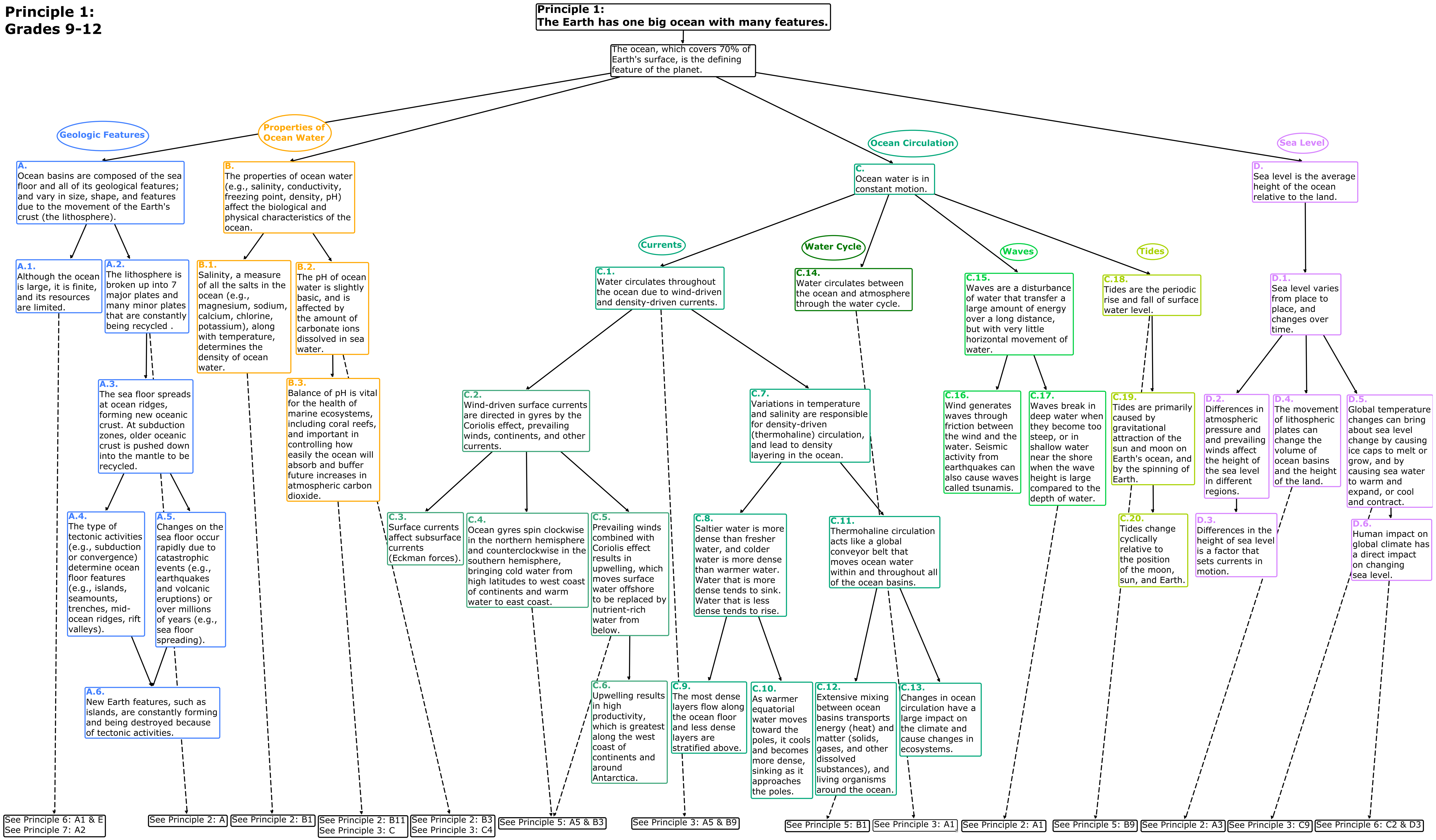
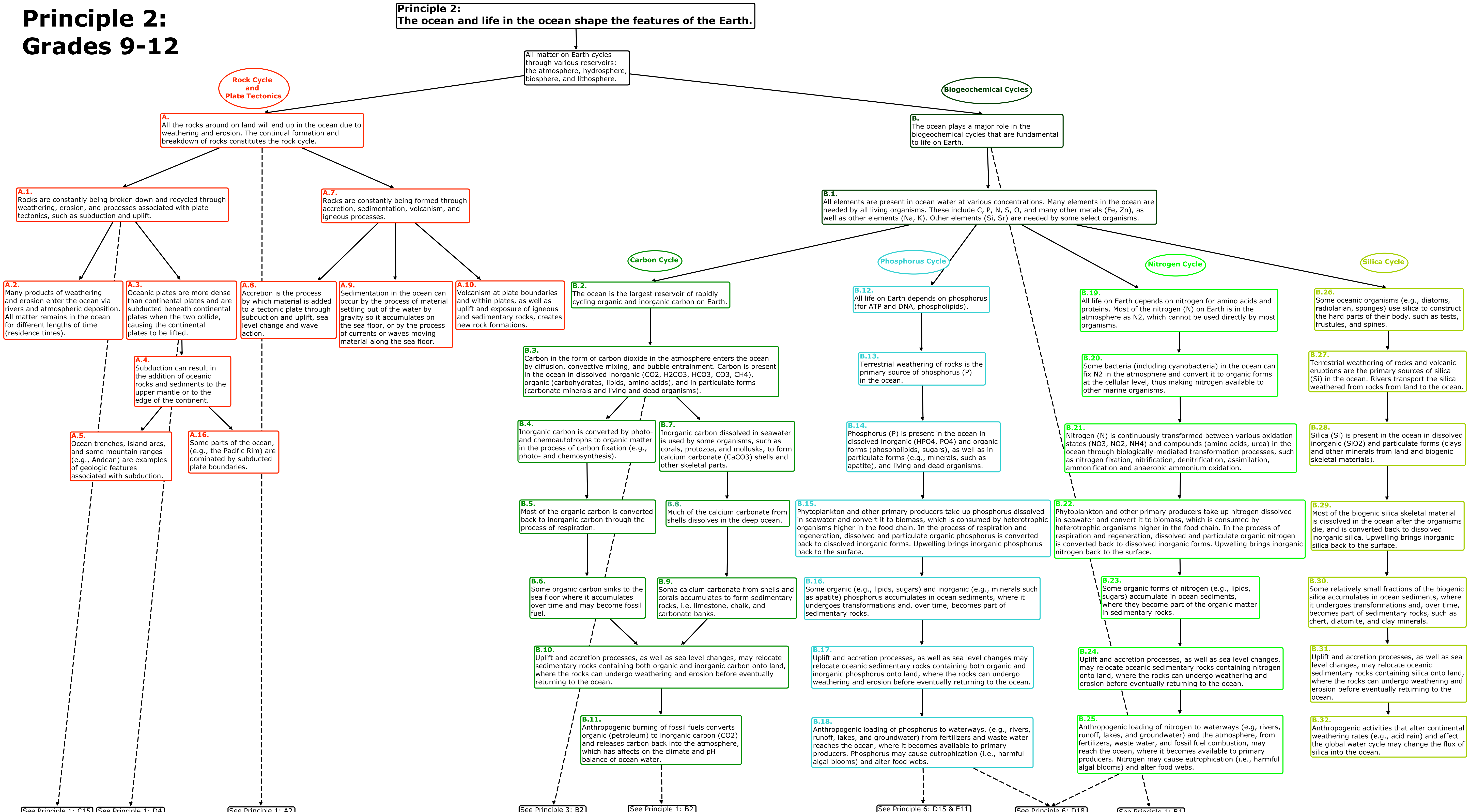
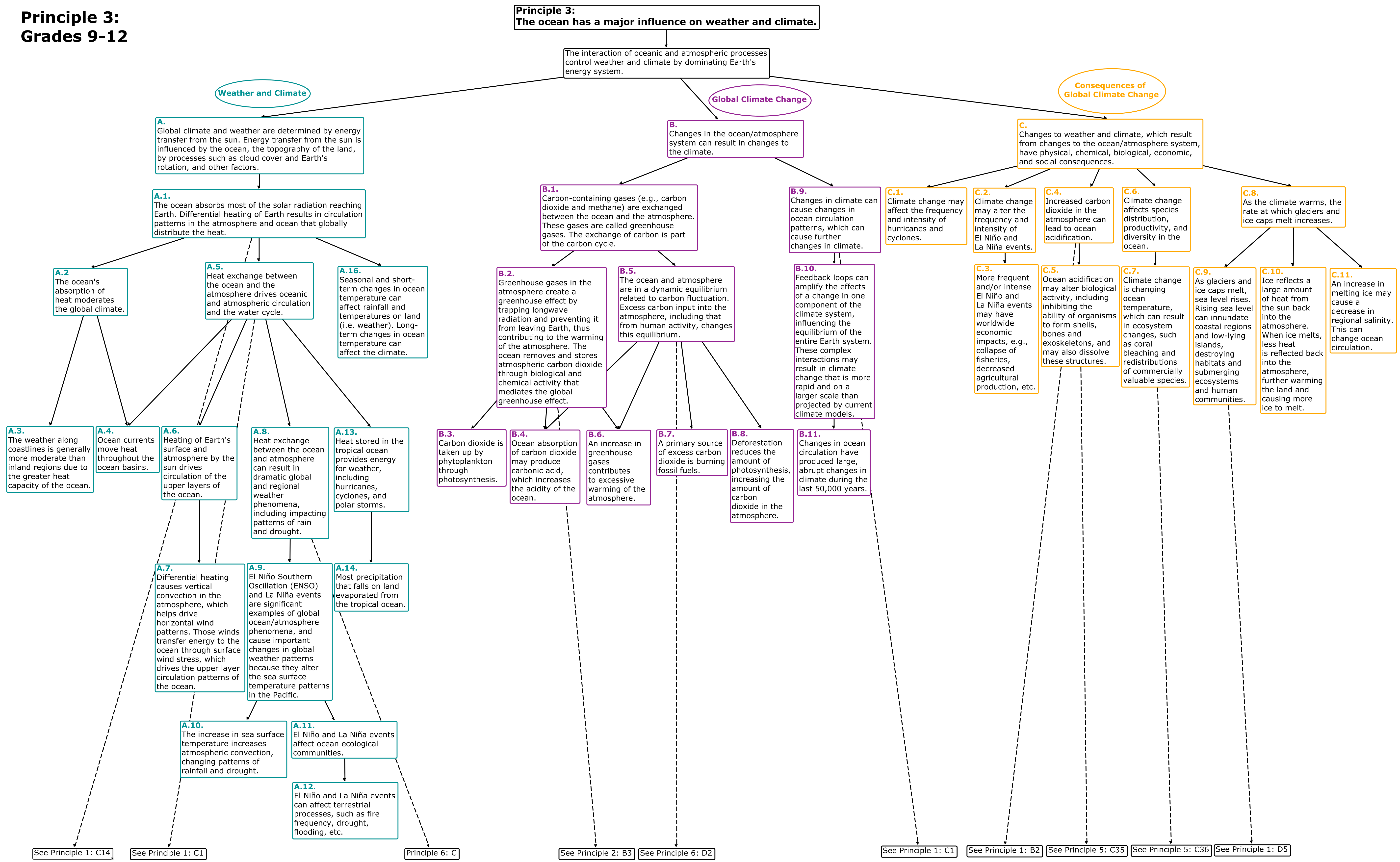
Principle 1: Grades 9-12



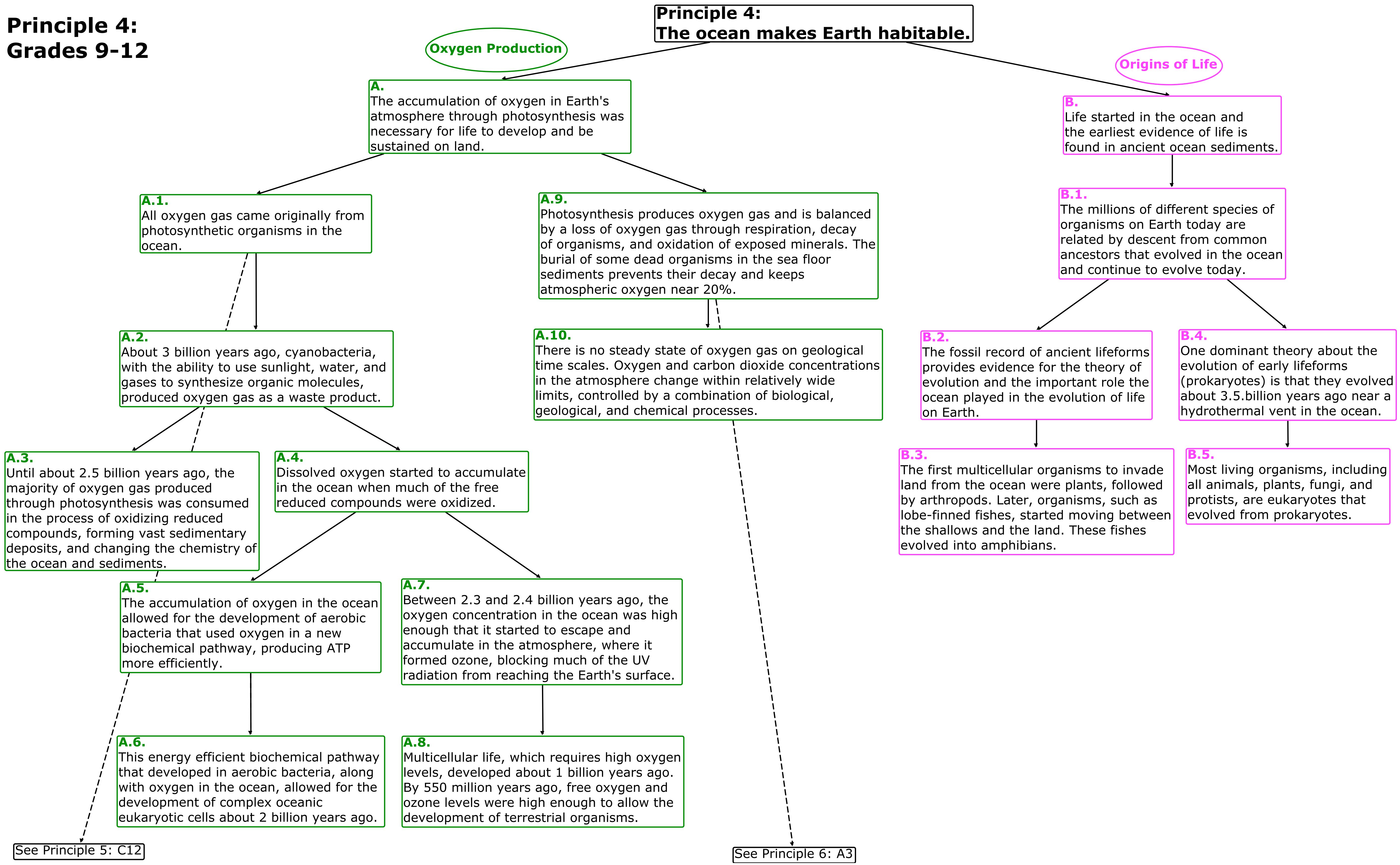
Principle 2: Grades 9-12



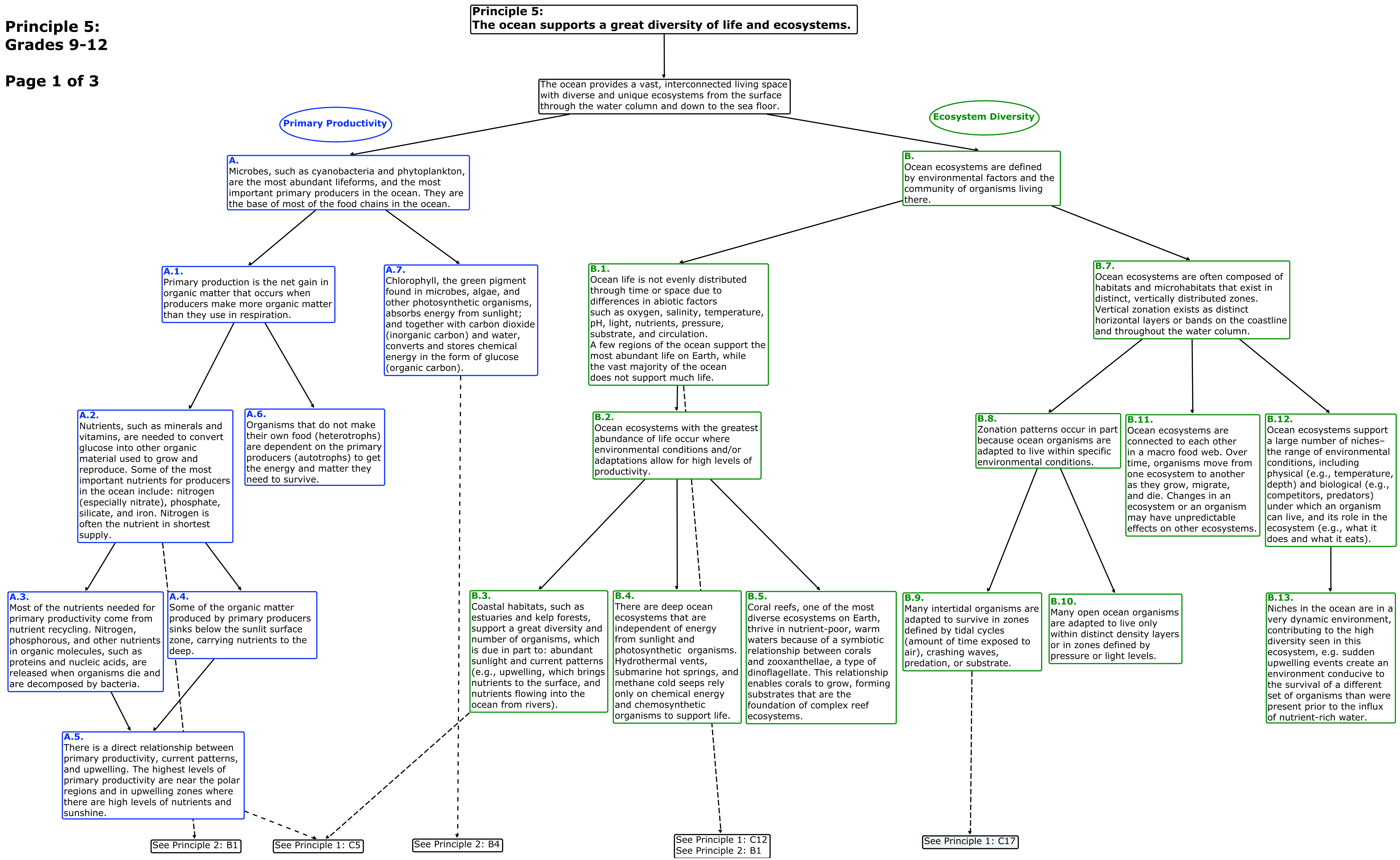
Principle 3: Grades 9-12



Principle 4:
Grades 9-12



Principle 5:
Grades 9-12



Principle 5:
Grades 9-12

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 support animals with much greater mass.
  - **C.21.** The great productivity of particular places in the ocean, such as of upwelling zones and polar regions, can support organisms larger than those that can exist on land.

Diverse Adaptations to Environmental Factors

C.22. Organisms in the ocean exhibit a wide variety of adaptations to survive in a watery environment.

- **C.23.** There are varying levels of light in the ocean. Some ocean organisms have adaptations that allow them to stay near the sunlit surface. These adaptations allow some to photosynthesize (e.g., phytoplankton, kelp) and others to stay near their food source (e.g., zooplankton).
  - **C.24.** Plankton have features, such as oil droplets, spines, cilia, flagella, and/or a large surface area to volume ratio.
- **C.25.** The ocean acts as a filter, and allows different wavelengths of light to penetrate to different depths: red, yellow, and orange wavelengths are filtered out in shallow water; green and blue light penetrate the deepest. The color of some organisms is a feature that allows them to be camouflaged at different depths.
  - **C.26.** Even in relatively shallow water, many red organisms appear gray and are camouflaged.
- **C.27.** Since sound travels through the ocean further and faster than light does, many marine animals, from shrimp to whales, rely on sound to communicate, find prey and mates, and sense their environments.
  - **C.28.** Many large whales use low-frequency sound to communicate across entire ocean basins. Many toothed whales use echolocation to find and/or capture prey. Pistol shrimps use blasts of sound to shock prey.
- **C.29.** Some ocean organisms have adaptations for living in or diving to the deep ocean.
  - **C.30.** Some marine mammals have many adaptations for deep diving, such as breath holding, slowing their heart rate, reducing blood flow to non-vital organs, and increasing oxygen storage. Many organisms use bioluminescence to find or attract prey and mates, and escape predators.
- **C.31.** Marine organisms have adaptations that allow them to osmoregulate in a saltwater environment.
  - **C.32.** The body fluids of many marine organisms, including most fish, are more dilute than the surrounding seawater, so they tend to lose water by osmosis. To compensate, fish drink seawater and excrete salt through their gills and urine. Other organisms change the amount of ions in their body to match the salinity in the environment, (e.g., sharks regulate urea in their blood to match the ocean's salinity).
- **C.33.** Marine organisms are adapted to live within particular ecosystems in a relatively stable ocean where there are only small fluctuations in pH and temperature.
  - **C.34.** Small changes in temperature and pH due to human activities can affect an organisms' 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:
Grades 9-12

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

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

Diversity of Life

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

Diversity of Feeding Behaviors

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

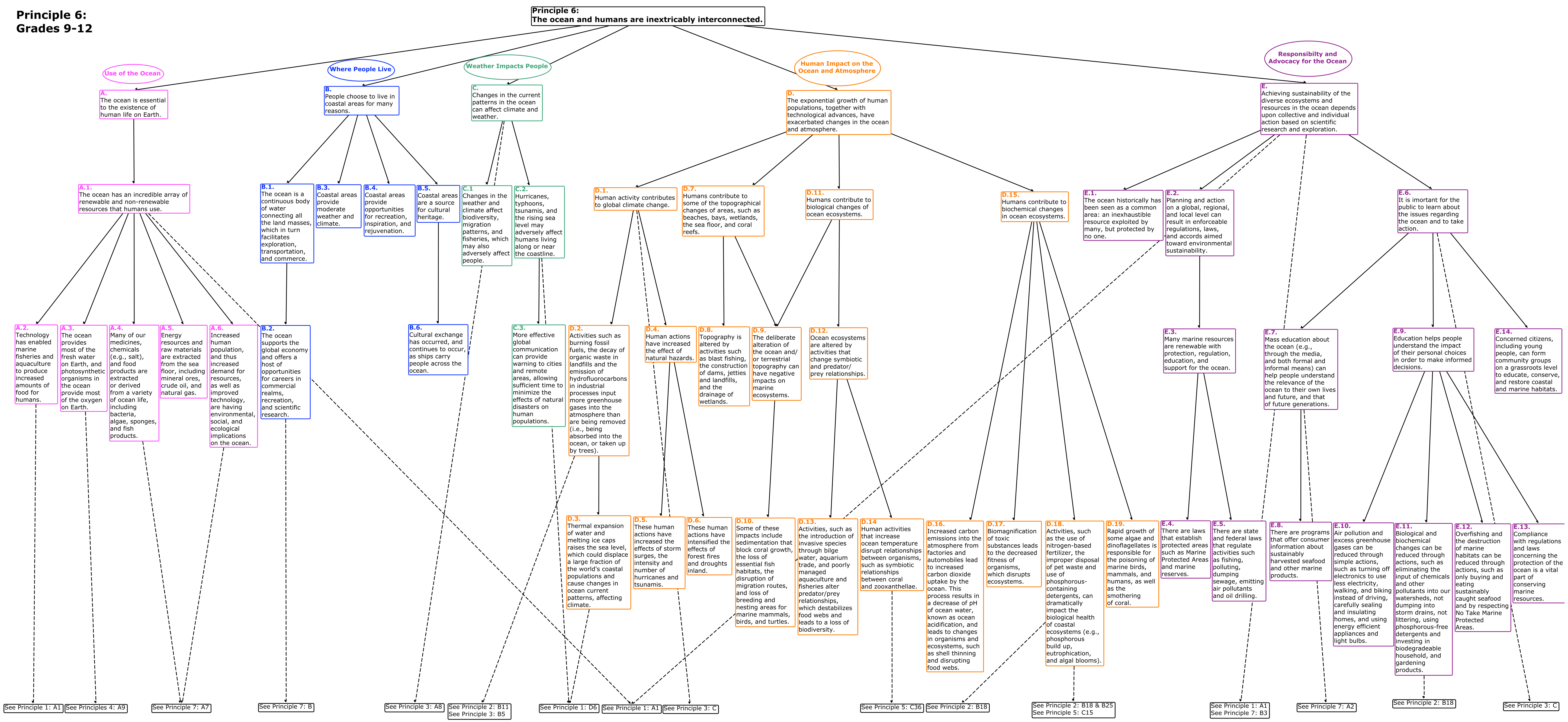
- **C.38.**
  Some marine organisms have strategies and/or structures for finding food in the vast ocean where there is: varied abundance of food in specific locations like in coastal regions and upwelling zones; or scarcity of food in large expanses like the open ocean and deep sea.
  - **C.39.**
 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

Diversity of Life Cycles and Reproductive Strategies

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

- **C.45.**
  Marine organisms have different lifestyles (i.e., planktonic, nektonic, benthic), and many transition between lifestyles as part of their life cycle, which allow them to survive in different ecosystems at different stages in their development. This is advantageous for a variety of reasons, such as: juveniles accessing different resources than adults (e.g., food and space); limiting competition between juveniles and adults; decreased predation rates on, and increased available nutrients for, juveniles.
  - **C.46.**
    Some examples of these changes between lifestyles include: benthic adult crabs in the intertidal with a juvenile planktonic larval form; and sessile adult mollusks with a planktonic larval form.
- **C.47.**
  Marine organisms have a range of life cycles and reproductive modes from simple, asexual reproduction to complex sexual reproduction, and some species shift between asexual and sexual (alternation of generation).
  - **C.48.**
    Some common forms of asexual reproduction among marine organisms include: splitting or fission (e.g., anemones) and budding (e.g., sponges). Organisms that reproduce asexually can have extremely fast growth rates under favorable environmental conditions (e.g., microbes, algae).
  - **C.49.**
    Some marine organisms have alternation of generations, switching between sexual and asexual reproduction each generation (e.g., jellyfish, seaweed). For seaweeds, diploid sporophyte generation produces haploid spores through meiosis, and a haploid gametophyte generation produces haploid gametes. The fertilized gametes produce the sporophyte. In some green and brown algae, the gametophyte and the sporophyte look identical, while in kelps the large organism we see is the sporophyte. The kelp gametophyte is microscopic.
  - **C.50.**
    Sexual reproduction may involve separate males and females; or switching between male and female or vice versa or have both male and female reproductive organs simultaneously (i.e., hermaphroditic). Some hermaphroditic species change sex in response to age, population changes, and shifts in environmental factors (e.g., brittlestars, coral reef fish).
- **C.51.**
  Reproductive strategies of marine organisms tend to be related to population density of the species, and thus are connected to mate competition and chances of finding mates.
  - **C.52.**
    In places with high-population density where there is high mate competition, organisms may change sex (e.g., blue head wrasse) or have multiple mates (e.g., squid). In places with low-population density, organisms may be monogamous (e.g., pelagic species like mahimahi), or develop parasitic relationships (e.g., anglerfish and isopods).
- **C.53.**
  Marine organisms have strategies for finding mates and maximizing fertilization of eggs in the vast ocean.
  - **C.54.**
    These strategies include: using mulitple environmental cues, such as day length, tidal cycles, seasonal variations in current patterns, to synchronize their breeding or spawning cycles (e.g., grunions, elephant seals, and butterfly fish). For species that have external fertilization, females and males produce millions of eggs and sperms (e.g., sea urchins, squids); and for deep sea and pelagic species, producing bioluminescent signals to attract mates (e.g., some pelagic octopuses).
- **C.55.**
  Marine organisms have strategies for maximizing survival and dispersal of offspring that has a range of parental care levels, thus the strategies entail different amounts of energy resources and investments from the parents.
  - **C.56.**
    These strategies include: releasing millions of eggs and sperm into the water (broadcast spawning), which offers no parental care, but increase 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: Grades 9-12



Principle 7: Grades 9-12

Principle 7: The ocean is largely unexplored.

People Explore the Ocean

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

A.5. Data gathered from advanced technology enable scientists to make better estimations and predictions of physical and biological phenomena.

A.6. 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).

A.7. Current exploration of ocean organisms is leading to new discoveries for human health and our interconnectedness to the ocean.

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.

See Principle 1: A1
See Principle 6: E7

See Principle 6: A4 & A6

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.

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.2. 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.3. 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.4. 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.4. The communication of accurate and timely information allows the public to make informed decisions that promote sustainability of the ocean.

B.5. 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

Ocean Exploration Requires Technological Innovations

C. The ocean covers 70% of the Earth, but less than 5% of it has been explored, 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 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.3. 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.4. Simulations are the implementation of these models over time to test, analyze, and experiment with the representations of these real-world ocean systems.

C.5. 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.6. 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.7. 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.8. 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.9. 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. 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 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. 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 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.14. 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.15. 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.16. 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.17. 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.18. 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.19. 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.20. 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.21. 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.22. 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.

C.23. 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).