Chapter 13 - Primary Production of Life in the Oceans

Primary productivity is the rate at which **energy is converted to organic substances** in a region or **ecosystem**.
• Energy is converted through **autotrophic** ("self-feeding") organisms, converting solar or chemical energy into **biomass**.
• Primary production is **generation of food** by "making organic matter from inorganic matter."
• **Primary process** is **photosynthesis** (in shallow surface waters), and small amount from **chemosynthesis** (at deep sea vents and underground).
• **Solar energy** is the primary source of energy in the production of biomass in the global oceans, with comparatively trace amount coming from chemosynthetic sources.

A **trophic pyramid** exemplifies "**feeding levels within an ecosystem**"

There are three major categories of living organisms in an ecosystem and each has a special role:
• **producers** (plants)
• **consumers** (animals)
• **decomposers** (detritus feeders).

Tropic Levels (feeding levels of organisms) - 4 levels

Tropic Levels	Organisms
Tertiary consumers	carnivores (larger animals, i.e. tuna, sharks, birds, sea mammals, etc.)
Secondary consumers	carnivores and detritus feeders (ie, small fish, crustaceans)
Primary consumers	herbivores (zooplankton)
Primary producers	photosynthetic bacterial - plankton - plants (**focus of this chapter**)

A “**food chain**” is a hierarchical series of organisms each dependent on the next as a source of food.
A “**food web**” is a system of interlocking and interdependent food chains.
Note: "food chains" range from simple to complex! For instance, larvae of some organisms may start as primary consumers but rise to secondary levels as they mature.

The first organisms on the primitive Earth had access to an abundance of the organic compounds in the young oceans and continents. However, most of these original compounds were used up billions of years ago.

Through evolution over time, today, the vast majority of the organic materials required by living cells are produced by photosynthetic organisms, including many types of **photosynthetic bacteria**, **green algae**, and **plants**.

Photosynthesis

Green plants, algae, and some bacteria use sunlight to synthesize foods from carbon dioxide and water. These organisms thrive with sunlight with minimal nutrient requirements. They use water and the energy of sunlight to convert atmospheric CO_2 into organic compounds—a process called **carbon fixation**. A bi-product is oxygen (O_2) released into water, and eventually, the atmosphere**.**

Photosynthesis in plants generally involves the green pigment **chlorophyll** (but also other colors and compounds) and generates oxygen as a byproduct. The process is:

$6 H_2O + 6 CO_2 = C_6H_{12}O_6$ (glucose) + $6O_2$

In the oceans, photosynthesis is completed by **microscopic** and **macroscopic plants**.

Microscopic Plants: Phytoplankton

Phytoplankton means "**floating plants.**" **Over 90% of the worlds food (carbohydrates)** come from phytoplankton. It is the single most important process for life and the production of food on Earth.

Types of phytoplankton include bacteria, protists, and single-celled plants.

Primitive photosynthetic bacterial appear in the fossil record about 3 billion years ago. Their oxygen production is what made life possible for aerobic organisms (particularly animals) to evolve.

Photosynthetic Bacteria

Bacteria are very small in size, and many varieties. Some have evolved to be capable of photosynthesis (called photosynthetic bacteria). They contribute a large amount to primary production in certain parts of the oceans, and may
contribute up to 50% of the world's biomass.

Cyanobacteria (commonly called called blue-green algae) are photosynthetic algae common in marine and freshwater environments. Cyanobacteria contain **chlorophyll** while other forms of bacteria contain **bacteriochlorophyll**. Although bacteriochlorophyll resembles chlorophyll, it absorbs light of a longer wavelength than chlorophyll. Common kinds are cyanobacteria in the marine environment include **golden algae** and **green algae**.

Golden Algae

Golden Algae are characterized by the presence of the pigments chlorophyll, carotene, and xanthophyll, which impart yellow-brown to golden colors**.** Types of Golden Algae in the marine environment include: **diatoms**, **coccoliths**, and **dinoflagellates**.

Diatoms: (from Greek *diatomos* meaning 'cut in two") **Diatoms are the most productive in the oceans**. They have skeletal cell walls (**tests**) composed of silica and thrive mostly cooler waters. Their tests come in a variety of shapes but has a top and bottom that fit together like a shoe box and a single cell in the "box" (**Figure 13-7**). Nutrients and waste are pushed through the test perforations. Diatoms are the chief component of **siliceous ooze** throughout ocean basins. Diatomaceous earth (or diatomite) is a naturally occurring, soft, siliceous sedimentary rock that is easily crumbled into a fine white to off-white powder used in filters and manufacture of glass and ceramic products.

Coccoliths (*coccus*-berry, *lithos*-stone)(also called *coccolithopores*): These produce less than the diatoms. They have a calcareous shell that is made up of a number small individual round plates (**Figure 13-8**). Coccoliths have calcareous tests prefer warmer waters. Coccoliths are the prime component of **calcareous ooze** which becomes the sedimentary rock: chalk.

Dinoflagellates (dino-whirling flagellum-whip) (**Figure 13-9**): These have cellulose tests which are biodegradable (typically not preserved in marine sediments).
They also have a small whip-like tail which provides a small means of locomotion.
These are the critters that produce **red-tides** or **harmful algae blooms (HAB)**.

Green algae (and plants, which share ancestral roots) developed much later, and utilize **chloroplasts**—internal organelles that use “chlorophyll” (photosynthetic compounds) that produce sugars for metabolism. Chloroplasts are thought to have evolved by through symbiosis between primitive (and ancient) cyanobacteria and other eukaryotic cells. For instance, lichens are a combination of a symbiotic algae and a fungus. Mitochondria in cells are also an example of ancient symbiosis of ancient bacteria. Photosynthesis is the mechanism for organisms to first thrive in the oceans, and eventually on land.

Macroscopic Marine Algae ("Seaweeds")

Although in terms of ocean biomass, they are relatively insignificant compared to microscopic planktonic forms, however, they fill important niches is marine ecosystems, often found attached to the seabed offshore or extending up into the intertidal zone.

Brown algae: Occur in temperate or cooler waters.
Kelp and **Sargassum** are examples.
Can be attached to bottom like kelp or encrusting mostly in the intertidal zone.
The Sargasso Sea in the North Atlantic gets its names for large patches of sargassum floating in the open ocean.

Green algae: Mostly attached to bottom.
Sea lettuce, sea grass, and dead mans fingers are examples.

Red algae: These are encrusting or sometimes branching in the near-shore environment. Very hardy.

Marine Plants

Some plants have adapted to transitional marine environments (being salt tolerant). Examples include eel grass, prickleweed, and mangroves.
Eel grass is common in protected lagoons and estuaries.
Pickleweed is abundant here in California covering tidal flats in protected bays and lagoons.
Mangroves are common in tropical regions.

Factors influencing Primary Production

Sunlight and Nutrient Availability

Sunlight penetration decrease with depth; it is impacted by water clarity (**turbidity**).

The **Epipelagic Zone** is also called the **Euphotic Zone** (where sunlight penetrates).
The **euphotic zone** extends downward around 200 meters in the open ocean, but varies with seasonal changes in turbidity. This zone is also called the neritic zone on continental shelves and the epipelagic zone in open ocean settings. The euphotic zone where all photosynthesis takes place. It is also the part of the ocean most likely to have a thermocline is mostly above the **oxygen minimal zone** (OMZ).

Compensation Depth: where respiration (consumption) equals photosynthesis production. The compensation depth is depth at which the light intensity is just sufficient to balance between the amount of oxygen produced and consumed by algae (typically a depth where only 0.1-1% of solar radiation penetrates). The compensation depth varies with latitude, water clarity, and nutrient availability.

Nutrients: These are not like food, they are more like a "fertilizer." Major nutrients in need for biological activity include nitrogen, phosphorus, and silicon, iron, zinc, and copper. Organic compounds including vitamins are also essential. However, some nutrients can become toxic if concentrations become too high.

Sources of nutrients include:
* **Upwelling from deep ocean** (particularly nitrates and phosphates)
* **Rock weathering** (minerals provide iron, silica, and other element)
* **Decaying organic matter** (releases elements and vitamins back into seawater)

Human activities are also creating artificial sources of nutrients: **Agriculture** (fertilizers) and **pollution** (sewers, etc.)

Measuring Primary Productivity

Primary Productivity is measured in biomass or in gC/m^2 day (or grams of carbon per square meter per day).

Ocean biomass is measured by pulling fine nets to catch plankton and weighing/examining catch (however, smallest organisms pass through nets).

Ocean biomass is also measured by **satellite**: 2 dimensions (ie: square meters per day). Satellites can "see" chlorophyll, but not far below the surface.

Global and Seasonal Distribution of Plankton Biomass

Figure 13-22 shows the net productivity of the oceans observed from satellite data. **Figure 13-23** compares ocean productivity to regions on vegetation cover on land. In general, plants on land have access to more concentrated light, but the availability of water and nutrients are a factor of climate and geology. Although tropical forests account for a large volume of biomass, the volume is a fraction of the amount of biomass in the oceans because of the differences in surface area. Productivity in the oceans are influenced by atmospheric and oceanographic factors:

Tropics: Reliable sunlight but the strong tropical thermocline prevents mixing of cold deep nutrient rich water. The warm water on top is too buoyant. The exception to this are coral reef areas.

Temperate: Reliable sunlight and weak thermocline. Most productive zone. In California we get lots of production in the winter as that's when we get upwelling from our coastal winds.

Polar regions: Lots of nutrients little or no thermocline. Sunlight limited only in the few months of summer, but is highly productive.

Examples of Satellite Evaluations of Ocean Productivity

Figure 13-25 is a satellite composite image showing the Gulf of Mexico and East Coast of the United States. Warm water at the surface creates a strong thermocline preventing nutrient upwelling in the open ocean. However, nutrients from rivers and stream are abundant along coastal waters, allowing phytoplankton to proliferate.

Chapter 14 - Marine Environments

This chapter focuses on the physical, chemical, and biological factors affecting marine communities in the oceans and coastal waters.

What is a "Marine Community?"

A marine community is an **area** where a group of marine organisms live and interact with each other.

An "**ecosystem**" is defined as a community involving the **interactions** of living and nonliving things in an **area**." Marine ecosystems have distinct groups of organisms and have characteristics that result from unique combinations of physical factors that create them.
Click on thumbnail images for a larger view.

Marine communities include different feeding (trophic) levels:

Tropic Levels
Organisms
Tertiary consumers
carnivores (larger animals, i.e. tuna, sharks, birds, sea mammals, etc)
Secondary consumers
carnivores and detritus feeders (ie, small fish, crustaceans)
Primary consumers
herbivores (zooplankton)
Primary producers
photosynthetic bacterial - plankton - plants **(focus of chapter 13)**

Definitions

* **Planktonic: "**Floaters/drifters" (zooplankton are animals, phytoplankton are plants.)

* **Nektonic:** "Swimmers"

* **Pelagic**: means "relating to the open sea, chiefly shallow layers" Planktonic and nektonic organisms live in "open water" (more in chapter 14).

* **Benthic:** means "relating to, or occurring at the bottom of a body of water (oceans, lakes), relates to "bottom dwellers" (more in chapter 15).

"Benthic" applies to:
• **shoreline and nearshore environments** (**littoral** and **estuarine**)
• **littoral** (pertaining to the shore and very near shore of ocean or lake)
• **estuarine** (pertaining to transition from river to ocean settings)
• **neritic** (pertaining to the seabed in shallow ocean and deep water settings)
• **limnetic** (pertaining to lakes)

* **Terrestrial** refers to "**land**" environments (desert, mountain, rivers, etc) - some marine predators live in terrestrial environments.

Fig. 14-3. Benthic and pelagic zones.

Fig. 14-4. Elkhorn slough, a tidal estuary in central California, has littoral, estuarine, neritic, and limnetic subenvironments.

Feeding behaviors

* **Autotrophic:** Produce their own food (primary producers)
* **Heterotrophic:** Eat other things (living or dead) (consumers - primary, secondary, and tertiary).

Feeding strategies of heterotrophic marine organisms:

* **Filter feeding:** ex: shellfish
* **Deposit feeding:** Eat deposits of dead or decaying matter
* **Carnivorous feeding:** Capture and eat it!

Fig. 14-5. Humpback whales and birds joining in on a feeding frenzy on smaller fish who were feeding on zooplankton.

Natural factors influencing marine life:

Physical factors:

a) **Temperature** (very significant!)
b) **Salinity** (also very significant!)
c) **Tides, Waves, Currents** (“**energy**" in the environment)
d) **Water Transparency**
e) **Nutrients**
f) **pH** (acidity and alkalinity)
g) **Pressure** (depth)
h) **Dissolved Gases**
i) **Environmental Stability**

Biological factors:

i) **Competition** for mates, food, and space
j) **Predators**

a) Temperature

Temperature governs the rate chemical and metabolic rates especially in cold-blooded organisms. Many organisms are sensitive to changes in temperature and this results in **species zonation.**

Example—Different species of sharks: Sharks can be classified as tropical, temperate, or polar, depending on the surface temperature of the ocean region they inhabit.

Tropical sharks live year round in warm temperature waters (21° - 30° C, 69.8° - 86° F). Examples include nurse shark, the tiger shark, and the bull shark. They are only comfortable in warm waters where food is plentiful, so they remain there year-round without migrating.

Sharks in Temperate regions tolerate temperatures within a range (10°-21°C, 50-69.8° F). Sharks in temperate regions tend to migrate south in the winter and north in the summer and as their food sources move up and down the coast.

Sharks in Polar regions always stay in colder waters (below 5° C, 41° F). For example, Greenland sleeper shark is adapted to living under ice floes and will not migrate.

Temperature controls an organism's metabolism
For poikilothermic ("cold blooded") organisms: every 10° C rise in temperature doubles their metabolism. Most fish, reptiles, and invertebrates are cold blooded.
For homeothermic ("warm blooded") organisms: metabolism increases with decreasing temperature to stay warm. Only mammals and birds are warm blooded.
Some species have various degrees of "**thermo regulation**" - ability to raise or lower their body temperature. An example in fish is Opah an Blue Fin Tuna.

Fig. 14-6. Hammerhead sharks live in tropical waters

Fig. 14-7. Great white sharks live in temperate regions.

Fig. 14-8. Polar bears are homeothermic and adapted to living on arctic ice flows.
b) Salinity

Salinity in the open ocean is typically in a "normal range" of most marine creatures (about 3.5‰ [ppt]). However, salinity is variable near landmasses (ie: tide pools, river outlets and with depth).

Different organisms have different tolerances to salinity changes. For examples, some **bull sharks** can tolerate both freshwater and marine water settings. **Oysters** can't tolerate normal seawater because of predation and food supply.

Fig. 14-9. Bull shark
Fig. 14-10. Oysters
c) Water transparency

Water has a high transparency. So many organisms use different strategies to survive predation.

Countershading or **camouflaging** help organisms hide from predators.
- Animals that display countershading are typically dark colored on top and light colored underneath.
- Animals that use camouflaging typically have skin or scales that match the habitat where they live and feed.

Migration into **darker areas during the day** and **lighter areas at dawn and dusk** is another means of survival.

Another consideration is clarity for photosynthesis.
- **Photic zone**: The upper part of the ocean where sunlight penetrates (down to ~3,300 feet in very clear water!).
- **Euphotic Zone**: upper ½ of photic zone where most primary production occurs.

Fig. 14-11. Trout displaying countershading.

Fig. 14-12. Goosefish displaying camouflaging.

d) Nutrients

Nutrients: are not "food," more like vitamins and minerals essential to life functions

- Aids in the production of food (primary production).
- Photosynthesis formula shows only basic steps.
- There are many more intermediate processes requiring nutrients to produce other complex organic compounds (proteins, carbohydrates, fats, etc).

Sources of Nutrients: Upwelling and continental weathering & erosion
Primary = nitrates and phosphates
Secondary = minerals: calcium, iron, zinc, sodium, and many others.

Fig. 14-13. Upwelling brings nutrients to the surface where they are utilized in **primary production**.

e) pH (acidity and alkalinity)

Seawater averages about 8.1 on a scale from 1 – 14 (1 is acidic, 14 is basic and 7 is neutral).
Seawater is a **buffered system** meaning it is controlled in a range.
If it gets too acidic it dissolves $CaCO_3$, if its too basic it precipitates $CaCO_3$

Seawater becomes slightly more acidic near the **CCD (carbonate compensation depth)**.

Animals with carbonate shells and tests need slightly basic (alkaline) water in order to precipitate and maintain their shells. This is a potentially HUGE problems for the oceans with the increasing accumulation of CO_2 in the atmosphere and oceans.

Fig. 14-14. Carbonate compensation depth (CCD)

f) Pressure

Pressure is the same inside an organism as outside.
Organisms at great depths must be able to withstand great internal pressures.
Many species of fish have gas-filled bladders in order to maintain buoyancy.

Sperm whales hold the deep diving record for cetaceans at 3050m (10,000 ft). They can dive for over one hour in search of their main prey—squid and some fish.

Humans get the bends if they rise to the surface too quickly (causing nitrogen to boil out of the blood). The same happens to deep water fish when they are brought to the surface.

Fig. 14-15. Sperm whales can dive to great depths in search of food.

Fig. 14-16. Nautilus controls pressure in it shell and changes its buoyancy.

g) Dissolved gases

There must be sufficient CO_2 for plants and O_2 for animals or they must: move, adapt or die.
Most ocean pollutants remove the waters ability to hold CO_2 or O_2.

Hypoxia and **eutrophification** are discussed in chapter 8).

Fig. 14-17. Fish killed by hypoxia (lack of O_2).

h) Environmental Stability

The open ocean is generally a very stable environment compared to shallow and nearshore environments where the factors listed above may vary wildly with weather changes and other natural and artificial causes, both physical or biological in nature. Destabilizing forces include the impacts of superstorms, undersea landslides (causing turbidity flows), and hypoxia. Reefs and coastal ecosystems can be destroyed by the effects of hurricanes, but like wildfire on land, sea life can and will re-establish itself if the physical factors (described above) normalize. Coastal communities (ecosystems) can be heavily damaged by superstorms, but many species have evolved means to adapt to occasional events, and even take advantage of the aftermath.

Fig. 14-18. Hurricane Katrina

Biological factors:

i) Competition for mates, food, and space

• competition may be between members of a species or between species

j) Predators

• too many predators can wipe out a community; not enough predators cause population explosions, resource exhaustion, and collapse.

Fig. 14-19. Predator and prey (seal with fish meal).

Seasonal Impacts of Food Resources in the Marine Environment

Primary productivity is a primarily function of sunlight an available nutrients. **Figure 14-20** shows the primary productivity of the three zones: tropical, temperate, and polar.

Primary productivity in the **tropical zone** is limited not by sunlight it receives, but because a thick thermocline prevents nutrients from moving up in to the surface in the photic zone.

Primary productivity in the **polar zones** are most intense in the summer months when both sunlight and nutrients are available.

Primary productivity in the **temperate zones** have two peaks in the spring and fall. Productivity is limited in the summer months because a thermocline builds up, shutting down the nutrient supply to the upper ocean. Primary productivity increases in the spring when sunlight increases and before a strong thermocline shuts down the supply of nutrients. Productivity also increases in the fall when cooler weather breaks up the thermocline (allowing upwelling of nutrients) while ample sunlight is still available to support phytoplankton growth.

Impacts on Consumers

Primary, **secondary**, and **tertiary consumers** follow the the cycles of primary productivity described above. A proliferation of **zooplankton (primary consumers)** occurs when their food (phytoplankton) becomes increasingly available. Zooplankton populations grow at the ultimate expense of the phytoplankton, and their populations peak, phytoplankton first, then zooplankton next. Secondary and tertiary consumer populations consume the recourses, and then migrate to search of other sources of food, following the "blooms" in productivity northward in the spring and then returning south for the winter.

Figure 14-21 compares the **biomass** of phytoplankton and zooplankton for the tropical, temperate, and polar zones through the months of year. **Figure 14-22** compares the availability of nutrients and sunlight with biomass of phytoplankton and zooplankton for the temperate zone through seasons of the year.

Fig. 14-20. Primary productivity in 3 zones.

Fig. 14-21. Plankton biomass by season in three zones.

Fig. 14-22. Temperate zone productivity by seasons.

Divisions in the Marine Environment

The Pelagic (open sea) environment is divided into the **Neritic** (neritos-of the coast) and **Oceanic Provinces**.

Neritic (nearshore zone): Extends from shore with water less than 200 meters. It is subdivided into two zones:
* **Littoral (intertidal) zone**: Interval between high and low tides
* **Sub-littoral zone:** Below the littoral zone to a depth of 200 meters.

Fig. 14-23. Coral reef in the neritic zone.

Oceanic Provinces (based on depth)

* **Epipelagic:** Water less than 200 meters
* **Mesopelagic:** Water between 200 and 1000meters
* **Bathypelagic:** Water between 1000 and 4000meters
* **Abyssopelagic**: Water deeper than 4000 meters
* **Hadal:** Depths below 6000 meters in deep sea trenches

Fig. 14-24. Depth zones

Sunlight penetration has its own divisions (**Figure 14-25**):
* **Photic zone:** The upper part of the ocean where sunlight penetrates
* **Euphotic Zone:** upper ½ of photic zone (usually to about 100 meters)
* **Dysphotic Zone**: lower ½ of photic zone
* **Aphotic Zone**: No light penetrates

Fig. 14-25. Photic Zones

Zoning and Extinction in Marine Communities

Both **physical and biological factors** result in **zoning** of organisms in a specific environment.

Each group of organisms are affected by **physica**l and **biological factors** (listed above). These conditions exist within geographically definable areas ranging from large (entire oceans) to microenvironments (such as a rock outcrop on a beach).

Extinction results when all members of a species dies off. Die offs happen when a local community is disrupted by changes in physical and biological factors. A species will survive when those factors return to tolerable conditions, and a nearby population can supply offspring to repopulate a location. With climate change, many areas are loosing species, causing local extinctions. Another factor is the introduction of non-native species that either out-compete native species, or modify the environment that make a habitat intolerable for survival of native species.

Fig. 14-26. A lone rock on a beach is an example of a microenvironment.

Carrying Capacity in Marine Communities

Carrying capacity is the stable number of individuals in a community. Carrying capacity has limiting factors including living space, food availability, and the physical and biological factors (previously discussed). For example prey and predator populations have limits within a geographic area.

Example: Raise the temp 10 degrees C for a group of **poikilothermic** organisms with a limiting factor of food and hold other factors constant -- what is the most likely result?
Same problem but with **homeothermic** organisms?

Changes in in physical and biological factors **create opportunity** and **misfortune/bad luck**, operating under **natural selection** (**Adapt, move, or die!**)

Local die-offs happen frequently; when **all viable reproducing members** of a "species" or "biological organization" die off it is **extinction**.

Global environmental changes and irresponsible exploitation are current driving forces of extinction.

Fig. 14-27. Lionfish, native to the tropical Pacific, were introduced the Caribbean. These toxic beasts have no predators to control their population, and they are wiping out population of native species.
Distribution of Organisms - how are they distributed throughout an environmental setting?

i. **Random**: rare in marine environment
ii. **Uniform**: more common than random. Examples: eels in holes or penguins on nests
iii. **Clustered**: most common **schooling fish**. Examples clusters of barnacles and mussels on rocks.
iv. **Zoned**: species or community of species living together in a limited geographic range defined by physical and biological factors. Examples: oyster reef along an estuary with a limiting range in salinity.

Most organisms in marine environment are **ZONED** or **CLUSTERED**.

Fig. 14-28. School of unicorn fish on a Hawaiian reef.
Symbiotic Relationships

* **Mutualism**: benefits both host and symbiant.
Example: Anemone and the anemone fish; fish cleans and feeds anemone,
stays with anemone for protection – fish can't be stung (clown fish) (**Figure 14-29**)

* **Commensalisms**: no effect on host, benefits symbiant.
Example: Shark and pilot fish (pilot fish eats leftovers). Or barnacles attached to a humpback whale (**Figure 14-30**).

* **Parasitism:** Harms host, benefits symbiant.

Examples: Parasites in tuna. Humans catching and eating tuna (with parasites).

Fig. 14-29. Clown fish living in a mutual relationship with a sea anemone.
Fig. 14-30. Barnacles attached to a humpback whale.

Evolution in Marine Environments

Physical, chemical, and biological factors drive evolution in marine communities in the oceans and coastal waters. The life mission of any species is to "eat, survive, and reproduce." Every species is adapted to a limited range of physical, chemical, and biologic factors. When the conditions of the physical environment are ideal, a species, or community of species, can thrive and expand. However, if environmental changes occur that affect the range of factors they can tolerate, populations will decline from such factors of loss of body mass, reduced reproduction, diseases, and attrition from competition. Collapses in populations result in isolation of groups of individuals. These isolated groups, if they don't go extinct, become the nucleus of a subsequent population that may evolve into a new species over time, perhaps better adapted to expand their populations when environmental conditions become favorable. The ability to move or migrate in search of more favorable conditions is an important factor.

Fig. 14-31. How evolution works.

Human consumption and interactions are the most influential driving force affecting species evolution and extinction in the world today. Humans have been extremely successful in their ability to adapt to new environments and to "eat, survive, and reproduce." Humans have essentially eliminated many "threats" (physical and biological) that have allowed the global human population to rise (through advances in agriculture, medicine, housing, transportation, technology, etc.). However, these "eliminations" have resulted in new threats. It took all of human history until about the year 1804 to reach a population of 1 billion. The next billion was added around 1927. Since then the global population is doubling with each generation. The amount of material and space consumed by humans have also been roughly doubling with each generation. The problem is that Earth has limited resources.

What is the carrying capacity for Humans on Earth?

Every human has an impact related to both environmental changes and to competition (with other humans and with other species). The effects of unmitigated human consumption of land and natural resources, and the introduction of invasive species by growing human populations are becoming increasingly obvious around the world. Can "we" collectively adapt? What role do we have as individuals in facing global environmental problems? What are the roles of government, corporate, and societal organizations? What defines "success" and "failure?" Can we move beyond "survival of the fittest?"

Chapter 15 - Animals in the Pelagic Environment

This chapter focuses on "higher-level" organisms in the marine environment, specifically vertebrates, all of which are "pelagic" animals that can swim (or fly) in the open ocean or coastal marine environments. The next chapter 16 focuses on "invertebrates" - most of which are either attached or live on or with the seabed (the benthic environment).

General classifications of Living Things

Taxonomy is the system of classifying and naming organisms.
Carolus Linnaeus was first to development of a hierarchical system of classification of nature (biological organism, present and past) .

Today, this system includes seven **taxa: kingdom, phylum, class, order, family, genus, and species**. (These are constantly being split into additional taxa levels as discoveries are made. Look at the example of humans.

Taxa
Example: Taxonomy of Humans

kingdom

kingdom: Animalia

phylum

phylum: Chordata
(subphylum: **vertebrata**)

class

class: Mammalia
(subclass: Theria)
(Infraclass: Eutheria)

order

order: Primates
(suborder: Anthropoidea)

family

(superfamily: Hominidae)
family: Hominidae

genus

Homo

species
sapiens

Click on thumbnail images for a larger view.

Fig. 15-1. Bioscientists are constantly reclassifying life forms as discoveries and new information becomes available. "**Domain**" has been added to apply to "**super kingdoms**" subdivision status based largely on modern discoveries in microbiology - still under debate!This figure shows one of the more complex diagrams showing all the current know domains and lineages of life forms on Earth.

Kingdoms of Life

KINGDOMS
Examples
Monera
Bacteria/algae (more complex classification of monera is illustrated in **Figure 15-1**)
Protista
Forams/amoebas
Fungi
Mushrooms, molds
Plantea
Ferns, mosses, flowering plants (all are **Autotrophs**, **photosynthetic)**
Animalia
includes I**nvertebrates**, **Vertebrates** (all are **Heterotrophs**)

Vertebrates

Vertebrates are a large group of animals distinguished by the possession of a backbone or spinal column. They belong in the taxa:

Kingdom
Animalia

Phylum
Chordates

Subphylum
Vertebrata

Fig. 15-2. This Wyoming fish fossil displays a well preserved backbone (spinal column), common to all vertebrates.

Classes in Vertabrata in the Marine Environment

CLASS	Examples
Mammalia	Whales, seals, sea lions, otters, polar bears (mammals)
Amphibia	Frogs, salamanders (amphibians are rare in marine environments but a few species exist in "near marine" settings)
Reptilia	Snakes, turtles, lizards (crocodillians, iguanas)
Aves	Birds
Osteichthyes	Fish with bony skeletons
Chondrichthyes	Fish with cartilage skeletons- sharks (very old fish with cartilage, some are up to 280 million years old)

Example of the taxonomy of "whales"

Taxa	**Example: Taxonomy of Whales**
kingdom	**kingdom: Animalia**
phylum	**phylum: Chordata** (subphylum: **vertebrata**)

class

class: Mammalia

order

order: Cetacea

family

Mysteceti (mustache whales)
Odontoceti (toothed whales)
Archeoceti (ancient whales - now extinct)

genus

one or several genus within families

species
one or more species within a genus

Characteristics of All Marine Mammals

- **Land-dwelling ancestors**

- **Warm-blooded**

- **Breathe air**

- **Hair/fur**

• Bear live young

• Mammary glands for milk

Fig. 15-3. Are humans marine vertebrates?
Taxonomy of marine vertebrates include:

ORDER
Carnivora

(**have prominent canine teeth**)

FAMILY
Mustelidea
• **Sea otters**
Among the smallest of marine mammals, range: North Pacific, largest member of the "weasel" family. Each carries a "pebble tool" to break open shells.

FAMILY
Ursus
• Polar bears
Live in the arctic circle, primary diet of seals, lives on ice, snow, open ocean.

FAMILY
Pinnipeds

GENUS
• Walruses
Range is in the Arctic and subarctic in Northern Hemisphere on continental shelves. Large tusks and whiskers used for foraging for bivalves on seabed.

GENUS
• Seals
Fin-footed ("flippers"), semi-aquatic marine mammals, 33 extant species worldwide.

GENUS
• Sea lions
Sea lion have external ear flaps, long fore flippers, the ability to walk on all fours, and are voracious eaters. Six species worldwide, except N. Atlantic.

GENUS
• Fur seals

Similar to sea lions (smaller), 1 species in North Pacific, 7 species in S. Hemisphere; have external ear flaps, long fore flippers, ability to walk on all fours.

Examples of Marine Carnivores

Fig. 15-4. Sea otter
Fig. 15-5. Polar bears
Fig. 15-6. Walrus
Fig. 15-7. Walruses on ice.

Fig. 15-8. Monk seal
Fig. 15-9. Steller sea lion
Fig. 15-10. Steller sea lion colony
Fig. 15-11. Fur seals

ORDER
Sirenia

(Aquatic herbivores living in coastal areas)

FAMILY
• Manatees (tropical Atlantic Ocean)

FAMILY
• Dugongs (Indian and western Pacific Oceans)

Examples of Sirenia

Fig. 15-12. Manatees
Fig. 15-13. Dugong

ORDER
Cetacea
Cetaceans have elongated skull with **blowholes** on top, use **echolocation**: they emit " clicks" and get return, used to detect fish, can be used to stun fish)
(Large brains relative to body size; can communicate with each other, “trainable”)
SUB ORDER
Odontocetes

Toothed whales:

FAMILY
• dolphins (*Delphinidae*) - seven genera with about 40 species, worldwide

FAMILY
• porpoises (Phocoenidae) - compared with dolphins, porpoises have shorter beaks and flattened, spade-shaped teeth

FAMILY
• killer whales (technically a subfamily of dolphins, called "blackfish" or "orcas"- 6 species)

FAMILY
• beaked whales (have prominent "noses" - 22 species)

FAMILY
• Sperm whales - largest of the toothed whales, 3 species, (use echolocation to hunt giant squid)

SUBORDER
Mysticeti

• baleen whales (baleen - fibrous plates in whale mouths used to sieve prey items**)**

FAMILY
Right whales (Balaenidae): 4 species, northern oceans, mostly North Atlantic

FAMILY (1species)
Rorquals whales (9 species, worldwide), includes:
* **Blue whale** - largest of all mammal species - up to 30 m (98 ft), 180 tons

FAMILY
Humpback whales (1 species) - found in all oceans

FAMILY
Gray whales (1 species) - coastal waters of Northern Pacific only

Examples of Cetaceans

Fig. 15-14. Dolphin

Fig. 15-15. Porpoises
Fig. 15-16. Killer whale
Fig. 15-17. Narwhales

Fig. 15-18. Sperm whale
Fig. 15-19. Blue whale
Fig. 15-20. Humpback whale
Fig. 15-21. Atlantic right whale (baleen showing)

Migration of Gray Whales on the West Coast

Gray whales are probably the most commonly sighted whales in the coastal waters of California. Gray whales have the longest migration of any mammal species, about 10,000 miles every year.

Gray Whales have a routine. They spend the winter months (December to April) in their "birthing and mating grounds" the shallow bays and lagoons in and around the southern Baja California and southern Gulf of California.

Gray Whales begin their northward migration in late February to May along the coastline, following the spring blooms of phytoplankton and zooplankton. They are frequently seen moving in small groups (pods) several hundred yards beyond the breaker zones to about 4 kilometers (2.5 miles) from shore. Their destination is the rich summer feeding grounds along coastal Alaska and the Bering Sea, a distance of about 5,000-7,000 miles. Adult males and juveniles arrive in northern waters in June; females and young offspring leave and arrive a little later. They spend the summer (June to October) feasting. The first to head south are the pregnant females, followed by the others, some of whom don't make it as far south as Mexico if food resources are available farther north.

Fig. 15-24. Migration pattern of gray whales along the West Coast of North America.
Fig. 15-22. Gray whale

Fig. 15-23. Temperate zone productivity by seasons.
Marine Reptiles

Compared with the number of reptiles groups and species on Earth, relatively few are adapted to "marine" environments. The earliest marine reptiles appear in the Permian Period. Many groups emerged in the Mesozoic Era including more familiar varieties including **ichthyosaurs**, **plesiosaurs**, and **mosasaurs**. Many varieties of the Mesozoic Era vanish at the K/T Boundary extinction.
CLASS
Reptilians

ORDER
Crocodiles

ORDER
Lizards

ORDER
Sea Turtles

ORDER
Sea Snakes
Crocodiles

There are 23 living crocodilian species in both terrestrial aquatic and coastal marine environments. Crocodilians are found in the tropical to subtropical regions on all continents (not Antarctica); they're found in over 90 countries and islands. They are unable to survive and reproduce successfully in cold climates.
What's the difference between an alligator and a crocodile?
American Alligator

American Crocodile

Habit: feisty
Habit: more feisty, but shy and reclusive
Habitat: freshwater to brackish water
Habitat: brackish to salt water
Color: gray to black
Color: greenish gray
Encounters with humans: common
Encounters with humans: not so common
Diet: most everything, fish, birds, pets
Diet: mostly fish
Maximum size: `12 feet
Maximum size: ~13 feet
Characteristics: Alligators snout is blunt and shovel like (used like a shovel too)
Characteristics: Crocodile snout is pointed with more teeth sticking out (better for catching fish)
Range in US: Gulf & Atlantic coasts (TX to SC)
Range in US: South Florida only
Example: Figure 15-25
Example: Figure 15-26

Fig. 15-25. Alligator

Fig. 15-26. Crocodile
Marine Lizards

The only marine lizard is the **Galápagos marine iguana** (Amblyrhynchus cristatus)—found only on the Galápagos Islands. This iguana lives along rocky island shorelines and can dive over 9 m (30 ft) into the water to forage for its main diet of red and green algae (**Figure 15-27**).

Fig. 15-27. Galápagos marine iguana
Extinct Large Marine Reptiles

Aquatic reptiles first noted from the Permian Period. There were many varieties of large marine reptiles during the Mesozoic Era. All vanished at the end of the Cretaceous Period (about 65 million years ago).

Ichthyosaurs: Triassic to Late Cretaceous

Plesiosaurs: Early Jurassic - Late Cretaceous

Mosasaurs: Late Cretaceous

The ancient marine reptiles illustrated convergent evolution - they had terrestrial ancestors like dolphins and whales.

Fig. 15-28. A fossil itchyosaur from Berlin-Itchyosaur State Park, Nevada

Sea Turtles

There are seven species of sea turtles worldwide. Sea turtles sea turtles can be found in all oceans except for the polar regions, along the continents shelves and islands. They are known to nest in more than 80 countries. Sea turtles first appear in the geologic record in early Cretaceous time (land "proto-turtles" appeared in Permian time).

Unlike land turtles, sea turtles are unable to pull their heads or appendages into their shells. Sea turtle shells are lighter and more hydrodynamic than terrestrial turtle shells. There flippers enable them to swim long distances. Male sea turtles spend their entire lives at sea. Females return to the same beaches they were born on about every two years to lay eggs.

All adult **green sea turtles** are herbivores, feeding on algae, sea grasses, and other vegetation. Juvenile are carnivorous, feeding on jellies and other invertebrates. Large adult green sea turtles can weigh upward of 400 pound and over 1 meter.

Leatherback turtles are carnivorous, migrating thousands of miles each year to feed on jellyfish. Leatherback Turtles can weigh as much as 1500 pounds and reach lengths of over 2 meters.

Sea Turtles

Green sea turtle

Leatherback sea turtle

Loggerhead sea turtle

Fig. 15-29. Green sea turtle
Fig. 15-30. Leatherback sea turtle
Fig. 15-31. Loggerhead sea turtle.

Sea Snakes

There are about 50 species. They live in tropical waters of the west Pacific Ocean, around Australia, and in the Indian Ocean. Sea snakes inhabit marine environments for most or all their lives.

Sea snakes are generally non aggressive, brightly colored, with small mouth and fangs.

Sea snakes have very powerful venom.
An average of about 20 deaths per year happen from fishermen trying to remove them from nets.

Fig. 15-32. Sea snake.

Seabirds

There are many varieties of seabird (too many to discuss here!). Here are characteristics of seabirds:
• Seabirds are found on all continents and islands around the world.
• Seabirds can be highly pelagic, coastal, or partly terrestrial.
• Most species nest in colonies (dozens to millions of birds)
• Seabirds live longer, breed later, and have fewer young.
• Many species undertaking long annual migrations, crossing the equator or even circumnavigating the Earth.
• Seabirds feed both at the ocean's surface,below it, and even on each other.
• All seabirds share feed in saltwater (some may feed in both sea and terrestrial sources).
• Wing morphology and body shape depends the niche a species or family has evolved.
-- Longer wings and low wing loading are typical of more pelagic species,
-- Diving species have shorter wings.
-- Seabirds like albatross and pelicans use dynamic soaring to take advantage of wind deflected by waves to provides lift.
• Seabirds also almost always have webbed feet.
• Salt glands in their nasal cavities are used to excrete the salt they ingest by drinking and feeding.
• Birds appear in the Mesozoic Era, but **modern seabirds** proliferated in the Paleogene (after the K/T extinction).

Seabirds

Fig. 15-33. Seagull
Fig. 15-34. Arctic tern
Fig. 15-35. Pelican
Fig. 15-36. Penguins

Fish

There are many varieties of fish (too many to discuss here!). Here are important facts about fish.
Fish are found in nearly all aquatic environments (land & sea), and all depths of the oceans.
Fish are all aquatic, gill-bearing, craniate (head-bearing) animals that lack limbs with digits.
Fish groups account for **more than half of vertebrate species**.
At 32,000 species, fish exhibit greater species diversity than any other group of vertebrates.
* almost 28,000 known extant (not yet extinct) species,
~27,000 are bony fish,
~970 sharks, rays, and chimeras.
* over 100 hagfish and lampreys.
* many extinct varieties.

Most fish are ectothermic ("cold-blooded"), allowing their body temperatures to vary as ambient temperatures change some of the large active swimmers (examples white shark and tuna can hold a higher core temperature).

Fish are abundant in most bodies of water, all parts (depths) of the oceans.

Fish Evolution

Amphibians, reptiles, birds and mammals) and fish share a common evolutionary ancestry.
The earliest "fish-like" organisms appeared during the Cambrian period. (They lacked a true spine, but possessed notochords)
Fish evolve through the Paleozoic era, diversifying into a wide variety of forms.
Many Paleozoic fishes developed external armor that protected them from predators. The first fish with jaws appeared in the Silurian period, after which many (such as sharks) became formidable marine predators rather than just prey.

Osteichthyes
Fish with bony skeletons
Chondrichthyes
Fish with cartilage skeletons- sharks (very old fish with cartilage, some are up to 280 million years old)

Examples of Osteichthyes (bony fish)

Fig. 15-35. Oarfish (a species with ancient roots)
Fig. 15-36. Anchovies
Fig. 15-37. Marlin
Fig. 15-38. Blue fin tuna

Examples of Chondrichthyes (Sharks and Rays)

Fig. 15-39. Great white shark
Fig. 15-40. Hammerhead shark
Fig. 15-41. Whale shark
Fig. 15-42. Manta Rays

Adaptations to the Marine Environment

- **Ability to float** (**Zooplankton** – some produce fats or oils to stay afloat)
- **Ability to swim** (**Nekton** – larger fish and marine mammals)

Propulsion and movement of fish - the body plan of fish reflect adaptations to feeding on prey and fleeing predators.
Width/Length Ratio

Tuna - .28
Dolphin - .25
Swordfish - .24
Whale - .21

Most efficient is about.25, but there is a size-scale factor.
Ratio produced from natural selection "the fittest survive and produce offspring"

Fig. 15-43. Swordfish

Compare with Surfboard Design!

Type
Width
Length
Ratio
Comments
Short Board
19 ¼
6'4"
0.25
Small – medium waves
PT (Ebenizer Townsend, 1798)
19 ¼
6'7"
0.24
Large waves
Average Long Board
22"
9'0"
0.20
Like a whale – scale factor
Average Surf Board
18 ¼"
6'2"
0.25
rapid turns, harder to control

Kinds of Zooplankton ("floaters and drifters")

Microscopic Zooplankton:
Radiolarians, Foraminifers, Copepods

Macroscopic Zooplankton:
• Krill (resemble mini shrimp or large copepods, critical in Antarctic food chains)

Fig. 15-44. Copepods
Fig. 15-45. krill
Floating Macroscopic Zooplankton include:

• **Portuguese man-of-war** (gas-filled float)
• **Jellyfish** (soft, low-density bodies)

Fig. 15-46. Portuguese man-of-war
Fig. 15-45. Jellyfish
Swimming "Nekton" Organisms

Includes all fish, squids, sea turtles and sea snakes, and marine mammals

• Swim by trapping water and expelling it (squid, octopus)

• Swim by curving body from front to back (fish, etc.)

Fig. 15-48. Squid
Adaptations for Finding Prey

• **Lungers** wait for prey and pounce (grouper).

• **Cruisers** actively seek prey (tuna).

Fig. 15-49. Groupers are lungers
Fig. 15-50. Tuna are cruisers
Adaptations to Avoid Predation
• **Speed**
• **Hiding**: includes **Transparency**, **Camouflage** and **Countershading**
• **Poison** (to touch or eat: examples: sea snakes, blowfish, lion fish)
• **Schooling** (safety in numbers, appear as a larger unit, maneuvers confuse predators)

Video: Schooling anchovies at Scripps Pier (Scripps Institute of Oceanography)

Fig. 15-51. Lionfish are highly poisonous.
Protecting and Preserving Marine Life: A Most-Essential Goal For the 21st Century

The efforts of human exploitation of ocean resources have had catastrophic effects on marine life. The large disasters of modern times have brought attention to some of the problems (i.e. The Alaska-Exxon Valdez oil spill (1989), the destruction of Kuwait's oil fields in the 1st Gulf Wa (1991)r, and the BP Deepwater Horizon Oil Spill in the Gulf of Mexico (2010) are high-profile examples of marine ecosystem disasters (each having long-term impacts). However, it is the small scale, daily exploitation impacts of a growing human population that is having catastrophic effects on marine ecosystems (and human communities that rely on marine resources).

* 80% of available fish stock are now fully exploited, overexploited, or depleted/recovering.
* Large predatory fish reduced are greatly reduced in populations.

* Global warming of ocean waters is causing havoc on marine ecosystems: warmer water increases metabolism needs of marine life, affecting their life and reproduction cycles. In addition, tthicker thermoclines reduce upwelling of nutrient-rich waters, reducing primary production.

Many countries are now using **Fisheries Management**. Fisheries management involves **regulation, education, enforcement,** with an effort to **create self-sustaining ecosystems**.

Much work needs to be done!

Chapter 16 - Marine Communities in Benthic Environments

What is a Benthic Community?

• An **area** where a group of marine organisms live and interact with each other on, near, or within the seafloor.

Benthic or **benthos** means "relating to, or occurring at the bottom of a body of water (oceans, lakes)."

Benthic environments include:
• **littoral** (includes shore or nearshore)
• **neritic** (seabed in shallow ocean/continental shelf)
• **limnetic** (pertaining to lakes)
• **estuarine** (pertaining to transition from river to ocean settings)
• **sub-littoral** (Below the littoral zone to a depth of 200 meters)
• **sub-neritic** (below 200 meters, include continental slope, continental rise, abyssal plain and trench settings)

Click on thumbnail images for a larger view.

Fig. 16-1. Shells collections from shorelines reveal information about benthic communities.
Marine Animals in Benthic Environments

Invertebrates

"**Animals without backbones**"
Invertebrates inhabit pelagic, benthic, and terrestrial environments. The majority of animal species in that inhabit benthic environments are **invertebrates.** These organisms feed on other benthic organism (plants and animals), pelagic organisms (small fish and plankton forms), and decaying matter. These animals are in turn eaten by a host of pelagic animals (secondary and tertiary tropic feeders).

PHYLUMS
Examples
Protozoa
Single-celled animals (microbes): single-celled zooplankton, ciliates, flagellates, amoebas
Porifera
Sponges – filter feeders
Coelenterada
Coral, Jellyfish, Anemones

Annelida
Worms
Mollusca
Bivalves, squid, octopus, nautilus, gastropods (things with shells or large cavities), (extinct varieties: cephalopods, belemnites, ammonites)
Brachiopoda
Have two valves, but valves are on top and bottom
Arthropoda
Crabs, shrimp, scorpions, and spiders (trilobites, euryterids)
Echinodermata
Sea Stars, urchins and sea cucumbers (spiny skin)

Fig. 16-2. Geologic Time Scale with summary of major events and appearance of plant and animal groups in the geologic record.

Protozoa

Protozoans are single-celled animals (microbes). In the ocean environment they have the role of primary consumers in the food chain (they are zooplankton).
Protozoa are a diverse group of unicellular eukaryotic organisms. Historically, protozoa have been defined as single-celled organisms with animal-like behaviors, including motility (able to move) and predation. Protozoan that are major contributors to the food chain and to marine sediments include foraminifera and radiolarians

Fig. 16-3. Many foraminifera have calcareous skeletans that accumulate as calcareous sediment.
Fig. 16-4. Radiolarians have siliceous tests that accumulate as siliceous sediment.
Porifera

Poriferans are "**sponges**." They are among the oldest known animal fossils, dating from the Late Precambrian. The fossil record exceeds 900 genera. There are about 5,000 living sponge species in three distinct groups: ***Demospongia*** (soft sponges), ***Hexactinellida*** (glass sponges), and ***Calcarea*** (calcareous sponges). **Sponges are filter feeders**. Sponges have tiny pores in their outer walls through which water is drawn in. Cells within sponge walls filter plankton from the water pumped through the body and out other larger openings.

Examples of Sponges

Fig. 16-5. Branching tube sponge (soft sponge)
Fig. 16-6. Barrel sponge
(soft sponge)
Fig. 16-7. Calcareous sponge
Fig. 16-8. Glass sponge

Coelenterada

Coelenterates include jellyfishes, sea anemones, corals, and hydra. They are among the most ancient multicellular organisms, appearing in Late Precambrian time. All coelenterates are aquatic, mostly marine. Coelenterates are animals that have very simple tissue organization, with only two layers of cells, external and internal. They are characterized by a single hollow internal cavity serving for digestion, excretion, and other functions and having tentacles on the oral end. radially symmetrical body arrangement. Coelenterates have a network of nerves is spread throughout the body. Many forms exhibit polymorphism, where individuals with different body arrangements are present in a colony for different functions.. Coelenterates generally reproduce asexually by budding, though sexual reproduction does occur in some groups.

Examples of Coelenterates

Fig. 16-9. Anemone
Fig. 16-10. Anemone
Fig. 16-11. Coral polyps
Fig. 16-12. Pink soft coral

Fig. 16-13. Jellyfish
Fig. 16-14. Jellyfish
Fig. 16-15. Moon jellyfish
Fig. 16-16. Elkhorn coral

Annelida

The annelids also known as **segmented worms**, are a large phylum, with over 17,000 species. They have soft bodies with no legs or hard skeleton. Annelid bodies are divided into many little ring-like segments. There are many other kinds of worms, but only annelids are segmented this way. Most marine species are polychaetes (two mostly terrestrial groups are earthworms and leaches). Annelids have bilaterally symmetrical, triploblastic (having three layers of flesh--ectoderm, mesoderm, and endoderm),; they have an internal body cavity with a mouth and anus), invertebrate organisms. They also have parapodia used for locomotion. Many species can reproduce sexually and asexually. Polychaetes produce planktonic larvae. Because they are soft-bodied, fossils are rare. Annelids are known from the Cambrian Period.

Examples of Annelid Worms

Fig. 16-17. Fireworm
Fig. 16-18. Christmas Tree Worms
Fig. 16-19. Tubeworms
Fig. 16-20. Flatworm

Mollusca

Mollusca (or “**mollusks**”) are a very diverse groups of animal with at about 85,000 living species. Mollusks are the largest marine phylum, comprising about 23% of all known marine organisms. Mollusks include clams, scallops, oysters, mussels, limpets, chitons, snails (gastropods—account for ~80% of species). **Cephalopods** are mollusks and include octopuses, squid, cuttlefish, and nautilus.

• Mollusks all have unsegmented soft bodies with a "head" and a "foot" region.
• Often their bodies are covered by a hard exoskeleton, as in the shells of snails and clams or the plates of chitons.
• Many have shells, either calcareous, or made of proteins and chitin.
• Most mollusks have eyes.
• Mollusks have a mantle with a body cavity (used for breathing and excretion), and the presence of a radula (something tongue-like).
• All molusks havea nervous system, blood circulation system, and often complex digestive system.
• All produce eggs that emerge as larvae or miniature adults.

Mollusks appeared in the Cambrian Period and have diversified into their multiple forms. A large group called **ammonites** dominated the oceans during the Mesozoic era, but vanished with many other species at the K/T Boundary extinction event. Their relatives, **squids**, that do not have calcareous shells, survived the K/T event. Another distant relative, the **nautilus**, also survived the K/T event.

Examples of Mollusks

Fig. 16-21. Clams
Fig. 16-22. Scallop
Fig. 16-23. Oysters
Fig. 16-24. Mussels

Fig. 16-25. Giant clams
Fig. 16-26. Limpet
Fig. 16-27. Chiton
Fig. 16-28. Nudibrach

Fig. 16-29. Gastropod
Fig. 16-30. Conch
Fig. 16-31. Cowrie
Fig. 16-32. Nautilus

Fig. 16-33. Octopus
Fig. 16-34. Squid
Fig. 16-35. Ammonite (extinct)
Fig. 16-36. Belemnites (extinct)

Brachiopoda

Brachiopods are marine animals that have hard "valves" on the upper and lower surfaces (different than bivalve mollusks that have a left and right arrangement Brachiopod valves are hinged at the rear end so that the front can be opened for feeding or closed for protection. Brachiopod have a stalk-like pedicle that projects from an opening in one of the valves that attaches the animal to the seabed. Brachiopods appeared in the early Cambrian, and diversified in stages throughout the Paleozoic Era. One group, *Lingula*, has been around since the Early Cambrian (Figure 15-37). At their peak the brachiopods were among the most abundant filter-feeders and reef-builders, but their significance diminished after the great extinction at the end of the Permian Period.

Fig. 16-37. Lingula
Fig. 16-38. Brachiopod (Ordovician)
Fig. 16-39. Brachiopod (Mississippian)
Fig. 16-40. Brachiopod (Paleocene)

Arthropoda

Arthropods include **insects**, **arachnids** (spiders), **myriapods** (millipedes, centipedes), and **crustaceans**.

Only crustaceous are abundant in the marine environment.

Arthropods have an exoskeleton (external skeleton), a segmented body, and jointed appendages (limbs) and cuticle made of chitin, often mineralized with calcium carbonate. The exockeletons inhibits growth, so arthropods replace their rigid cuticle periodically by molting.

Most species have compound eyes.

Arthropods appeared in the Cambrian period with **trilobites** a dominant group throughout the early Paleozoic Era. **Eurypterids** (sea scorpions) grew to over a meter in length in the Silurian Period. Most Paleozoic forms vanished at in the end of the Permian extinction event, but they have since successfully diversified into inhabit nearly all of Earth’s environmental settings.

Examples of Arthropods

Fig. 16-41. Crayfish
Fig. 16-42. Horseshoe crabs
Fig. 16-43. Blue crab

Fig. 16-44. Dungeness crab

Fig. 16-45. Krill
Fig. 16-46. Tiger shrimp
Fig. 16-47. Mantis shrimp
Fig. 16-48. Blue Crab

Fig. 16-49. Ghost crab
Fig. 16-50. Spiny Lobster
Fig. 16-51. Trilobite (Ordovician)
Fig. 16-52. Eurypterid (Silurian)

Echinodermata

Echinoderms are marine animals recognizable by their (usually five-point) radial symmetry. Echinoderms include starfish, sea urchins, sand dollars, and sea cucumbers, and crinoids (sea lilies). Echinoderms are found at every ocean depth. The phylum contains about 7000 living species. There are no known freshwater or terrestrial species. They are one of the groups of organisms that successful proliferate in the deep-sea environment.

Crinoids have “flower-like” crowns that filter plankton. The crowns are connected to stocks attached to the solid sea floor (making them “sessile” organisms). Other echinoderms are mobile, capable of moving to avoid prey, seek prey, or adapt to changing conditions on the seafloor.

Most echinoderms appear to have a “five sided” or pentagonal or star-shaped appearance (it is really bilateral symmetry). Sand dollars and sea biscuits have small spicules similar to sea urchin spines. They use them to move and to work food toward their mouth-like openings.

Echinoderms first appear in abundance in the early Paleozoic Era. Echinoderms have "ossified" skeletons composed of calcium carbonate, and are a major contribution to many ancient limestone deposits.

Fig. 16-53. Urchin
Fig. 16-54. Crinoid
Fig. 16-55. Starfish
Fig. 16-56. Brittle Star

Fig. 16-57. Sea cucumber

Fig. 16-58. Sand Dollars
Fig. 16-59. Crinoids
Fig. 16-60. Sea Biscuit

Benthic Communities

Rocky Intertidal Zonation

Species are either:
• Attached to bottom (e.g., anemones, corals)
• Move over seafloor (e.g., crabs, snails)

Rocky shores subdivisions include:

Spray and Upper Tide Zone
• Harsh environment - few organisms
• Experiences large temperature and salinity changes
• Both Marine and Land Predators
Middle Tide Zone (Transition Zone)
• More Species Diversity
• More Organisms, most move with the tides
• Seaweeds, limpets, chitins, mussels attached to rocks
Low tide zone
• Life is easy here!
• Stable temp/salinity
• Lots of Species Diversity
• Space is limited

Fig. 16-61. Rocky shore tide pool (Point Lobos, CA).
Communities on Sandy Beach Shores

* **Sandy Beach Intertidal Zone**
• No stable, fixed surface
• Burrowing provides more stable environment
• Less risk of temperature extremes and drying out

Burrowing invertebrates include:
Mollusks - Soft body, hard shell (most, not all) including clams and mussels
Worms (annelids)
Sand Crabs

Fig. 16-62. Mussels on an isolated rock on a sandy beach.
Communities on Sandy Beach Shores

* **Sandy Beach Intertidal Zone**
• No stable, fixed surface
• Burrowing provides more stable environment

• Less risk of temperature extremes and drying out

Burrowing invertebrates include: **Mollusks** (with a soft body, hard shell—most, not all) (clams and mussels most common); **Worms** (annelids) and **Sand Crabs.**

Fig. 16-63. Most sandy beaches appear deceivingly barren of marine life.

Shallow Offshore Benthic Communities

• **offshore sand bars** (mostly inhabited by burrowing organisms)
• **rocky bottoms** (host many attached organisms)
• **coralline reefs** (complex, self-constructing communities)

Described as "rich ecosystems" because of the diversity and abundance of organisms in some of these environmental settings.

Fig. 16-64. Northern Europe rocky bottom community

Kelp and Kelp Forests

Kelp attaches to **rocky bottoms**
Can grow up to 0.6 meters (2 feet) per day
Provides shelter for other organisms

Fig. 16-65. Kelp "forest"

Fig. 16-65. Offshore kelp bed on the California coast.

Coral Reefs

Coral reefs are located in Tropical settings.
• Reefs require **warm, clear, shallow water**.
• Reefs also provide sediments and food to deeper water settings.

Corals are animals communities consisting of "**Polyps**" – each polyp is an individual coral animals. Corals produce calcium carbonate skeletal structures.

Other "reef" forming animals include coralline algae (plants!), bryozoans, sponges, mollusks, and many others.
Animals feeding on reef-forming organisms produce large quantities of sediment (building up reefs).

Fig. 16-66. Coral reef

Importance of Coral Reefs

Reefs are the largest structures created by living organisms
• • **Great Barrier Reef**, Australia, more than 1250 miles long
• • **Florida Keys, Bahamas**, many coastal **Caribbean** destinations
• • **Atolls** throughout the South Pacific and Indian Oceans
• • Coastlines of Red Sea, Persian Gulf, and Africa

Coral reefs have great diversity of species.

Reefs protect shorelines and freshwater supplies.

Coral Reefs are in decline.
30% healthy today, 41% healthy in 2000.

Threats to coral reefs:
- Hurricanes
- Floods
- Coral bleaching
- Human encroachment and exploitation

Fig. 16-67. Atoll reef community

Fig. 16-68. Hawaiian reef community
Deep-Ocean Floor Communities

- The deep ocean is largely unexplored.
- Light is completely absent below 3300 feet.
- Temperature usually 28°F to 37°F.
- A very high pressure environment.
- Oxygen depleted environment compared to the surface environment.

Fig. 16-69. Deep-sea community
Hydrothermal Vents

Abundance of "unusual" life forms
Life supported by **Chemosynthesis**

Microscopic organisms (base of local food chain) – thrive on **hydrogen sulfide** from vents
- microbes manufacture sugar, carbon dioxide, and dissolved oxygen.

Hydrothermal Vent Species
- Giant tubeworms
- Giant clams
- Giant mussels
- Crabs

Vents may active for years or decades.

Animals species are similar at widely separated vents.

Larvae drift from site to site.