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

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

Primary Productivity — A

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

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

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

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

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

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

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

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

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Ecosystem Diversity — B

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

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

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

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

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

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

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

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

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

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

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

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

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

Diversity of Life — C

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

Phyletic Diversity — C1

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

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

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

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

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

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

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

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).