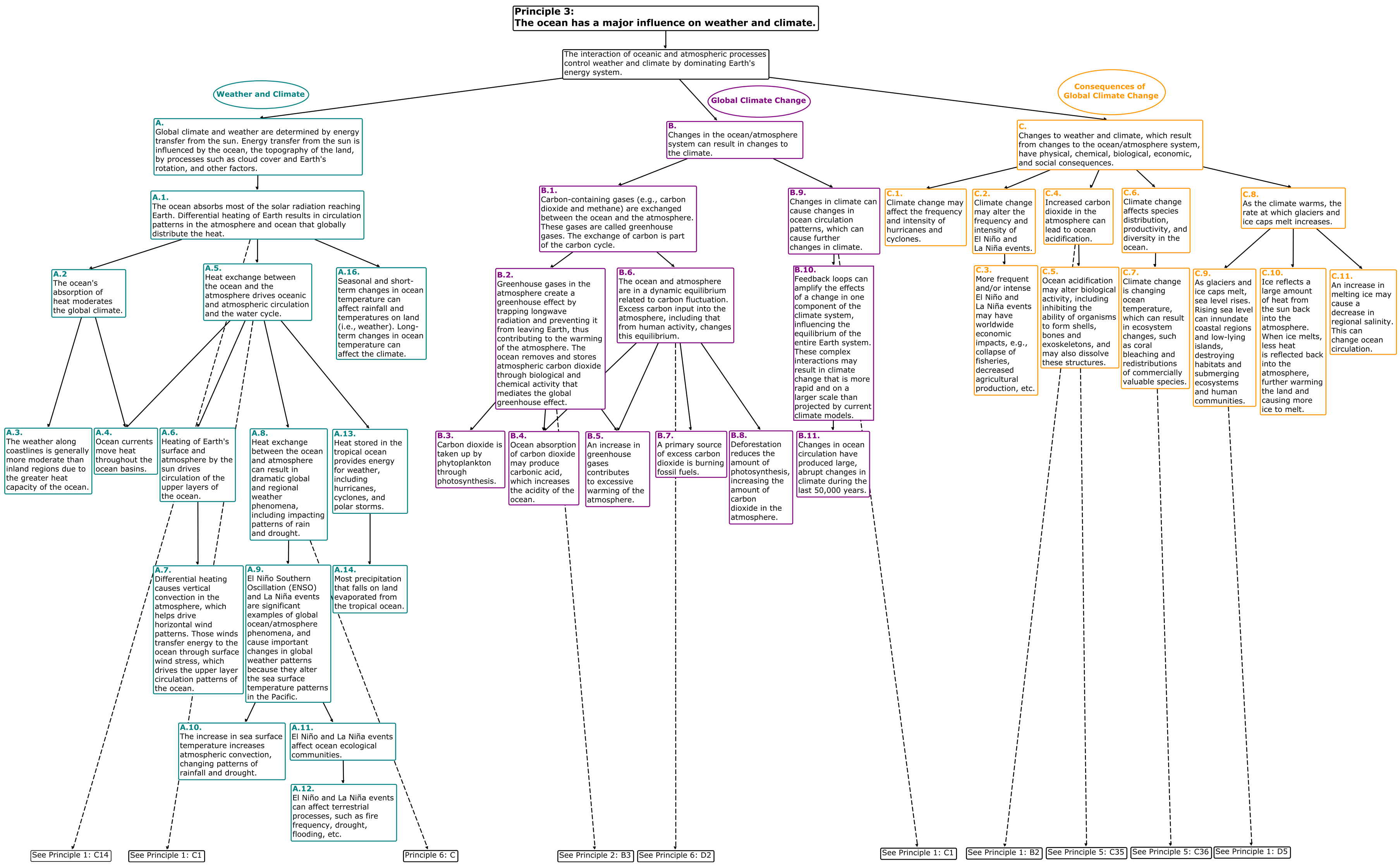
Some relatively small fractions of the biogenic silica accumulates in ocean sediments, where it undergoes transformations and, over time, becomes part of sedimentary rocks, such as chert, diatomite, and clay materials.

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.
See Principle 1: C14
See Principle 1: C1
See Principle 6: C
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.
See Principle 2: B3
See Principle 6: D2
See Principle 1: C1
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: 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 throughout the ocean basins.
A4	Ocean currents move heat throughout the ocean basins.
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.
A13	Heat stored in the tropical ocean provides energy for weather, including hurricanes, cyclones, and polar storms.
A7	Differential heating causes vertical convection in the atmosphere, which helps drive horizontal wind patterns. Those wind patterns transfer energy to the ocean through surface wind stress, which drives the upper layer circulation patterns in the ocean.
A9	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.
A14	Most precipitation that falls on land evaporated from the tropical ocean
A10	The increase in sea surface temperature increases atmospheric convection, changing patterns of rainfall and drought.
A11	El Niño and La Niña events affect ocean ecological communities.
A12	El Niño and La Niña events can affect terrestrial processes, such as fire frequency, drought, flooding, etc.

Global Climate Change — B

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

B1	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.
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.
B3	Carbon dioxide is taken up by phytoplankton through photosynthesis.
B4	Ocean absorption of carbon dioxide may produce carbonic acid, which increases the acidity of the ocean.
B5	An increase in greenhouse gases contributes to excessive warming of the atmosphere.
B4	Ocean absorption of carbon dioxide may produce carbonic acid, which increases the acidity of the ocean.
B5	An increase in greenhouse gases contributes to excessive warming of the atmosphere.
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.

C1	Climate change may alter the frequency and intensity of hurricanes and cyclones.
C2	Climate change may alter the frequency and intensity of El Niño and La Niña events.
C4	Increased carbon dioxide in the atmosphere can lead to ocean acidification.
C6	Climate change affects species distribution, productivity, and diversity in the ocean.
C8	As the climate warms, the rate at which glaciers and ice caps melt increases.
C3	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.
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.
C10	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.
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.

See Principle 5: C12

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 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	Origins of Life — B
The accumulation of oxygen in Earth's atmosphere through photosynthesis was necessary for life to develop and be sustained on land.	Life started in the ocean and the earliest evidence of life is found in ancient ocean sediments.

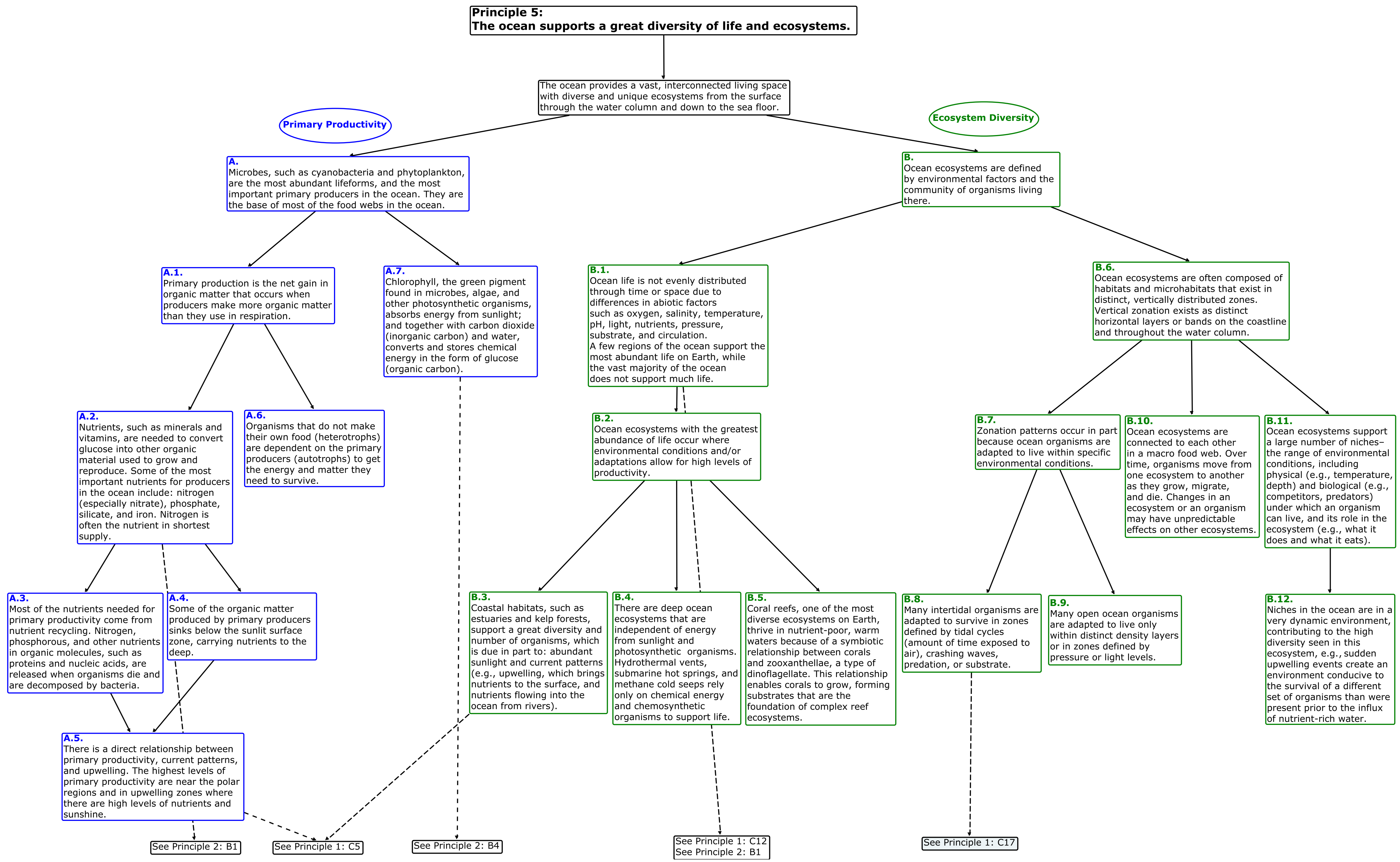
A1	A9	B1
All oxygen gas came originally from photosynthetic organisms in the ocean.	Photosynthesis produces oxygen gas and is balanced by a loss of oxygen gas through respiration, decay of organisms, and oxidation of exposed minerals. The burial of some dead organisms in the sea floor sediments prevents their decay and keeps atmospheric oxygen near 20%.	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.

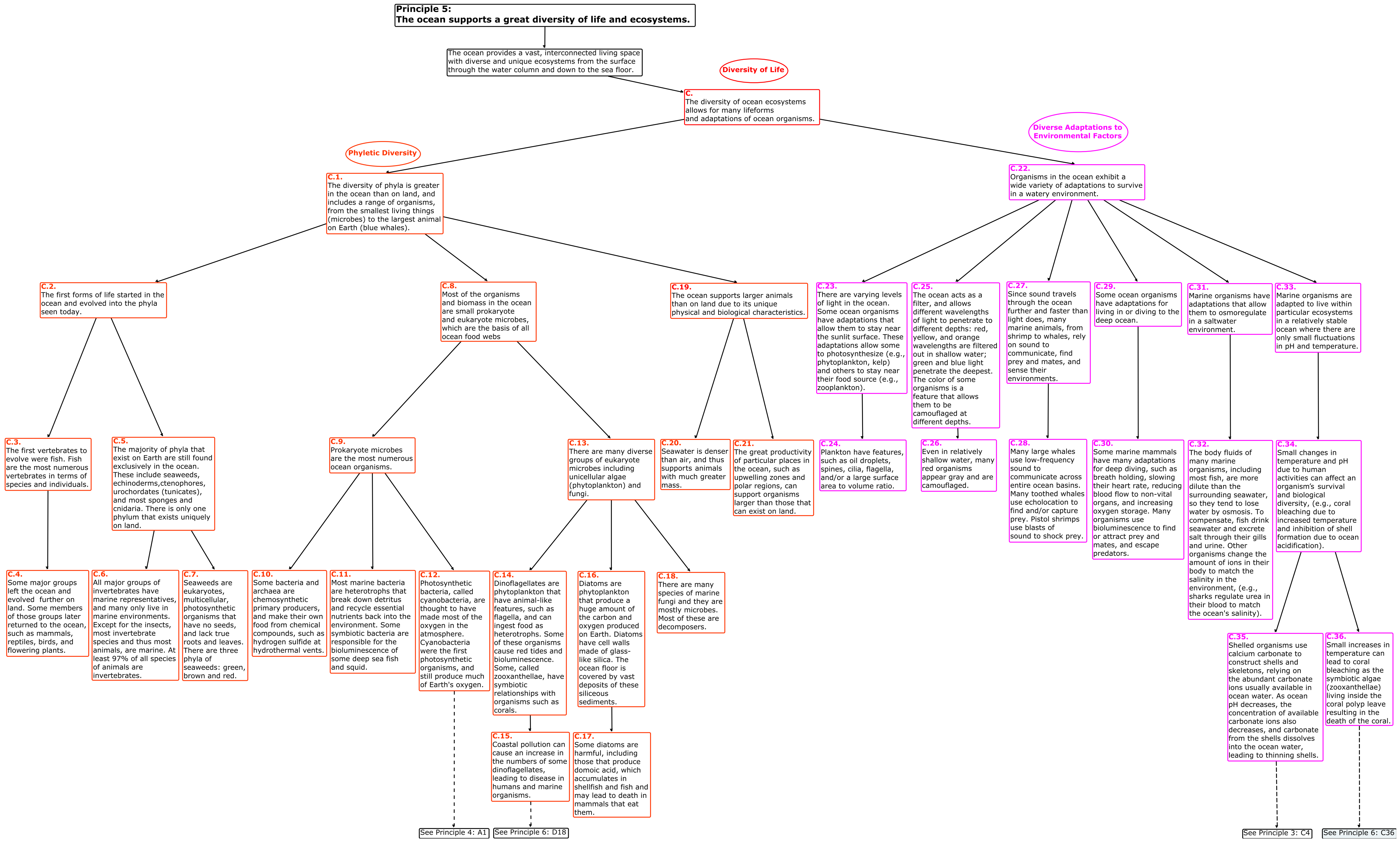
A2	A10	B2	B4
About 3 billion years ago, cyanobacteria, with the ability to use sunlight, water, and gases to synthesize organic molecules, produced oxygen gas as a waste product.	There is no steady state of oxygen gas on geological time scales. Oxygen and carbon dioxide concentrations in the atmosphere change within relatively wide limits, controlled by a combination of biological, geological, and chemical processes.	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.	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.

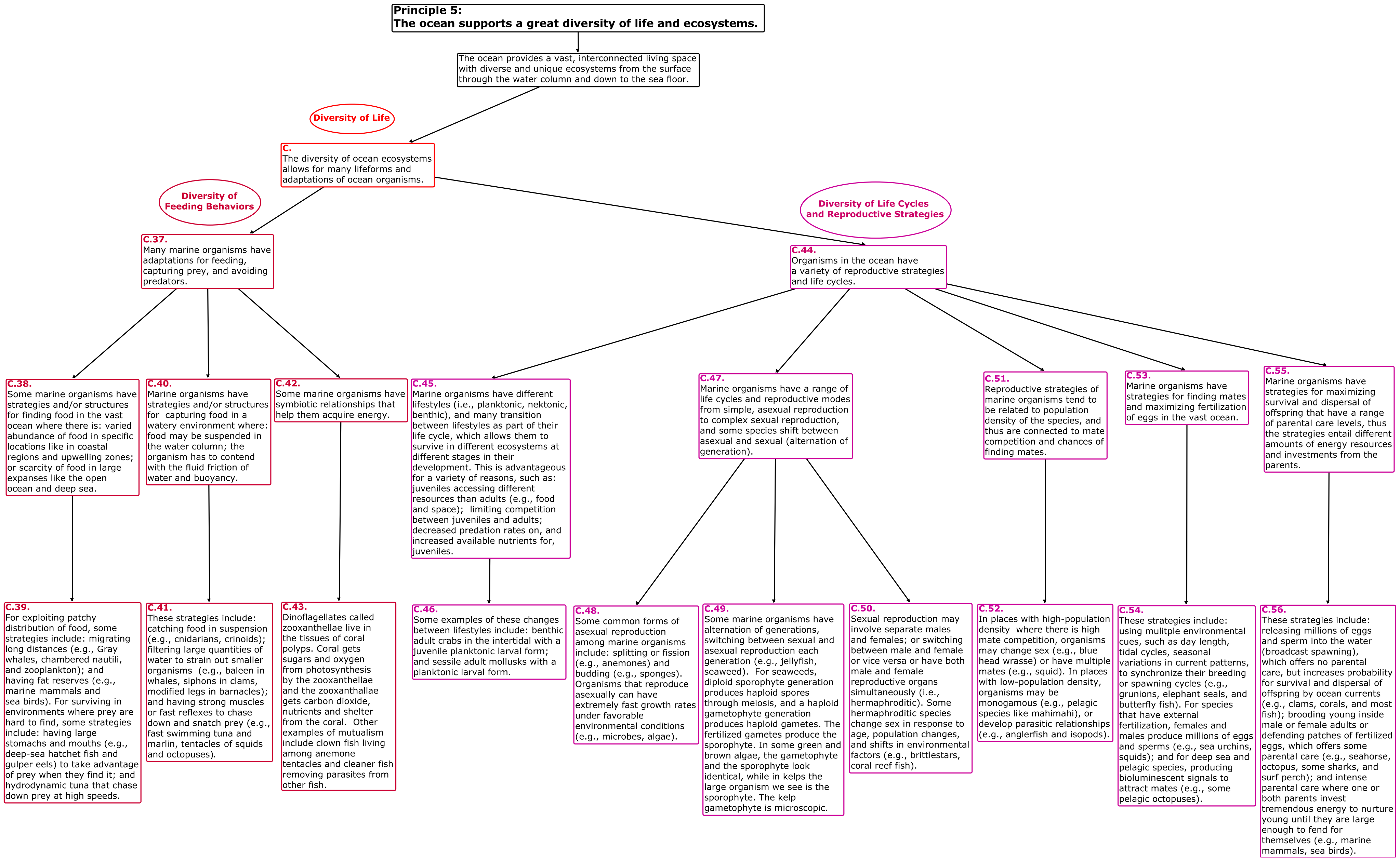
A3	A4	B3	B5
Until about 2.5 billion years ago, the majority of oxygen gas produced through photosynthesis was consumed in the process of oxidizing reduced compounds, forming vast sedimentary deposits, and changing the chemistry of the ocean and sediments.	Dissolved oxygen started to accumulate in the ocean when much of the free reduced compounds were oxidized.	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.	Most living organisms, including all animals, plants, fungi, and protists, are eukaryotes that evolved from prokaryotes.

A5	A7
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.	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.

A6	A8
This energy efficient biological pathway that developed in aerobic bacteria, along with oxygen in the ocean, allowed for the development of complex oceanic eukaryotic cells about 2 billion years ago.	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.


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.
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).
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.
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.
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.
B. Ocean ecosystems are defined by environmental factors and the community of organisms living there.
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.2. Ocean ecosystems with the greatest abundance of life occur where environmental conditions and/or adaptations allow for high levels of productivity.
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.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.
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).
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.
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 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.
Diversity of Life Cycles and Reproductive Strategies
C.44. Organisms in the ocean have a variety of reproductive strategies and life cycles.
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.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.42. Some marine organisms have symbiotic relationships that help them acquire energy.
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.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.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.53. Marine organisms have strategies for finding mates and maximizing fertilization of eggs in the vast ocean.
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.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.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.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.
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.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.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.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.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.

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.

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.

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

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.

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.

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

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.

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).

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.

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

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.

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.

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.

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.

C9 — Prokaryote microbes are the most numerous ocean organisms.

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.

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

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.

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

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.

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.

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

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

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.

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).

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

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.

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

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.

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.

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

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.

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

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).

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.

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.

C39 — 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.

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.

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).

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

C43 — Dinoflagellates called zooxanthellae live in the tissues of coral polyps. Coral gets sugars and oxygen from photosynthesis by the zoxanthellae and the zooxanthellae 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 — 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.

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.

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).

C48 — 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).

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).

C51 — 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.

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).

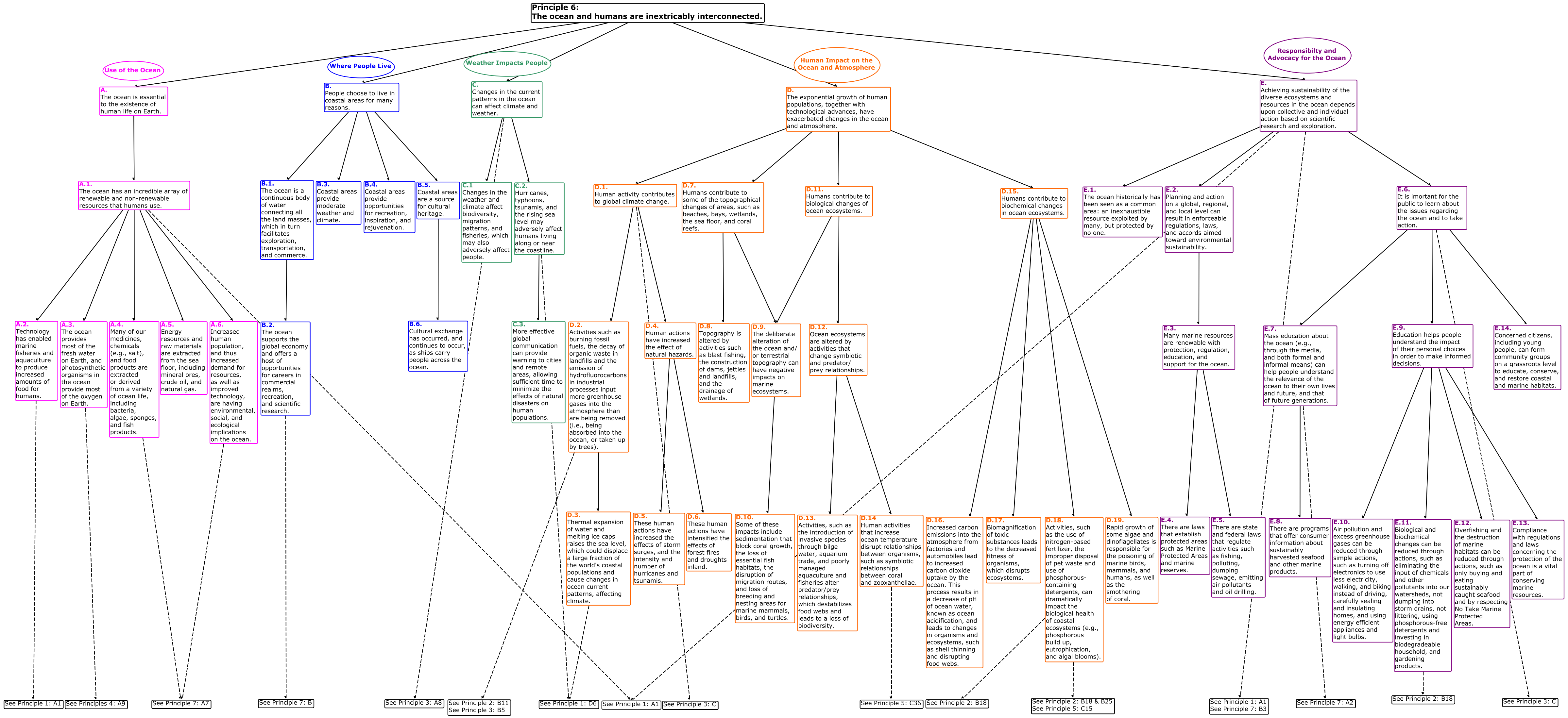
C53 — Marine organisms have strategies for finding mates and maximizing fertilization of eggs in the vast ocean.

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).

C55 — 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.

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


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.

B2 The ocean supports the global economy and offers a host of opportunities for careers in commercial realms, recreation, and scientific research.

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.

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.

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).

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.

D4 Human actions have increased the effect of natural hazards.

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.

D7 Humans contribute to some of the topographical changes of areas, such as beaches, bays, wetlands, the sea floor, and coral reefs.

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.

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.

D11 Humans contribute to biological changes of ocean ecosystems.

D9 The deliberate alteration of the ocean and/or terrestrial topography can have negative impacts on marine ecosystems.

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.

D12 Ocean ecosystems are altered by activities that change symbiotic and predator/prey relationships.

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.

D15 Humans contribute to biochemical changes in ocean ecosystems.

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.

E3 Many marine resources are renewable with protection, regulation, education, and support for the ocean.

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.

E6 It is important for the public to learn about the issues regarding the ocean and to take action.

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.

E8 There are programs that offer consumer information about sustainably harvested seafood and other marine products.

E9 Education helps people understand the impact of their personal choices in order to make informed decisions.

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.

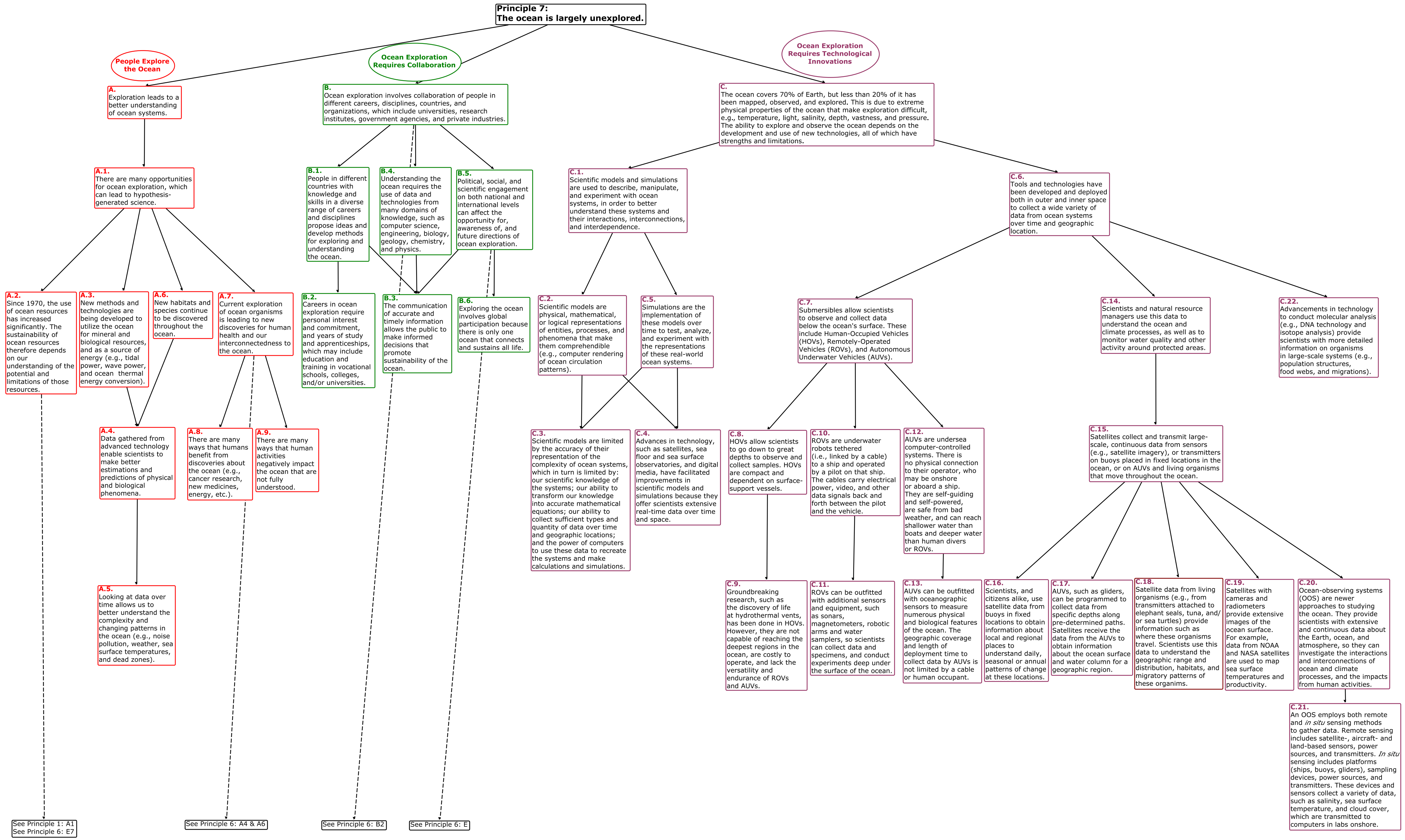
E11 Biological and biochemical changes can be reduced through actions, such as eliminating the input of chemicals and other pollutants into our watersheds, not dumping into storm drains, not littering, using phosphorous- free detergents, and investing in biodegradeable household and gardening products.

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.

E14 Concerned citizens, including young people, can form community groups on a grassroots level to educate, conserve, and restore coastal and marine habitats.

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).
See Principle 1: A1
See Principle 6: E7
See Principle 6: A4 & A6
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.
See Principle 6: B2
See Principle 6: E
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 comprehendible (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 boats and deeper 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, continuous 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 organims.
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.

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).

C3
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.

C4
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.

C5
Simulations are the implementation of these models over time to test, analyze, and experiment with the representations of these real-world ocean systems.

C3
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.

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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.

C6
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.

C7
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).

C8
HOVs allow scientists to go down to great depths to observe and collect samples. HOVs are compact and dependent on surface-support vessels.

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.

C10
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.

C11
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.

C12
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 boats and deeper water than human divers or ROVs.

C13
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.

C14
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.

C15
Satellites collect and transmit largescale, continuous 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.

C16
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.

C17
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.

C18
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.

C19
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.

C20
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.

C21
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.

C22
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).

Alignment of the Ocean Literacy Framework to the NGSS

Introduction to the *Alignment of Ocean Literacy to the Next Generation Science Standards* (NGSS)

You can't be science literate without being ocean literate. This document provides evidence to prove that statement and tools to achieve it. This innovative and rigorous document aligns Ocean Literacy to the Next Generation Science Standards (NGSS) by detailing why teaching ocean concepts is integral and essential to achieving the vision of NGSS. Intended for teachers, school leaders, informal educators, and curriculum developers, this alignment document provides critical guidance about when and how ocean concepts should be strategically inserted into the K through 12 science curriculum and can be used to influence state, district, and school science implementation plans. The *Alignment of Ocean Literacy to the Next Generation Science Standards* also provides strong justification for educators to provide ocean sciences learning experiences to supplement traditional texts that typically don't adequately address ocean concepts.

The *Alignment of Ocean Literacy to the Next Generation Science Standards* is one part of the Ocean Literacy Framework which includes three other 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*; and
- *International Ocean Literacy Survey*.[1]

This alignment document details the correlations between NGSS, specifically the Disciplinary Core Ideas (DCI) and Performance Expectations (PE), and the concepts included in the other Ocean Literacy Framework documents. It provides coherence across the Ocean Literacy Framework and NGSS, leveraging our community's work and making it more valuable and useful.

This alignment is a necessary tool to focus attention on places in the NGSS where Ocean Literacy is essential to understanding the DCI, but the connection may not be obvious. The alignment documents are organized by grade band and provide a 4-point scale with a description for each rating that describes in detail the relationship between the NGSS at each grade level and each of the seven Ocean Literacy principles. There are many examples of Disciplinary Core Ideas in NGSS that directly match content described in *Ocean Literacy: The Essential Principles of Ocean Sciences for Learners of All Ages* and *The Ocean Literacy Scope and Sequence for Grades K–12* (**see #1 in the rating scale below**). There are also many examples of DCIs that do not explicitly mention the ocean, but cannot be fully understood without addressing the ocean component (**see #2 in the rating scale**).

1 For more information and to access online versions of the Ocean Literacy Framework documents, please visit **www.marine-ed.org/ocean-literacy/overview**

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Rating Scale for Alignment of the Ocean Literacy Framework to Next Generation Science Standards (NGSS)[2]

1 means there is verbatim or nearly verbatim language in the Ocean Literacy Guide, the Scope & Sequence, and the NGSS. This rating is self-explanatory. The connection and alignment should be obvious and not in need of any explanation.

2 means that understanding these Ocean Literacy Principles and/or Fundamental Concepts is essential to helping students to achieve full understanding of the Disciplinary Core Ideas (DCIs) and/or Performance Expectations (PE).

This rating is given for all the DCIs that have a terrestrial bias or ignore the uniqueness of ocean systems, such as: decomposition breaks things down into soil; references to only terrestrial habitats, ecosystems and food webs, etc. This rating says that a learner cannot achieve full understanding of the DCI without understanding the ocean component of the concept, e.g., you don't fully understand primary productivity if you don't understand chemosynthesis; you don't fully understand decomposition if you only understand how it relates to soil, but not to detritus and marine snow in the water column; you don't fully understand food webs and trophic levels unless you understand about microbes in the ocean because they play a very different role than plants do on land. The ocean "examples" are more than just examples; they illustrate different aspects of the concept than the terrestrial examples do.

3 means examples from the Ocean Literacy Guide or Scope & Sequence (not just any ocean examples) are excellent for teaching and understanding these DCIs and/or PEs.

This rating is given when an example from the Ocean Literacy Guide or the Scope & Sequence could be used to explain a general science DCI and/or PE, but using that example to explain that concept is not essential to ocean literacy, nor is it essential to understanding DCI, such as, ocean waves, as mentioned in some OLPs, are good examples of the physical properties of waves.

4 means these DCIs and/or PEs are building blocks or foundational ideas that help students to understand these Ocean Literacy Principles and/or Fundamental Concepts.

This rating is given for general science concepts that help students understand the mechanisms behind OL concepts, such as force and motion helping to explain currents or phase change, and conservation of matter helping to explain the water cycle.

2 The Ocean Literacy-NGSS alignments were developed by the National Marine Educators Association Ocean Literacy Committee. Special acknowledgement goes to the Lawrence Hall of Science at the University of California, Berkeley for leading the development and supporting the final editing and design. The following individuals made significant contributions: Lincoln Bergman (Lawrence Hall of Science), Scott Carley (College of Exploration), Catherine Halversen (Lawrence Hall of Science), Kurt Holland (Seventh Generation Advisors), Beth Jewell (West Springfield High School), Lisa Klofkorn (Lawrence Hall of Science), Diana Payne (Connecticut Sea Grant), Sarah Pedemonte (Lawrence Hall of Science), Sarah Schoedinger (NOAA), Craig Strang (Lawrence Hall of Science), Lynn Tran (Lawrence Hall of Science), Peter Tuddenham (College of Exploration), Emily Weiss (Lawrence Hall of Science), Jim Wharton (Seattle Aquarium), Lynn Whitley (USC Wrigley Institute for Environmental Studies and Sea Grant)

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Examples of a rating of 4:

K-PS2 Motion and Stability: Forces and Interactions.

Ocean Literacy Essential Principle 2: These basic ideas are important conceptual building blocks that help us understand waves, erosion, and landforms of the coast.

1-LS3 Heredity: Inheritance and Variation of Traits.

Ocean Literacy Essential Principle 5: DCI introduces the concept of inheritance and variation and provides an introduction to the concept of diversity described in OLFC 5A & C.

When no rating is given it means there is no substantive or helpful relationship. There is no rating given when no plausible, helpful, or meaningful relationship appears to exist between the OL Principles and/or Fundamental Concepts and the DCIs and/or PEs.

Example:

K-PS2 Motion and Stability: Forces and Interactions

Ocean Literacy Essential Principle 5: No relationship

Now that we have explained the rating scale, let's dive in and explore these alignments in more detail!

NGSS Terminology

PS = Physical Science

ESS = Earth and Space Science

LS = Life Science

ETS = Engineering, Technology, and the Application of Science

SEP = Science and Engineering Practice

CC = Crosscutting Concept

DCI = Disciplinary Core Idea

PE = Performance Expectation

Ocean Literacy Terminology

OLP = Ocean Literacy Essential Principle

OLFC = Ocean Literacy Fundamental Concept

S&S = Scope and Sequence

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GRADES K THROUGH 2

Standards by Disciplinary Core Idea (DCI)	OLP 1	OLP 2	OLP 3	OLP 4	OLP 5	OLP 6	OLP 7	Specific DCI & Performance Expectations (PE)
K-2-ETS1 Engineering Design						3	3	ETS1.A, B, C
K-ESS2 Earth's Systems			4			2		ESS2.D, E; ESS3.C
K-ESS3 Earth and Human Activity				2	2	1	2	ESS3.A, B, C
K-LS1 From Molecules to Organisms: Structures and Processes					3	3		LS1.C
K-PS2 Motion and Stability: Forces and Interactions		3						PS2.B
K-PS3 Energy			4					PS3.B
1-ESS1 Earth's Place in the Universe								
1-LS1 From Molecules to Organisms: Structures and Processes					3			LS1.A, B, C
1-LS3 Heredity: Inheritance and Variation of Traits					4			LS3.A, B
1-PS4 Waves and Their Applications in Technologies for Information Transfer							3	PS4.C
2-ESS1 Earth's Place in the Universe		3						ESS1.C
2-ESS2 Earth's Systems	1	1						ESS2.A, B, C
2-LS2 Ecosystems: Interactions, Energy, and Dynamics					3			LS2.A
2-LS4 Biological Evolution: Unity and Diversity					1			LS4.D
2-PS1 Matter and Its Interactions	3							PS1.A

Explanation for Ratings

K through 2 ETS1 Engineering Design

OLP 6. This is a rating of 3 because people need to be able to design solutions to keep the ocean healthy and utilize ocean resources to improve our lives. Human interconnections with the ocean provide many examples (OLFC 6B, D, G; S&S grades K through 2, C strand) that illustrate and optimize the need for design solutions (DCI ETS1.A, B, C).

OLP 7. This is a rating of 3 because the ocean provides many examples (OLFC 7D, E, F; S&S grades K through 2, B2, B4) of engineering challenges (DCI ETS1.A, B, C) related to ocean exploration and opportunities ahead.

K-ESS2 Earth's Systems

OLP 3. This is a rating of 4 because learners need to understand what weather is and that weather changes (DCI ESS2.D) in order to understand what causes weather (OLFC 3A, D; S&S grades K through 2, A3).

OLP 6. This is a rating of 2 because understanding biogeology and human impacts on Earth systems (DCI ESS2.E, ESS3.C) would be incomplete without inclusion of ways humans impact the ocean. People change the environment, e.g., pollution, physical modifications (OLFC 6D, F; S&S grades K through 2, B, C1, and C3 strands), as they engage in activities to live comfortably. Everyone can make choices to reduce their impact and be responsible for caring for the ocean (OLFC 6G; S&S grades K through 2, C5 strand).

K-ESS3 Earth and Human Activity

OLP 4. This is a rating of 2 because understanding the natural resources living things need (DCI ESS3.A) is not complete without knowing that life as we know it does not exist without water (S&S grades K through 2, A). Almost all the water on Earth is in the ocean (S&S grades K through 2, B), and the ocean provided and continues to provide water, oxygen, and nutrients needed for life to exist on Earth (OLFC 4C).

OLP 5. This is a rating of 2 because understanding the natural resources living things need (DCI ESS3.A) is not complete without considering the ocean as an environment and habitat where organisms live (S&S grades K through 2, B).

OLP 6. This is a rating of 1 because human activities to live comfortably (DCI ESS3.B, C) involve use of resources from the ocean (OLFC 6B, C; S&S grades K through 2, A and B strands), and thus have an impact on the ocean (S&S grades K through 2, C strand). Everyone can make choices to reduce their impact and be responsible for caring for the ocean (OLFC 6G; S&S grades K through 2, C strand).

OLP 7. This is a rating of 2 because understanding that life on Earth depends on the ocean (OLFC 7A; S&S grades K through 2, A) and that people explore the ocean (S&S grades K through 2, B strand) are essential to understanding the natural resources that living things need to survive (DCI ESS3.A). Exploring the ocean helps us understand the health of the ocean and helps us find new medicines, food for humans, and new resources for energy for human activities (S&S grades K through 2, B2).

K-LS1 From Molecules to Organisms: Structures and Processes

OLP 5. This is a rating of 3 because the ocean (OLFC 5B, D; S&S grades K through 2, B2) provides many important examples of the organization for matter and energy flow in organisms (DCI LS1.C).

OLP 6. This is a rating of 3 because recognizing the ocean as a fundamental source of food and water (OLFC 6A, B; S&S grades K through 2, A2 and A3) is a good example of how all animals need food and all plants and algae need water and light to live and grow (DCI LS1.C).

K-PS2 Motion and Stability: Forces and Interactions

OLP 2. This is a rating of 3 because water in motion carries Earth materials from one place to another, especially in the coastal zone, leading to erosion and accretion (OLFC 2C; S&S grades K through 2, A strands). This is an important example of when objects touch or collide they push on one another and can change motion (DCI PS2.B).

K-PS3 Energy

OLP 3. This is a rating of 4 because learners need to understand that sunlight warms Earth's surface (DCI PS3.B) in order to understand the ocean absorbs heat energy from the sun (OLFC 3B).

1-ESS1 Earth's Place in the Universe

No alignment between OL and NGSS.

1-LS1 From Molecules to Organisms: Structures and Processes

OLP 5. This is a rating of 3 because there is a greater diversity of organisms in the ocean than are found on land (OLFC 5A, C, D; S&S grades K through 2, A strand). The variety of different structures and behaviors that marine organisms have to help them survive (S&S grades K through 2, A4) provide unique and important examples for understanding structure and function (DCI LS1.A), growth and development of organisms (DCI LS1.B), and how organisms process information for growth and survival (DCI LS1.C).

1-LS3 Heredity: Inheritance and Variation of Traits

OLP 5. This is a rating of 4 because inheritance of traits and variation of traits (DCI LS3.A, B) are building blocks for understanding the great diversity of organisms in the ocean (OLFC 5A, C; S&S grades K through 2, A strand).

1-PS4 Waves and Their Applications in Technologies for Information Transfer

OLP 7. This is a rating of 3 because existing ocean technology for exploration and communication, including sensors (e.g., side-scan, multi-beam, and lidar) that rely on sound waves for information transfer, are expanding our ability to explore the ocean and provide novel examples of information technologies and instrumentation (DCI PS4.C).

2-ESS1 Earth's Place in the Universe

OLP 2. This is a rating of 3 because the DCI, OLP, and S&S encourage direct examination of evidence to make Earth processes visible. Accretion, erosion, and associated coastline changes (OLFC 2C; S&S grades K through 2, A strands) are important examples for illuminating Earth events and timescales (DCI ESS1.C). Observing or experimenting with currents, waves, erosion, and deposition provide natural starting points for understanding these concepts.

2-ESS2 Earth's Systems

OLP 1. This is a rating of 1 because the OLP (OLFC 1A, E, and G) describe and elaborate the concept that water is found in the ocean, rivers, lakes, and ponds (DCI ESS2.C). In order for students to understand that maps show where things are located and that one can map the shapes and kinds of land and water in any area (DCI ESS2.B), they must understand that the ocean is the defining feature on the planet (OLFC 1A; S&S grades K through 2, B). Geologic features on the ocean floor (plains, valleys, mountains, volcanoes), which are shown on bathymetric maps and are similar to those on land (OLFC 1B; S&S grades K through 2, D strand), provide important and unique examples of the shapes and kinds of land and water in any area (DCI ESS2.B).

OLP 2. This is a rating of 1 because the concept that moving water can change the shape of the land is nearly identical in the DCI (ESS2.A), OLFC 2C, and S&S grades K through 2, A strands).

2-LS2 Ecosystems: Interactions, Energy, and Dynamics

OLP 5. This is a rating of 3 because photosynthetic microbes in the ocean (OLFC 5B) are examples of primary producers that depend on water and light to grow (DCI LS2.A).

2-LS4 Biological Evolution: Unity and Diversity

OLP 5. This is a rating of 1 because the DCI introduces the concept of many different kinds of organisms living in many different places on land and water (DCI LS4.D), which is essentially the concept represented in OLFC 5A through G, and I; and in S&S grades K through 2, A and B strands, related to the diversity of life and ecosystems in the ocean.

2-PS1 Matter and Its Interactions

OLP 1. This is a rating of 3 because understanding the unique structure and properties of seawater (OLFC 1E; S&S grades K through 2, A strand) are important and instructive examples of how matter has different observable structure and properties (DCI PS1.A). The freezing point of seawater (OLFC 1E) is a good example of how the heating or cooling of a substance may cause changes that can be observed (DCI PS1.B).

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3-5-ETS1 Engineering Design						3	3	ETS1.A, B, C
3-ESS2 Earth's Systems			3					ESS2.D
3-ESS3 Earth and Human Activity			3			3		ESS3.B
3-LS1 From Molecules to Organisms: Structures and Processes					1			LS1.B
3-LS2 Ecosystems: Interactions, Energy, and Dynamics					3			LS2.D
3-LS3 Heredity: Inheritance and Variation of Traits				4	3			LS3.A, B
3-LS4 Biological Evolution: Unity and Diversity		3		3	4	1	3	LS4.A, B, C, D
3-PS2 Motion and Stability: Forces and Interactions	3	3						PS2.A, B
4-ESS1 Earth's Place in the Universe	3	2						ESS1.C; PE-ESS1-1
4-ESS2 Earth's Systems	1	1						ESS2.A, B
4-ESS3 Earth and Human Activity			3			3		ESS3.A, B
4-LS1 From Molecules to Organisms: Structures and Processes					2			LS1.A, D
4-PS3 Energy			3					PS3.B
4-PS4 Waves and Their Applications in Technologies for Information Transfer						3	3	PS4.C
5-ESS1 Earth's Place in the Universe								
5-ESS2 Earth's Systems	1	2	2		1			ESS2.A, C
5-ESS3 Earth and Human Activity						1	2	ESS3.C
5-LS1 From Molecules to Organisms: Structures and Processes				2	2			LS1.C; PE 5-LS1-1
5-LS2 Ecosystems: Interactions, Energy, and Dynamics		4			2			LS2.B
5-PS1 Matter and Its Interactions								
5-PS2 Motion and Stability: Forces and Interactions	4				4			PS2.B
5-PS3 Energy					2			PS3.D

Explanation for Ratings

3 through 5 ETS1 Engineering Design

OLP 6. This is a rating of 3 because human development and activity around the ocean (OLFC 6D; S&S grades 3 through 5, A4) provide many examples of design solutions to problems (ETS1.A, B, C) that unintentionally led to other problems such as pollution, changes to ocean chemistry, and physical modifications.

OLP 7. This is a rating of 3 because technologies for exploring the ocean (OLFC 7D; S&S grades 3 through 5, C strand) provide good examples of how possible engineering solutions are developed (ETS1.B, C). Similarly, collaboration among interdisciplinary ocean scientists (OLFC 7F; S&S grades 3 through 5, B strand) is a good example of how communication and sharing of ideas among peers can lead to improved designs (ETS1.B, C).

3-ESS2 Earth's Systems

OLP 3. This is a rating of 3 because the interaction of the ocean and atmosphere (OLFC 3A through D; S&S grades 3 through 5, A1 and A2) controls and regulates most of Earth's weather and climate patterns that are recorded by scientists (DCI ESS2.D). Note: this could be rated as a 2 if the instructor's intent is for learners to understand causes of weather and climate rather than only to observe and record weather and climate.

3-ESS3 Earth and Human Activity

OLP 3. This is a rating of 3 because natural hazards related to the ocean, e.g., hurricanes, cyclones, and El Niño (OLFC 3C, D; S&S grades 3 through 5, A6) are important examples of natural hazards that may impact humans (ESS3.B).

OLP 6. This is a rating of 3 because tsunamis, hurricanes, cyclones, sea level change, and storm surges (OLFC 6F; S&S grades 3 through 5, B4) are important examples of natural hazards that may impact humans (ESS3.B).

3-LS1 From Molecules to Organisms: Structures and Processes

OLP 5. This is a rating of 1 because the DCI (LS1.B), OLFC (5B, D, I) and S&S (grades 3 through 5, B5) all discuss reproduction and unique and diverse life cycles. Understanding life in the ocean is essential to understanding the diversity of life on Earth.

3-LS2 Ecosystems: Interactions, Energy, and Dynamics

OLP 5. This is a rating of 3 because the ocean (OLFC 5D) provides unique examples of animals working in groups to obtain food, defend themselves, and cope with changes (DCI LS2.D). For example, schooling behavior can be readily observed in an aquarium in the classroom.

3-LS3 Heredity: Inheritance and Variation of Traits

OLP 4. This is a rating of 4 because knowing the concepts of inheritance and variation (DCI LS3.A, B) can help learners understand how millions of different species on Earth are related by descent from common ancestors that evolved in the ocean (OLFC 4B).

OLP 5. This is a rating of 3 because the great diversity of major groups of organisms in the ocean (OLFC 5A, C) are compelling and illustrative examples of the concepts of inheritance, variation and diversity (DCI LS3.A, B). The concept that the environment can affect an organism's traits (DCI LS3.A, B) is also related to the concept that physical factors influence the distribution of ocean organisms (OLFC 5F, H).

3-LS4 Biological Evolution: Unity and Diversity

OLP 2. This is a rating of 3 because marine fossils found on land (OLFC 2A; S&S grades 3 through 5, A3, A4) are excellent examples of fossils that provide evidence of the types of organisms that lived long ago and of their environments (DCI LS4.A). Additionally, for learners to understand the evidence provided by land-based marine fossils, it is useful for them to know that sea level changes over time have contracted continental shelves and destroyed inland seas (OLFC 2B).

OLP 4. This is a rating of 3 because learners begin to learn about fossils and the environments indicated by those fossils (DCI LS4.A). The ocean provides many excellent examples for such fossil environment relationships (S&S grades 3 through 5, A, A1) but is not required in order to understand the DCI.

OLP 5. This is a rating of 4 because understanding adaptation, diverse environments, natural selection, and biodiversity (LS4.B, C, D) build and support understanding that ocean ecosystems are defined by environmental factors and the community of organisms living there and that the ocean supports a great diversity of ecosystems and adaptations (OLFC 5F; S&S grades 3 through 5, B1). The DCI concepts generally support understanding of the ideas in the OLP and S&S.

OLP 6. This is a rating of 1 because the DCI (LS4.D), OLP, OLFC (6D), and S&S (grades 3 through 5, C1 through C4) all discuss how changes to a habitat may affect organisms living there.

OLP 7. This is a rating of 3 because the concept that people are not adapted to survive well in an ocean environment (S&S grades 3 through 5, C2, C3, C5, C6) is an excellent example of how some kinds of organisms survive better than others in particular environments (DCI LS4.C).

3-PS2 Motion and Stability: Forces and Interactions

OLP 1. This is a rating of 3 because ocean circulation (OLFC 1C; S&S grades 3 through 5, B, B1 through B10) provides a good example of forces and motion (DCI PS2.A). In later grades one would use an understanding of forces and motion to support deep understanding of ocean circulation.

OLP 2. This is a rating of 3 because forces that cause erosion and change the physical structure of coastal landforms (OLFC 2C, E; S&S grades 3 through 5, B strand) provide good examples of how objects in contact exert forces on one another (DCI PS2.B). Additionally, the concepts that objects can exert force on one another and that an object's motion can be observed and predicted (DCI PS2.A, B), support an understanding of the forces of waves and other forces that contribute to erosion and the formation of landforms (OLFC 2C, E).

4-ESS1 Earth's Place in the Universe

OLP 1. This is a rating of 3 because the presence of marine terraces and other geological marine features (OLFC 1B; S&S grades 3 through 5, C strand) seen on land provide examples of and support an explanation for change over time (DCI ESS1.C; PE-ESS1-1).

OLP 2. This is a rating of 2 because in order to have a complete understanding of how patterns of rock formation reveal changes over time and how fossils can provide indications of the order of the change-causing events (DCI ESS1.C) learners need to understand ocean life laid down sediments, dead ocean organisms falling into those sediments often formed fossils, and marine fossils found on land are evidence that the land was once covered by ocean (OLFC 2A; S&S grades 3 through 5, A2 through A4).

4-ESS2 Earth's Systems

OLP 1. This is a rating of 1 because DCI ESS 2.B, OLFC 1B, and S&S grades 3 through 5, C strand all list geologic seafloor features. Additionally, the OLP and DCI refer to plate movement/movement of Earth's crust as giving rise to many of these features (DCI ESS2.B; OLP 1B). The DCI and OLP also discuss the water cycle/rainfall and how water breaks down and transports materials (DCI ESS2.A; OLFC 1F, G).

OLP 2. This is a rating of 1 because DCI ESS2.A; OLFC 2C, D; and S&S grades 3 through 5, B strand all describe processes of erosion that act to shape the land/coastline. In addition, the idea that living things affect the physical characteristics of their regions (DCI ESS2.E) is directly supported by the concept that ocean life laid down the vast volume of siliceous and carbonate rocks (OLFC 2A; S&S grades 3 through 5, A2).

4-ESS3 Earth and Human Activity

OLP 3. This is a rating of 3 because ocean-related natural hazards, such as hurricanes and cyclones (OLFC 3D; S&S grades 3 through 5, A6), are strong examples of natural hazards humans cannot eliminate but can take steps to reduce their impact (DCI ESS3.B). The OLP and S&S also discuss the underlying causes of these natural hazards (OLFC 3D; S&S grades 3 through 5, A3, A5, A6). The standard does not call for a complete understanding of all natural hazards or their underlying causes. Therefore, it is not essential to understand ocean-related natural hazards to meet the standard, but ocean-related hazards are among the most prominent and dramatic examples.

OLP 6. This is a rating of 3 because the DCI ESS3.B discusses natural hazards and human response to those hazards. There are many ocean-related examples of these hazards as well as information about how humans may be affected because a large proportion of the human population live near the ocean (OLFC 6F; S&S grades 3 through 5, B4). Additionally, energy resources from the ocean (OLFC 6B; S&S grades 3 through 5, A4) provide examples of naturally-derived energy and fuels (DCI ESS3.A).

4-LS1 From Molecules to Organisms: Structures and Processes

OLP 5. This is a rating of 2 because learners' understanding of structure, function, and information processing (DCI LS1.A, D) is not complete unless they are aware of both terrestrial and marine examples (e.g., gills, collapsible lungs for deep diving, fins) since there are many categories of unique organisms that live only in the ocean. Ocean organisms provide many examples of unique life cycles and adaptations (OLFC 5D; S&S grades 3 through 5, B1 through B3, B5). The growth rates and life cycles of ocean microbes (OLFC 5B) are also connected, but not as strongly.

4-PS3 Energy

OLP 3. This is a rating of 3 because wave movement and heat exchange between the ocean and atmosphere (S&S grades 3 through 5, A through A5) are helpful examples of the transfer, transport, and conversion of energy (DCI PS3.B).

4-PS4 Waves and Their Applications in Technologies for Information Transfer

OLP 6. This is a rating of 3 because the ocean research and communications technology necessary for commerce, resource extraction, and resource management (OLFC 6B, D, E, G) would make interesting examples of information technologies and instrumentation (PS4.C) but are not essential to understanding them.

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OLP 7. This is a rating of 3 because examples of "new ocean technologies, sensors, and tools" (OLFC 7D) are dependent on the wave properties of sound and visible light (DCI PS4.C). These real-world examples would add interest for learners but are not essential to understanding the concepts.

5-ESS1 Earth's Place in the Universe

No alignment between OLP and NGSS.

5-ESS2 Earth's Systems

OLP 1. This is a rating of 1 because concepts connected to the role of water in Earth's surface processes (ESS2.C) are directly referenced throughout the OLFC (1A, E, G). Also, the DCI, OLP, and S&S all directly address ocean system concepts (DCI ESS2.A; OLFC 1C; S&S grades 3 through 5, A and B strands).

OLP 2. This is a rating of 2 because many of the concepts related to how the movement of water erodes and deposits material that shape the coastline (S&S grades 3 through 5, B strand) are essential to fully understanding how the ocean shapes landforms (ESS2.A).

OLP 3. This is a rating of 2 because the concepts about how the ocean and atmosphere interact (S&S grades 3 through 5, A and B strands) are essential for understanding how Earth's systems interact (ESS2.A).

OLP 5. This is a rating of 1 because the language regarding ocean ecosystems in the DCI (ESS2.A) is nearly the same as in the OLP (OLFC 5E through G, and I; S&S grades 3 through 5, A strand). The OLP and S&S provide multiple, diverse examples of ocean ecosystems.

5-ESS3 Earth and Human Activity

OLP 6. This is a rating of 1 because the OLP (OLFC 5D, E, G) and specifically the concepts developed in the S&S grades 3 through 5, C strand), provide an overview of how human activity has had and can have major effects on the ocean as identified in the DCI (ESS3.C).

OLP 7. This is a rating of 2 because in order to fully understand how communities use science ideas to protect Earth (DCI ESS3.C), related ocean science ideas must be considered (S&S grades 3 through 5, all strands). Excluding ocean concepts would result in an incomplete and inaccurate understanding of how to protect Earth's resources and environment.

5-LS1 From Molecules to Organisms: Structures and Processes

OLP 4. This is a rating of 2 because the concept that plants acquire material for growth chiefly from the air and water (DCI LS1.C; PE 5-LS1-1) demonstrates a terrestrial bias. The use of additional ocean examples, such as algae or microbes (S&S grades 3 through 5, B1) would address this bias and lead to a more complete understanding of primary productivity.

OLP 5. This is a rating of 2 because the concept that "plants" get what they need to live from air and water (DCI LS1.C) represents a terrestrial bias. An understanding of primary productivity is incomplete without understanding the huge ecological role played by photosynthetic ocean microbes and algae that do not require "air" (OLFC 5B; S&S grades 3 through 5, A6, B8).

5-LS2 Ecosystems: Interactions, Energy, and Dynamics

OLP 2. This is a rating of 4 because learners need to understand chemical cycling (DCI LS2.B) before being able to understand biogeochemical cycling (OLFC 2A). This DCI is a building block for comprehending the concept of chemical cycling that will support discussion of biogeochemical cycling in a later grade.

OLP 5. This is a rating of 2 because a full understanding of food webs (DCI LS2.B) requires examples of species and ecosystems from the ocean which are fundamentally different from those on land. Ocean food webs begin with microbes, not plants (OLFC 5B). There are unique types of energy transfer in the ocean that do not occur on land, including ecosystems that do not depend on light and photosynthesis (OLFC 5D, G; S&S grades 3 through 5, A2, A9).

5-PS1 Matter and Its Interactions

No alignment between OLP and NGSS.

5-PS2 Motion and Stability: Forces and Interactions

OLP 1. This is a rating of 4 because understanding the concept of gravitational force (DCI PS2.B) helps to build an understanding of density-driven currents and tides (S&S grades 3 through 5, B7, B9).

OLP 5. This is a rating of 4 because the focus on Earth's gravitational force (DCI PS2.B) is a building block to understanding tides. This DCI has a tangential but important relationship to the discussion of tide-influenced vertical zonation in intertidal habitats (OLFC 5H).

5-PS3 Energy

OLP 5. This is a rating of 2 because the idea that all ecosystems are driven by the sun's energy and all energy in food comes from the sun (DCI PS3.D) is inaccurate and represents a terrestrial bias. It is essential that learners explicitly understand there are important ecosystems and organisms supported through chemosynthetic processes (OLFC 5D, G).

Alignment of the Ocean Literacy Framework to the NGSS

Standards by Disciplinary Core Idea (DCI)	OLP 1	OLP 2	OLP 3	OLP 4	OLP 5	OLP 6	OLP 7	Specific DCI & Performance Expectations (PE)
MS-ESS1 Earth's Place in the Universe		4						ESS1.C
MS-ESS2 Earth's Systems	1	1	1	3				ESS1.C; ESS2.A, C, D; PE ESS2-4, 2-6
MS-ESS3 Earth and Human Activity			1			1		ESS3.B, C, D
MS-LS1 From Molecules to Organisms: Structures and Processes			1	4	2			LS1.B, C; PS3.D
MS-LS2 Ecosystems: Interactions, Energy, and Dynamics	4	2	4		2	2		LS2.A, B, C; LS4.D
MS-LS3 Heredity: Inheritance and Variation of Traits								
MS-LS4 Biological Evolution: Unity and Diversity				2	4			LS4.A, C
MS-PS1 Matter and Its Interactions		4	4			4		PS1.A, B; PS3A, B
MS-PS2 Motion and Stability: Forces and Interactions	4							PS2.A, B
MS-PS3 Energy	3		3					PS3.A, B, C
MS-PS4 Waves and Their Applications in Technologies for Information Transfer								
MS-ETS1 Engineering Design						3		ETS1.A, B

Explanation for Ratings

MS-ESS1 Earth's Place in the Universe

OLP 2. This is a rating of 4 because understanding geologic timescales as interpreted through rock strata and fossils (DCI ESS1.C) is a fundamental building block to understanding the geologic changes, plate tectonics, and rock cycle ideas (OLFC 2A; S&S grades 6 through 8 A17 through 19, and B strand).

MS-ESS2 Earth's Systems

OLP 1. This is a rating of 1 because the OLP focuses on the global movement of ocean water (OLFC 1C; S&S grades 6 through 8 C1), the water cycle (OLFC 1F; S&S grades 6 through 8 C), and watersheds and coastal ocean (OLFC 1G; S&S grades 6 through 8 C9). These concepts are closely aligned with the roles of water in Earth's (and ocean) processes (DCI ESS2.C), cycling of water through Earth's systems (PE ESS2-4), and patterns of ocean and atmospheric circulation (PE ESS2-6). In addition, tectonic processes (DCI ESS1.C) that move Earth's crust form features of the ocean floor (OLFC 1B; S&S grades 6 through 8 A strand).

OLP 2. This is a rating of 1 because of the strong connections between three DCIs and the OLP. The history of planet Earth (DCI ESS1.C) is strongly connected to how ocean processes and plate tectonics influence the structure of the coast (OLFC 2E; S&S grades 6 through 8 A18, A19). Energy flowing and matter cycling in the planet's systems over various scales have shaped Earth's history (DCI ESS2.A) is strongly connected to Earth's materials and geochemical cycles originating in the ocean (OLFC 2A) and to erosion redistributing sediments

(OLFC 2C). Roles of water in Earth's processes (DCI ESS2.C) is strongly connected to wind, waves, and currents eroding and redistributing earth materials (OLFC 2C) as well as to the formation of landforms through a combination of constructive and destructive forces where the ocean meets the land (S&S grades 6 through 8 A1 through A12).

OLP 3. This is a rating of 1 because of the strong connections between three DCIs and the OLP. The core ideas that Earth's history has been shaped by water (DCI ESS2.C) and by energy flowing and matter cycling (DCI ESS2.A) is strongly aligned to the concepts of the ocean's role in energy, water, and carbon systems (OLFC 3A through C; S&S grades 6 through 8 A1, A2, A4). The concept that the ocean has a significant influence on climate by moving heat, carbon, and water (OLFC 3F; S&S grades 6 through 8 A, A1, A7, A10) is strongly aligned with the ocean absorbing, storing, and moving heat through currents (DCI ESS2.D).

OLP 4. This is a rating of 3 because the concept that oxygen in the atmosphere originally came from organisms in the ocean (OLFC 4A; S&S grades 6 through 8 A strand) is an excellent example for understanding how interactions between energy flowing and matter cycling in the planet's systems over various scales produces chemical and physical changes in Earth's materials and living organisms, which have shaped Earth's history (DCI ESS2.A).

MS-ESS3 Earth and Human Activity

OLP 3. This is a rating of 1 because the effects of human activities on global climate change (DCI ESS3.D) is strongly aligned with the ideas that CO_2 absorbed by the ocean affect the interrelationship between the ocean and atmosphere which can result in changes to the climate (OLFC 3E through G; S&S grades 6 through 8 B, B1) and humans are changing the climate by releasing CO_2 into the atmosphere (S&S grades 6 through 8 B6). In addition, understanding the importance of mapping natural hazards and geologic forces to forecast future events (DCI ESS3.B) requires knowing about ocean weather maps and oceanographic data sets to predict future weather-related natural hazards, including hurricanes, extreme rainfall, droughts, and El Niño (S&S grades 6 through 8 A7, A8, A11, A12).

OLP 6. This is a rating of 1 because the DCI focuses on how human activities have altered the biosphere, damaging natural habitats and causing extinctions (DCI ESS3.C), and the effects of human activities on global climate change (DCI ESS3.D). These ideas are strongly connected to the following concepts: humans affect the ocean in a variety of ways, including impacting biological diversity and causing extinctions; most people live near coasts (OLFC 6D, F); human activity leads to excess input of greenhouse gases; and pollution affects life in the ocean (S&S grades 6 through 8 D13 through 22).

MS-LS1 From Molecules to Organisms: Structures and Processes

OLP 3. This is a rating of 1 because the process of photosynthesis (DCI LS1.C) occurs in the ocean with about half the world's photosynthesis taking place in the sunlit layers of the ocean (S&S grades 6 through 8 B3).

OLP 4. This is a rating of 4 because understanding photosynthesis (DCI LS1.C, PS3.D) serves as a building block to and is an integral part of understanding oxygen in the atmosphere originally came from photosynthetic organisms in the ocean (OLFC 4A; S&S grades 6 through 8 A4 through 6).

OLP 5. This is a rating of 2 because understanding growth and development of organisms (DCI LS1.B) is incomplete without knowing about adaptations for reproduction and growth in ocean organisms

(OLFC 5D; S&S grades 6 through 8 B strand). In addition, to fully understand organization of matter and energy flow in organisms (DCI LS1.C) learners need to understand that there is non-photosynthetic primary productivity in the ocean (OLFC 5G; S&S grades 6 through 8 A5, A6) and microorganisms in the ocean produce a huge amount of oxygen on Earth (OLFC 5B; S&S grades 6 through 8 A2 through A4).

MS-LS2 Ecosystems: Interactions, Energy, and Dynamics

OLP 1. This is a rating of 4 because an understanding that the basic functions of an ecosystem—interdependent relationships (DCI LS2.A), the cycling of matter and energy transfer (DCI LS2.B), and the dynamic nature of ecosystems (DCI LS2.C)—are integral to understanding ocean circulation (OLFC 1C; S&S grades 6 through 8 C strand) and physical and biological systems (OLFC 1E).

OLP 2. This is a rating of 2 because learners would have an incomplete understanding of the cycling of matter and energy through an ecosystem (DCI LS2.B) without learning about biogeochemical cycles in the ocean (OLFC 2A, D; S&S grades 6 through 8 B3).

OLP 3. This is a rating of 4 because cycles of matter and energy transfer in ecosystems (DCI LS2.B) is a building block for understanding the important role of the ocean in the carbon cycle (OLFC 3E; S&S grades 6 through 8 B2, B3). Additionally, an understanding of ecosystem dynamics, functioning, and resilience (DCI LS2.C) is a building block for comprehending how changes in the ocean–atmosphere system can result in changes to the climate and atmosphere (OLFC 3G; S&S grades 6 through 8 B1, B5, B6) with regard to disruptions in ecosystems.

OLP 5. This is a rating of 2 because learners would have an incomplete understanding of interdependent relationships in ecosystems (DCI LS2.A) and the cycling of matter and energy transfer in ecosystems (DCI LS2.B) if they do not understand how the ocean supports a great diversity of life and ecosystems including unique adaptations, behaviors, and ecosystems found only in the ocean (OLP 5; S&S grades 6 through 8 A and B strands).

OLP 6. This is a rating of 2 because to understand how changes in biodiversity can influence resources and ecosystem services (DCI LS4.D) learners must know how humans and the ocean are inextricably interconnected (OLP 6; S&S grades 6 through 8 B strand).

MS-LS3 Heredity: Inheritance and Variation of Traits

No alignment between OLP and NGSS.

MS-LS4 Biological Evolution: Unity and Diversity

OLP 4. This is a rating of 2 because to achieve a full understanding of the evidence of common ancestry and diversity (DCI LS4.A) learners need to learn about the origins of life (OLP 4; S&S grades 6 through 8 B strand).

OLP 5. This is a rating of 4 because an understanding of diversity (DCI LS4.A) and adaptations (DCI LS4.C) would be incomplete without learning about the diversity and unique adaptations of ocean life (OLFC 5D; S&S grades 6 through 8 B strand).

MS-PS1 Matter and Its Interactions

OLP 2. This is a rating of 4 because an understanding that substances react chemically in characteristic ways and that molecular balance is maintained (DCI PS1.B) is necessary to understand chemical weathering of rocks and minerals (S&S grades 6 through 8 A5).

Alignment of the Ocean Literacy Framework to the NGSS

GRADES 6 THROUGH 8

OLP 3. This is a rating of 4 because an understanding of the structure and properties of matter and changes of state (DCI PS1.A) and energy (DCI PS3.A) is needed for: understanding heat exchange, energy, and the water cycle (OLP 3B); condensation and where rain falls (OLFC 3D); and the ocean moves heat, carbon, and water (OLFC 3F, S&S grades 6 through 8 A). Learners must understand energy definitions (DCI PS3.A), heat transfer (DCI PS3.B), and molecular balance (DCI PS1.B) in order to understand how the ocean has such an influence on weather and climate (OLFC 3A, B, F; S&S grades 6 through 8 A strand).

OLP 6. This is a rating of 4 because understanding the structure and properties of matter (DCI PS1.A) and characteristics and results of chemical reactions (DCI PS1.B) are necessary for understanding how human activities can change ocean temperature and pH (S&S grades 6 through 8 D13 through 17) which in turn, can affect the survival of some organisms (OLFC 6E).

MS-PS2 Motion and Stability: Forces and Interactions

OLP 1. This is a rating of 4 because learners need to have a basic understanding of how gravity works (DCI PS2.A, B) to understand tides and density-driven thermohaline circulation (OLFC 1C). However, the information presented on gravity in these DCIs is not fully supportive of an understanding of thermohaline circulation; it is much more closely tied to understanding tides.

MS-PS3 Energy

OLP 1. This is a rating of 3 because thermohaline circulation in the ocean (OLFC 1C; S&S grades 6 through 8 C, C1, C6) provides a helpful example of how energy is transferred out of warmer regions into cooler ones (DCI PS3.B). There is also a connection to understanding that temperature is a measure of the average kinetic energy of particles of matter and that there is a relationship between temperature and the total energy in a system (DCI PS3.A).

OLP 3. This is a rating of 3 because energy transfer from the ocean to the atmosphere (OLFC 3B through D) offers useful examples for understanding energy transfer and related ideas (DCI PS3.A, B, C).

MS-PS4 Waves and their applications

No alignment between OLP and NGSS.

MS-ETS1 Engineering Design

OLP 6. This is a rating of 3 because the development of food, medicines and energy resources (OLFC 6B), engaging in discovery (OLFC 6E), modifying the ocean environment (OLFC 6D), and managing ocean resources (OLFC 6G) are all helpful examples of defining problems and developing engineered solutions (DCI ETS1.A, B).

GRADES 9 THROUGH 12

Alignment of the Ocean Literacy Framework to the NGSS

Standards by Disciplinary Core Idea (DCI)	OLP 1	OLP 2	OLP 3	OLP 4	OLP 5	OLP 6	OLP 7	Specific DCI & Performance Expectations (PE)
HS-ESS1 Earth's Place in the Universe	2	1						ESS1.C; ESS2.B; PE HS-ESS1-5
HS-ESS2 Earth's Systems	1	3	2	2		1		ESS2.A, C, D, E
HS-ESS3 Earth and Human Activity			1			1	2	ESS2.D; ESS3.B; ESS3.C; ESS3.D
HS-LS1 From Molecules to Organisms: Structures and Processes				4				LS1.C
HS-LS2 Ecosystems: Interactions, Energy, and Dynamics	2	1	2	3	2	1	3	LS2.A, B, C; LS4.D; ETS1.B
HS-LS3 Heredity: Inheritance and Variation of Traits								
HS-LS4 Biological Evolution: Unity and Diversity				2	3	1		LS4.A, C, D
HS-PS1 Matter and Its Interactions								
HS-PS2 Motion and Stability: Forces and Interactions	4							PS1A; PS2.A, B
HS-PS3 Energy			3			3		PS3.A, B, C
HS-PS4 Waves and Their Applications in Technologies for Information Transfer	3		4				3	PS4.A, B, C
HS-ETS 1 Engineering Design						3		ETS1.A, B

Explanation for Ratings

HS-ESS1 Earth's Place in the Universe

OLP 1. This is a rating of 2 because in order to completely understand plate tectonics as the unifying theory to explain geologic history (DCI ESS2.B; PE HS-ESS1-5), learners need to understand the lithosphere includes the seafloor and all of its geological features and ocean basins vary in size and shape due to movement of Earth's crust (OLFC 1B; S&S grades 9 through 12, A3 and A4).

OLP 2. This is a rating of 1 because there is alignment between the concepts that tectonic activity influences the physical structure and landforms of the coast (OLFC 2E; S&S grades 9 through 12, A through A4), many sedimentary rocks now exposed on land were formed in the ocean (OLFC 2A), processes associated with plate tectonics move sediments (OLFC 2C), and plate tectonics is the unifying theory that explains the past and current movement of rocks at Earth's surface (DCI ESS2.B; PE HS-ESS1–5).

HS-ESS2 Earth's Systems

OLP 1. This is a rating of 1 because the OLP focuses on the concept that the ocean is the defining feature of the planet (OLFC 1A), the ocean transports energy and matter around Earth (OLFC 1C; S&S grades 9 through 12, C7, C11, C12), and the unique properties of water (OLFC 1E; S&S grades 9 through 12, B strand). These concepts are closely aligned with the abundance of liquid water on Earth and its unique properties being central to the planet's dynamics (DCI ESS2.C).

OLP 2. This is a rating of 3 because the OLP provides important Earth system examples of the core idea that feedbacks between the biosphere and other Earth systems cause the co-evolution of life and Earth's surface (DCI ESS2.E). Examples include biogeochemical cycles and sedimentary rocks found on land originated in the ocean (OLFC 2A) and the ocean is the largest reservoir of rapidly cycling carbon on Earth, which is then used by shell and reef building organisms (OLFC 2D; S&S grades 9 through 12, B strand).

OLP 3. This is a rating of 2 because in order to fully understand the concepts that interactions and feedback effects between Earth's systems cause changes to climate (DCI ESS2.A) and the foundation of the climate system is energy from the sun and interactions with the atmosphere, ocean and land (DCI ESS2.D). Learners must have an understanding of the following concepts: the interaction of oceanic and atmospheric processes controls climate by dominating Earth's energy, water, and carbon systems (OLFC 3A; S&S grades 9 through 12, A and B strands); the ocean moderates climate by absorbing most of the solar radiation reaching Earth, and heat exchange between the ocean and atmosphere drives oceanic and atmospheric circulation (OLFC 3A, B, F; S&S grades 9 through 12, A and B strands); and changes in the ocean–atmosphere system can result in changes to the climate that in turn, cause further changes to the ocean and atmosphere (OLFC 3G; S&S grades 9 through 12, C strand).

OLP 4. This is a rating of 2 because to fully understand the concepts of changes in Earth's atmosphere and feedbacks among Earth's systems (DCI ESS2.D, E), learners must have an understanding of the influence of the ocean on the formation of and changes to Earth's atmosphere and interaction with other systems (OLFC 4A, C; S&S grades 9 through 12, A and B strands).

OLP 6. This is a rating of 1 because concepts addressing changes in the atmosphere due to human activity are described in both the DCI (ESS2.D) and the S&S (D1, D2).

HS-ESS3 Earth and Human Activity

OLP 3. This is a rating of 1 because the core ideas of weather and climate models (DCI ESS2.D) are addressed in the OLP, which also provides additional examples of the ocean's influence on weather and climate (OLFC 3F, G; S&S grades 9 through 12, B1, B2, B5, B6).

OLP 6. This is a rating of 1 because there are strong connections between three DCIs and the OLP. The core idea about natural hazards (DCI ESS3.B) is aligned with ideas about human actions increasing the effects of hurricanes and tsunamis (OLFC 6F; S&S grades 9 through 12, D4 through D6). Ideas about resource availability and their effect on human society (DCI ESS3.C) are aligned with concepts about foods, medicines, and mineral and energy resources from the ocean that humans depend on (OLFC 6B; S&S grades 9 through 12, A strand). Ideas about human impacts and management of Earth systems (DCI ESS3.C) are aligned with concepts on ocean resource management (OLFC 6E; S&S grades 9 through 12, A2, D1, E3 through E5). Concepts about discovering and modeling Earth's systems (ESS3-D) are aligned with making discoveries about the ocean–atmosphere–biosphere interactions and managing human impacts, including climate change (OLFC 6G; S&S grades 9 through 12, D14, D15, E2).

OLP 7. This is a rating of 2 because in order to fully understand the core idea of modeling future climate (DCI ESS2.D) an understanding of ocean exploration and new technologies is needed (OLFC 7D, E; S&S grades 9 through 12, A4, C2 through C5). To fully understand concepts about global climate change (ESS3.D) an understanding of the complexities and limitations of ocean modeling are needed (S&S grades 9 through 12, C3).

HS-LS1 From Molecules to Organisms: Structures and Processes

OLP 4. This is a rating of 4 because to understand oxygen production and the effect of oxygen on life on Earth (OLFC 4A; S&S grades 9 through 12, A strands) learners need to know about the process of photosynthesis as described in the DCI (LS1.C).

HS-LS2 Ecosystems: Interactions, Energy, and Dynamics

OLP 1. This is a rating of 2 because to fully understand cycles of matter and energy transfer in ecosystems and ecosystem dynamics (DCI LS2.B, C) an understanding of how ocean circulation transports (heat) energy and matter and how changes to it affect climate and climate stability are needed (OLFC 1C).

OLP 2. This is a rating of 1 because the concepts that many biogeochemical cycles originate in the ocean (OLFC 2A), the role that rapidly cycling carbon plays in the ocean (OLFC 2D), and the connection of these cycles to the processes of photosynthesis and respiration (S&S grades 9 through 12, B strand) are strongly aligned with the cycles of matter and energy transfer, including photosynthesis, respiration, and the carbon cycle as described in the DCIs (LS2.B).

OLP 3. This is a rating of 2 because to fully understand ecosystem dynamics, functioning, and resilience (DCI LS2.C) an understanding of the ocean's influence on climate change and stability is needed (OLFC 3E through G; S&S grades 9 through 12, B and C strands). Additionally, to fully understand cycles of matter and energy transfer in ecosystems (DCI LS2.B) learners need to understand the ocean's role in the carbon cycle (OLFC 3E; S&S grades 9 through 12, B1 through B8).

OLP 4. This is a rating of 3 because the concept of Earth's changing atmosphere (OLFC 4C; S&S grades 9 through 12, A strand) provides an example of ecosystem dynamics, functioning, and resilience found in the DCI (LS2.C).

OLP 5. This is a rating of 2 because in order to fully understand matter and energy transfer in ecosystems (DCI LS2.B) an understanding of the role microbes play as primary producers in ocean ecosystems (OLFC 5B; S&S grades 9 through 12, A strand) is needed. Understanding the uniqueness and diversity of ocean ecosystems (OLFC 5E, G; S&S grades 9 through 12, B strand) and the diversity of life and adaptations of ocean organisms (OLFC 5C, D, F, H; S&S grades 9 through 12, C strand) are essential to comprehending how ecosystems are defined by environmental factors and the community of organisms living there (DCI LS2.A).

OLP 6. This is a rating of 1 because the idea that human interactions with the ocean and ocean–atmosphere ecosystems may have negative consequences (OLFC 6D, E; S&S grades 9 through 12, D strand) is closely aligned to the concept that complex ecosystem interactions are affected by stability vs. extreme fluctuations and anthropogenic effects such as pollution, overexploitation, and climate change (DCI LS2.C). Also, humans depend on living resources and benefit from biodiversity (DCI LS4.D) which aligns with the concept that humans benefit from the food, medicine, resources, biodiversity, and inspiration provided by the ocean (OLFC 6A through D; S&S grades 9 through 12, A and B strands).

OLP 7. This is a rating of 3 because many examples of different technological advances to explore the ocean are provided, each with strengths and limitations which must be considered (OLFC 7C through E; S&S grades 9 through 12, C strand) when exploring how human activity impacts ecosystems

(DCI LS2.C) and when evaluating solutions (DCI ETS1.B) to sustain biodiversity (DCI LS4.D).

HS-LS4 Biological Evolution: Unity and Diversity

OLP 4. This is a rating of 2 because understanding that the earliest evidence of life is found in the ocean (OLFC 4B; S&S grades 9 through 12, B strand) is essential to fully understanding evidence of common ancestry and diversity as described in the DCI (LS4.A).

OLP 5. This is a rating of 3 because the ocean provides excellent and diverse examples of adaptations as well as environmental conditions and variations (OLFC 5D, G, H; S&S grades 9 through 12, B and C strands) introduced in the DCI (LS4.C) which focuses on the process of adaptation and connections to environmental change.

OLP 6. This is a rating of 1 because the concepts that humans are dependent on natural resources and other benefits provided by biodiversity and on preserving landscapes for recreation and inspiration (DCI LS4.C, D) are strongly aligned with the ocean literacy concepts that although there is a strong interconnection to the environment, humans are having adverse impacts on biodiversity and resources (OLFC 6D, E; S&S grades 9 through 12, A and D strands).

HS-PS1 Matter and Its Interactions

No alignment between OL and NGSS.

HS-PS2 Motion and Stability: Forces and Interactions

OLP 1. This is a rating of 4 because learners need to understand the structure and properties of matter (DCI PS1.A) as well as forces and motion (DCI PS2.A, B) in order to understand thermal expansion and the forces at play in ocean circulation (OLFC 1C, D; S&S grades 9 through 12, C strand).

HS-PS3 Energy

OLP 3. This is a 3 because the ocean literacy concepts provide important Earth system examples of fundamental physical energy principles including definitions of energy (DCI PS3.A), conservation of energy, and energy transfer (DCI PS3.B, C). Examples include absorption of solar radiation by the ocean and the energy exchange between the ocean–atmosphere system, which drives Earth's circulation, moderates climate, and provides the energy for hurricanes (OLFC 3A through D; S&S grades 9 through 12, A, A1, A4 through A8, A13).

OLP 6. This is a rating of 3 because the ocean literacy concepts provide examples of energy resources from the ocean (OLFC 6B; S&S grades 9 through 12, A5) which help to apply fundamental physical energy principles, including definitions of energy (DCI PS3.A; PE HS-PS3-3).

HS-PS4 Waves and Their Applications in Technologies for Information Transfer

OLP 1. This is a rating of 3 because the core ideas about ocean waves, including how waves transfer energy over a long distance but with very little horizontal movement (S&S grades 9 through 12, C15 through 17), provide strong examples and an application of the concept of wave properties (DCI PS4.A).

OLP 3. This is a rating of 4 because in order to understand solar radiation and heat exchange between the ocean and atmosphere (OLFC 3B, C; S&S grades 9 through 12, A and B strands) it is helpful to understand electromagnetic radiation, absorption, and conversion to thermal energy (DCI PS4.B).

OLP 7. This is a rating of 3 because the development and use of information technologies in ocean exploration (OLFC 7D; S&S grades 9 through 12, C strand) are examples of the importance of applying our understanding of waves and their interactions with matter in the use and development of essential tools (DCI PS4.A, C).

HS-ETS1 Engineering Design

OLP 6. This is a rating of 3 because as the human population, climate change, and impact on ocean resources increases (OLFC 6D; S&S grades 9 through 12, A6, D1) achieving environmental sustainability in the ocean depends upon action based on scientific research and exploration (S&S grades 9 through 12, E strand) as well as regulations (S&S grades 9 through 12, E2 through E8, E10). These ocean examples of global challenges may be addressed through engineering (DCI ETS1.A). When evaluating these solutions it is important to take into account social, cultural, and environmental impacts (DCI ETS1.B).

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