Aquatic Ecology & Marine Biology

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Aquatic Ecosystem

An estuary mouth and coastal waters, part of an aquatic ecosystem

An **aquatic ecosystem** is an ecosystem located in a body of water. Communities of organisms that are dependent on each other and on their environment live in aquatic ecosystems. The two main types of aquatic ecosystems are marine ecosystems and freshwater ecosystems.

Types

Marine

Marine ecosystems cover approximately 71% of the Earth's surface and contain approximately 97% of the planet's water. They generate 32% of the world's net primary production. They are distinguished from freshwater ecosystems by the presence of dissolved compounds, especially salts, in the water. Approximately 85% of the dissolved materials in seawater are sodium and chlorine. Seawater has an average salinity of 35 parts per thousand (ppt) of water. Actual salinity varies among different marine ecosystems.

Marine ecosystems can be divided into the following zones: oceanic (the relatively shallow part of the ocean that lies over the continental shelf); profundal (bottom or deep water); benthic (bottom substrates); intertidal (the area between high and low tides);

estuaries; salt marshes; coral reefs; and hydrothermal vents (where chemosynthetic sulfur bacteria form the food base).

Classes of organisms found in marine ecosystems include brown algae, dinoflagellates, corals, cephalopods, echinoderms and sharks. Fish caught in marine ecosystems are the biggest source of commercial foods obtained from wild populations.

Environmental problems concerning marine ecosystems include unsustainable exploitation of marine resources (for example overfishing of certain species), marine pollution, climate change and building on coastal areas.

Freshwater

Freshwater ecosystems cover 0.80% of the Earth's surface and inhabit 0.009% of its total water. They generate nearly 3% of its net primary production. Freshwater ecosystems contain 41% of the world's known fish species.

There are three basic types of freshwater ecosystems:

- Lentic: slow-moving water, including pools, ponds and lakes.
- Lotic: rapidly-moving water, for example streams and rivers.
- Wetlands: areas where the soil is saturated or inundated for at least part of the time.

Lake ecosystems can be divided into zones: pelagic (open offshore waters); profundal; littoral (nearshore shallow waters); and riparian (the area of land bordering a body of water). Two important subclasses of lakes are ponds, which typically are small lakes that intergrade with wetlands and water reservoirs. Many lakes, or bays within them, gradually become enriched by nutrients and fill in with organic sediments, a process called eutrophication. Eutrophication is accelerated by human activity within the water catchment area of the lake.

Freshwater ecosystem

The major zones in river ecosystems are determined by the river bed's gradient or by the velocity of the current. Faster moving turbulent water typically contains greater concentrations of dissolved oxygen, which supports greater biodiversity than the slow moving water of pools. These distinctions forms the basis for the division of rivers into

upland and lowland rivers. The food base of streams within riparian forests is mostly derived from the trees, but wider streams and those that lack a canopy derive the majority of their food base from algae. Anadromous fish are also an important source of nutrients. Environmental threats to rivers include loss of water, dams, chemical pollution and introduced species.

Wetlands are dominated by vascular plants that have adapted to saturated soil. Wetlands are the most productive natural ecosystems because of the proximity of water and soil. Due to their productivity, wetlands are often converted into dry land with dykes and drains and used for agricultural purposes. Their closeness to lakes and rivers means that they are often developed for human settlement.

Ponds

These are a specific type of freshwater ecosystems that are largely based on the autotroph algae which provide the base trophic level for all life in the area. The largest predator in a pond ecosystem will normally be a fish and in-between range smaller insects and microorganisms. It may have a scale of organisms from small bacteria to big creatures like water snakes, beetles, water bugs, frogs, tadpoles and turtles. This is important for the environment.

Functions

Aquatic ecosystems perform many important environmental functions. For example, they recycle nutrients, purify water, attenuate floods, recharge ground water and provide habitats for wildlife. Aquatic ecosystems are also used for human recreation and are very important to the tourism industry, especially in coastal regions.

The health of an aquatic ecosystem is degraded when the ecosystem's ability to absorb a stress has been exceeded. A stress on an aquatic ecosystem can be a result of physical, chemical or biological alterations of the environment. Physical alterations include changes in water temperature, water flow and light availability. Chemical alterations include changes in the loading rates of biostimulatory nutrients, oxygen consuming materials and toxins. Biological alterations include the introduction of exotic species. Human populations can impose excessive stresses on aquatic ecosystems.

Abiotic characteristics

An ecosystem is composed of biotic communities and abiotic environmental factors, which form a self-regulating and self-sustaining unit. Abiotic environmental factors of aquatic ecosystems include temperature, salinity and flow.

The amount of dissolved oxygen in a water body is frequently the key substance in determining the extent and kinds of organic life in the water body. Fish need dissolved oxygen to survive. Conversely, oxygen is fatal to many kinds of anaerobic bacteria.

The salinity of the water body is also a determining factor in the kinds of species found in the water body. Organisms in marine ecosystems tolerate salinity, while many freshwater organisms are intolerant of salt. Freshwater used for irrigation purposes often absorb levels of salt that are harmful to freshwater organisms. Though some salt can be good for organisms.

Biotic characteristics

The organisms (also called biota) found in aquatic ecosystems are either autotrophic or heterotrophic.

Autotrophic organisms

Autotrophic organisms are producers that generate organic compounds from inorganic material. Algae use solar energy to generate biomass from carbon dioxide and are the most important autotrophic organisms in aquatic environments. Chemosynthetic bacteria are found in benthic marine ecosystems. These organisms are able to feed on hydrogen sulfide in water that comes from volcanic vents. Great concentrations of animals that feed on this bacteria are found around volcanic vents. For example, there are giant tube worms (*Riftia pachyptila*) 1.5m in length and clams (*Calyptogena magnifica*) 30cm long.

Heterotrophic organisms

Heterotrophic organisms consume autotrophic organisms and use the organic compounds in their bodies as energy sources and as raw materials to create their own biomass. Euryhaline organisms are salt tolerant and can survive in marine ecosystems, while stenohaline or salt intolerant species can only live in freshwater environments.

Chapter- 2

Marine Ecosystem

Coral reefs form complex marine ecosystems with tremendous biodiversity

Here, we can see different types of starfish, coral reefs and fishes in the Great Barrier Reef.

Marine ecosystems are among the largest of Earth's aquatic ecosystems. They include oceans, salt marsh and intertidal ecology, estuaries and lagoons, mangroves and coral reefs, the deep sea and the sea floor. They can be contrasted with freshwater ecosystems, which have a lower salt content. Marine waters cover two-thirds of the surface of the Earth. Such places are considered ecosystems because the plant life supports the animal life and vice-versa.

Marine ecosystems are very important for the overall health of both marine and terrestrial environments. According to the World Resource Center, coastal habitats alone account for approximately 1/3 of all marine biological productivity and estuarine ecosystems (i.e., salt marshes, seagrasses, mangrove forests) are among the most productive regions on the planet. In addition, other marine ecosystems such as coral reefs, provide food and shelter to the highest levels of marine diversity in the world.

Marine conservation

Marine conservation, also known as **marine resources conservation**, is the protection and preservation of ecosystems in oceans and seas. Marine conservation focuses on limiting human-caused damage to marine ecosystems and on restoring damaged marine ecosystems. Marine conservation also focuses on preserving vulnerable marine species.

Overview

Marine conservation is the study of conserving physical and biological marine resources and ecosystem functions. This is a relatively new discipline. Marine conservationists rely on a combination of scientific principles derived from marine biology, oceanography and fisheries science, as well as on human factors such as demand for marine resources and marine law, economics and policy in order to determine how to best protect and conserve marine species and ecosystems. Marine conservation can be seen as a subdiscipline of conservation biology.

Techniques

Strategies and techniques for marine conservation tend to combine theoretical disciplines, such as population biology, with practical conservation strategies, such as setting up protected areas, as with marine protected areas (MPAs) or Voluntary Marine Conservation Areas. Other techniques include developing sustainable fisheries and restoring the populations of endangered species through artificial means.

Another focus of conservationists is on curtailing human activities that are detrimental to either marine ecosystems or species through policy, techniques such as fishing quotas, like those set up by the Northwest Atlantic Fisheries Organization, or laws such as those listed below. Recognizing the economics involved in human use of marine ecosystems is key, as is education of the public about conservation issues. This includes educating tourists that come to an area that might not be familiar of certain rules and regulations regarding the marine habitat. One example of this is a project called Green Fins that uses the SCUBA diving industry to educate the public based in SE Asia. This project, implemented by UNEP, encourages scuba diving operators to educate the public they teach to dive about the importance of marine conservation and encourage them to dive in an environmentally friendly manner that does not damage coral reefs or associated marine ecosystems.

Laws and treaties

International laws and treaties related to marine conservation include the 1966 Convention on Fishing and Conservation of Living Resources of the High Seas. United States laws related to marine conservation include the 1972 Marine Mammal Protection Act, as well as the 1972 Marine Protection, Research and Sanctuaries Act which established the National Marine Sanctuaries program.

In 2010, the Scottish Parliament enacted new legislation for the protection of marine life with the Marine (Scotland) Act 2010. The provisions in the Act include: Marine planning, Marine licensing, marine conservation, seal conservation and enforcement.

Organizations and education

The shore of the Pacific Ocean in San Francisco, California

There are marine conservation organizations throughout the world that focus on funding conservation efforts, educating the public and stakeholders and lobbying for conservation law and policy. Examples of these organizations are Oceana (non-profit group), the Marine Conservation Biology Institute (United States), Blue Frontier Campaign (United States), Frontier (the Society for Environmental Exploration) (United Kingdom), Marine Conservation Society (United Kingdom), The Reef-World Foundation (United Kingdom) and [Australian Marine Conservation Society].

On a regional level, PERSGA- the Regional Organization for the Conservation of the Environment of the Red Sea and the Gulf of Aden, is a regional entity serves as the secretariat for the Jeddah Convention-1982, one of the first regional marine agreements. PERSGA Member States are: Djibouti, Egypt, Jordan, Saudi Arabia, Somalia, Sudan and Yemen.

Chapter- 3

Lentic Ecosystem

Fig. 1 This mountain pool is an example of a lentic system

A **lentic ecosystem** is the ecosystem of a lake, pond or swamp. Included in the environment are the biotic interactions (amongst plants, animals and micro-organisms) and the abiotic interactions (physical and chemical).

Lentic refers to standing or still water. It is derived from the Latin *lentus*, which means sluggish. Lentic ecosystems can be compared with lotic ecosystems, which involve flowing terrestrial waters such as rivers and streams. Together, these two fields form the more general study area of freshwater or aquatic ecology.

Lentic systems are diverse, ranging from a small, temporary rainwater pool a few inches deep to Lake Baikal, which has a maximum depth of 1740 m. The general distinction

between pools/ponds and lakes is vague, but Brown states that ponds and pools have their entire bottom surfaces exposed to light, while lakes do not. In addition, some lakes become seasonally stratified (discussed in more detail below.) Ponds and pools have two regions: the pelagic open water zone and the benthic zone, which comprises the bottom and shore regions. Since lakes have deep bottom regions not exposed to light, these systems have an additional zone, the profundal. These three areas can have very different abiotic conditions and, hence, host species that are specifically adapted to live there.

Lentic system biota

Bacteria

Bacteria are present in all regions of lentic waters. Free-living forms are associated with decomposing organic material, biofilm on the surfaces of rocks and plants, suspended in the water column and in the sediments of the benthic and profundal zones. Other forms are also associated with the guts of lentic animals as parasites or in commensal relationships. Bacteria play an important role in system metabolism through nutrient recycling, which is discussed in the Trophic Relationships section.

Primary producers

Algae, including both phytoplankton and periphyton are the principle photosynthesizers in ponds and lakes. Phytoplankton are found drifting in the water column of the pelagic zone. Many species have a higher density than water which should making them sink and end up in the benthos. To combat this, phytoplankton have developed density changing mechanisms, by forming vacuoles and gas vesicles or by changing their shapes to induce drag, slowing their descent. A very sophisticated adaptation utilized by a small number of species is a tail-like flagella that can adjust vertical position and allow movement in any direction. Phytoplankton can also maintain their presence in the water column by being circulated in Langmuir rotations. Periphytic algae, on the other hand, are attached to a substrate. In lakes and ponds, they can cover all benthic surfaces. Both types of plankton are important as food sources and as oxygen providers.

Plants, or macrophytes, in lentic systems live in both the benthic and pelagic zones and can be grouped according to their manner of growth: 1) emergent macrophytes = rooted in the substrate but with leaves and flowers extending into the air, 2) floating-leaved macrophytes = rooted in the substrate but with floating leaves, 3) submersed macrophytes = not rooted in the substrate and floating beneath the surface and 4) free-floating macrophytes = not rooted in the substrate and floating on the surface. These various forms of macrophytes generally occur in different areas of the benthic zone, with emergent vegetation nearest the shoreline, then floating-leaved macrophytes, followed by submersed vegetation. Free-floating macrophytes can occur anywhere on the system's surface.

Aquatic plants are more buoyant than their terrestrial counterparts because freshwater has a higher density than air. This makes structural rigidity unimportant in lakes and ponds

(except in the aerial stems and leaves). Thus, the leaves and stems of most aquatic plants use less energy to construct and maintain woody tissue, investing that energy into fast growth instead. In order to contend with stresses induced by wind and waves, plants must be both flexible and tough (Reynolds 2004). Light is the most important factor controlling the distribution of submerged aquatic plants. Macrophytes are sources of food, oxygen and habitat structure in the benthic zone, but cannot penetrate the depths of the euphotic zone and hence are not found there.

Invertebrates

Water striders are predatory insects which rely on surface tension to walk on top of water. They live on the surface of ponds, marshes and other quiet waters. They can move very quickly, up to 1.5 m/s.

Zooplankton are tiny animals suspended in the water column. Like phytoplankton, these species have developed mechanisms that keep them from sinking to deeper waters, including drag-inducing body forms and the active flicking of appendages such as antennae or spines. Remaining in the water column may have its advantages in terms of feeding, but this zone's lack of refugia leaves zooplankton vulnerable to predation. In response, some species, especially Daphnia sp., make daily vertical migrations in the water column by passively sinking to the darker lower depths during the day and actively moving towards the surface during the night. Also, because conditions in a lentic system can be quite variable across seasons, zooplankton have the ability to switch from laying

regular eggs to resting eggs when there is a lack of food, temperatures fall below 2 °C, or if predator abundance is high. These resting eggs have a diapause, or dormancy period that should allow the zooplankton to encounter conditions that are more favorable to survival when they finally hatch. The invertebrates that inhabit the benthic zone are numerically dominated by small species and are species rich compared to the zooplankton of the open water. They include Crustaceans (e.g. crabs, crayfish and shrimp), molluscs (e.g. clams and snails) and numerous types of insects. These organisms are mostly found in the areas of macrophyte growth, where the richest resources, highly oxygenated water and warmest portion of the ecosystem are found. The structurally diverse macrophyte beds are important sites for the accumulation of organic matter and provide an ideal area for colonization. The sediments and plants also offer a great deal of protection from predatory fishes.

Very few invertebrates are able to inhabit the cold, dark and oxygen poor profundal zone. Those that can are often red in color due to the presence of large amounts of hemoglobin, which greatly increases the amount of oxygen carried to cells. Because the concentration of oxygen within this zone is low, most species construct tunnels or borrows in which they can hide and make the minimum movements necessary to circulate water through, drawing oxygen to them without expending much energy.

Fishes and other vertebrates

Fishes have a range of physiological tolerances that are dependent upon which species they belong to. They have different lethal temperatures, dissolved oxygen requirements and spawning needs that are based on their activity levels and behaviors. Because fishes are highly mobile, they are able to deal with unsuitable abiotic factors in one zone by simply moving to another. A detrital feeder in the profundal zone, for example, that finds the oxygen concentration has dropped too low may feed closer to the benthic zone. A fish might also alter its residence during different parts of its life history: hatching in a sediment nest, then moving to the weedy benthic zone to develop in a protected environment with food resources and finally into the pelagic zone as an adult.

Other vertebrate taxa inhabit lentic systems as well. These include amphibians (e.g. salamanders and frogs), reptiles (e.g. snakes, turtles and alligators) and a large number of waterfowl species. Most of these vertebrates spend part of their time in terrestrial habitats and thus are not directly affected by abiotic factors in the lake or pond. Many fish species are important as consumers and as prey species to the larger vertebrates mentioned above.

Trophic relationships

Primary producers

Lentic systems gain most of their energy from photosynthesis performed by aquatic plants and algae. This autochthonous process involves the combination of carbon dioxide, water and solar energy to produce carbohydrates and dissolved oxygen. Within a lake or pond, the potential rate of photosynthesis generally decreases with depth due to light

attenuation. Photosynthesis, however, is often low at the top few millimeters of the surface, likely due to inhibition by ultraviolet light. The exact depth and photosynthetic rate measurements of this curve are system specific and depend upon: 1) the total biomass of photosynthesizing cells, 2) the amount of light attenuating materials and 3) the abundance and frequency range of light absorbing pigments (i.e. chlorophylls) inside of photosynthesizing cells. The energy created by these primary producers is important for the community because it is transferred to higher trophic levels via consumption.

Bacteria

The vast majority of bacteria in lakes and ponds obtain their energy by decomposing vegetation and animal matter. In the pelagic zone, dead fish and the occasional allochthonous input of litterfall are examples of coarse particulate organic matter (CPOM>1 mm). Bacteria degrade these into fine particulate organic matter (FPOM<1 mm) and then further into usable nutrients. Small organisms such as plankton are also characterized as FPOM. Very low concentrations of nutrients are released during decomposition because the bacteria are utilizing them to build their own biomass. Bacteria, however, are consumed by protozoa, which are in turn consumed by zooplankton and then further up the trophic levels. Nutrients, including those that contain carbon and phosphorus, are reintroduced into the water column at any number of points along this food chain via excretion or organism death, making them available again for bacteria. This regeneration cycle is known as the microbial loop and is a key component of lentic food webs.

The decomposition of organic materials can continue in the benthic and profundal zones if the matter falls through the water column before being completely digested by the pelagic bacteria. Bacteria are found in the greatest abundance here in sediments, where they are typically 2-1000 times more prevalent than in the water column.

Benthic invertebrates, due to their high level of species richness, have many methods of prey capture. Filter feeders create currents via siphons or beating cilia, to pull water and its nutritional contents, towards themselves for straining. Grazers use scraping, rasping and shredding adaptations to feed on periphytic algae and macrophytes. Members of the collector guild browse the sediments, picking out specific particles with raptorial appendages. Deposit feeding invertebrates indiscriminately consume sediment, digesting any organic material it contains. Finally, some invertebrates belong to the predator guild, capturing and consuming living animals. The profundal zone is home to a unique group of filter feeders that use small body movements to draw a current through burrows that they have created in the sediment. This mode of feeding requires the least amount of motion, allowing these species to conserve energy. A small number of invertebrate taxa are predators in the profundal zone. These species are likely from other regions and only come to these depths to feed. The vast majority of invertebrates in this zone are deposit feeders, getting their energy from the surrounding sediments.

Fish

Fish size, mobility and sensory capabilities allow them to exploit a broad prey base, covering multiple zonation regions. Like invertebrates, fish feeding habits can be categorized into guilds. In the pelagic zone, herbivores graze on periphyton and macrophytes or pick phytoplankton out of the water column. Carnivores include fishes that feed on zooplankton in the water column (zooplanktivores), insects at the water's surface, on benthic structures, or in the sediment (insectivores) and those that feed on other fishes (piscivores). Fish that consume detritus and gain energy by processing its organic material are called detritivores. Omnivores ingest a wide variety of prey, encompassing floral, faunal and detrital material. Finally, members of the parasitic guild acquire nutrition from a host species, usually another fish or large vertebrate. Fish taxa are flexible in their feeding roles, varying their diets with environmental conditions and prey availability. Many species also undergo a diet shift as they develop. Therefore, it is likely that any single fish occupies multiple feeding guilds within its lifetime.

Lentic food webs

As noted in the previous sections, the lentic biota are linked in complex web of trophic relationships. These organisms can be considered to loosely be associated with specific trophic groups (e.g. primary producers, herbivores, primary carnivores, secondary carnivores, etc.). Scientists have developed several theories in order to understand the mechanisms that control the abundance and diversity within these groups. Very generally, top-down processes dictate that the abundance of prey taxa is dependent upon the actions of consumers from higher trophic levels. Typically, these processes operate only between two trophic levels, with no effect on the others. In some cases, however, aquatic systems experience a trophic cascade; for example, this might occur if primary producers experience less grazing by herbivores because these herbivores are suppressed by carnivores. Bottom-up processes are functioning when the abundance or diversity of members of higher trophic levels is dependent upon the availability or quality of resources from lower levels. Finally, a combined regulating theory, bottom-up:top-down, combines the predicted influences of consumers and resource availability. It predicts that trophic levels close to the lowest trophic levels will be most influenced by bottom-up forces, while top-down effects should be strongest at top levels.

Community patterns and diversity

Local species richness

The biodiversity of a lentic system increases with the surface area of the lake or pond. This is attributable to the higher likelihood of partly terrestrial species of finding a larger system. Also, because larger systems typically have larger populations, the chance of extinction is decreased. Additional factors, including temperature regime, pH, nutrient availability, habitat complexity, speciation rates, competition and predation, have been linked to the number of species present within systems.

Succession patterns in plankton communities – the PEG model

Phytoplankton and zooplankton communities in lake systems undergo seasonal succession in relation to nutrient availability, predation and competition. Sommer *et al.* described these patterns as part of the Plankton Ecology Group (PEG) model, with 24 statements constructed from the analysis of numerous systems. The following includes a subset of these statements, as explained by Brönmark and Hansson illustrating succession through a single seasonal cycle:

Winter
1. Increased nutrient and light availability result in rapid phytoplankton growth towards the end of winter. The dominant species, such as diatoms, are small and have quick growth capabilities. 2. These plankton are consumed by zooplankton, which become the dominant plankton taxa.

Spring
3. A clear water phase occurs, as phytoplankton populations become depleted due to increased predation by growing numbers of zooplankton.

Summer
4. Zooplankton abundance declines as a result of decreased phytoplankton prey and increased predation by juvenile fishes.
5. With increased nutrient availability and decreased predation from zooplankton, a diverse phytoplankton community develops.
6. As the summer continues, nutrients become depleted in a predictable order: phosphorus, silica and then nitrogen. The abundance of various phytoplankton species varies in relation to their biological need for these nutrients.
7. Small-sized zooplankton become the dominant type of zooplankton because they are less vulnerable to fish predation.

Fall
8. Predation by fishes is reduced due to lower temperatures and zooplankton of all sizes increase in number.

Winter
9. Cold temperatures and decreased light availability result in lower rates of primary production and decreased phytoplankton populations. 10. Reproduction in zooplankton decreases due to lower temperatures and less prey.

The PEG model presents an idealized version of this succession pattern, while natural systems are known for their variation.

Latitudinal patterns

There is a well-documented global pattern that correlates decreasing plant and animal diversity with increasing latitude, that is to say, there are fewer species as one moves

towards the poles. The cause of this pattern is one of the greatest puzzles for ecologists today. Theories for its explanation include energy availability, climatic variability, disturbance, competition, etc. Despite this global diversity gradient, this pattern can be weak for freshwater systems compared to global marine and terrestrial systems. This may be related to size, as Hillebrand and Azovsky found that smaller organisms (protozoa and plankton) did not follow the expected trend strongly, while larger species (vertebrates) did. They attributed this to better dispersal ability by smaller organisms, which may result in high distributions globally.

Natural lake lifecycles

Lake creation

Lakes can be formed in a variety of ways, but the most common are discussed briefly below. The oldest and largest systems are the result of tectonic activities. The rift lakes in Africa, for example are the result of seismic activity along the site of separation of two tectonic plates. Ice-formed lakes are created when glaciers recede, leaving behind abnormalities in the landscape shape that are then filled with water. Finally, oxbow lakes are fluvial in origin, resulting when a meandering river bend is pinched off from the main channel.

Natural extinction

All lakes and ponds receive sediment inputs. Since these systems are not really expanding, it is logical to assume that they will become increasingly shallower in depth, eventually becoming wetlands or terrestrial vegetation. The length of this process should depend upon a combination of depth and sedimentation rate. Moss gives the example of Lake Tanganyika, which reaches a depth of 1500 m and has a sedimentation rate of 0.5 mm/yr. Assuming that sedimentation is not influenced by anthropogenic factors, this system should go extinct in approximately 3 million years. Shallow lentic systems might also fill in as swamps encroach inward from the edges. These processes operate on a much shorter timescale, taking hundreds to thousands of years to complete the extinction process.

Human Impacts

Acidification

Sulfur dioxide and nitrogen oxides are naturally released from volcanoes, organic compounds in the soil, wetlands and marine systems, but the majority of these compounds come from the combustion of coal, oil, gasoline and the smelting of ores containing sulfur. These substances dissolve in atmospheric moisture and enter lentic systems as acid rain. Lakes and ponds that contain bedrock that is rich in carbonates have a natural buffer, resulting in no alteration of pH. Systems without this bedrock, however, are very sensitive to acid inputs because they have a low neutralizing capacity, resulting in pH declines even with only small inputs of acid. At a pH of 5-6 algal species diversity

and biomass decrease considerably, leading to an increase in water transparency – a characteristic feature of acidified lakes. As the pH continues lower, all fauna becomes less diverse. The most significant feature is the disruption of fish reproduction. Thus, the population is eventually composed of few, old individuals that eventually die and leave the systems without fishes. Acid rain has been especially harmful to lakes in Scandinavia, western Scotland, west Wales and the north eastern United States.

Eutrophication

Eutrophic systems contain a high concentration of phosphorus (~30+µg/L), nitrogen (~1500+µg/L), or both. Phosphorus enters lentic waters from wastewater treatment effluents, discharge from raw sewage, or from runoff of farmland. Nitrogen mostly comes from agricultural fertilizers from runoff or leaching and subsequent groundwater flow. This increase in nutrients required for primary producers results in a massive increase of phytoplankton growth, termed a plankton bloom. This bloom decreases water transparency, leading to the loss of submerged plants. The resultant reduction in habitat structure has negative impacts on the species' that utilize it for spawning, maturation and general survival. Additionally, the large number of short-lived phytoplankton result in a massive amount of dead biomass settling into the sediment. Bacteria need large amounts of oxygen to decompose this material, reducing the oxygen concentration of the water. This is especially pronounced in stratified lakes when the thermocline prevents oxygen rich water from the surface to mix with lower levels. Low or anoxic conditions preclude the existence of many taxa that are not physiologically tolerant of these conditions.

Invasive species

Invasive species have been introduced to lentic systems through both purposeful events (e.g. stocking game and food species) as well as unintentional events (e.g. in ballast water). These organisms can affect natives via competition for prey or habitat, predation, habitat alteration, hybridization, or the introduction of harmful diseases and parasites. With regard to native species, invaders may cause changes in size and age structure, distribution, density, population growth and may even drive populations to extinction. Examples of prominent invaders of lentic systems include the zebra mussel and sea lamprey in the Great Lakes.

Chapter- 4

Lotic Ecosystem

This stream in the redwoods can be thought of as a lotic ecosystem

A **lotic ecosystem** is the ecosystem of a river, stream or spring. Included in the environment are the biotic interactions (amongst plants, animals and micro-organisms) as well as the abiotic interactions (physical and chemical).

Lotic refers to flowing water, from the Latin *lotus*, past participle of *lavere*, to wash. Lotic ecosystems can be contrasted with lentic ecosystems, which involve relatively still terrestrial waters such as lakes and ponds. Together, these two fields form the more general study area of freshwater or aquatic ecology.

Lotic waters can be diverse in their form, ranging from a spring that is only a few centimeters wide to a major river that is kilometers in width. Despite these differences, the following unifying characteristics make the ecology of running waters unique from that of other aquatic habitats.

- Flow is unidirectional.
- There is a state of continuous physical change.
- There is a high degree of spatial and temporal heterogeneity at all scales (microhabitats).
- Variability between lotic systems is quite high.
- The biota is specialized to live with flow conditions.

Abiotic factors

Rapids in Mount Robson Provincial Park

Flow

Water flow is the key factor in lotic systems influencing their ecology. The strength of water flow can vary between systems, ranging from torrential rapids to slow backwaters that almost seem like lentic systems. The speed of the water flow can also vary within a system. It is typically based on variability of friction with the bottom or sides of the channel, sinuosity, obstructions and the incline gradient. In addition, the amount of water input into the system from direct precipitation, snowmelt and/or groundwater can affect flow rate. Flowing waters can alter the shape of the streambed through erosion and deposition, creating a variety of habitats, including riffles, glides and pools.

Light

A pensive Cooplacurripa River, NSW

Light is important to lotic systems, because it provides the energy necessary to drive primary production via photosynthesis and can also provide refuge for prey species in shadows it casts. The amount of light that a system receives can be related to a combination of internal and external stream variables. The area surrounding a small stream, for example, might be shaded by surrounding forests or by valley walls. Larger river systems tend to be wide so the influence of external variables is minimized and the sun reaches the surface. These rivers also tend to be more turbulent, however and particles in the water increasingly attenuate light as depth increases. Seasonal and diurnal

factors might also play a role in light availability because the angle of incidence, the angle at which light strikes water can lead to light lost from reflection. Known as Beer's Law, the shallower the angle, the more light is reflected and the amount of solar radiation received declines logarithmically with depth. Additional influences on light availability include cloud cover, altitude and geographic position (Brown 1987).

Temperature

Castle Geyser, Yellowstone National Park

Most lotic species are poikilotherms whose internal temperature varies with their environment, thus temperature is a key abiotic factor for them. Water can be heated or cooled through radiation at the surface and conduction to or from the air and surrounding substrate. Shallow streams are typically well mixed and maintain a relatively uniform temperature within an area. In deeper, slower moving water systems, however, a strong difference between the bottom and surface temperatures may develop. Spring fed systems have little variation as springs are typically from groundwater sources, which are often very close to ambient temperature. Many systems show strong diurnal fluctuations and seasonal variations are most extreme in arctic, desert and temperate systems. The amount of shading, climate and elevation can also influence the temperature of lotic systems.

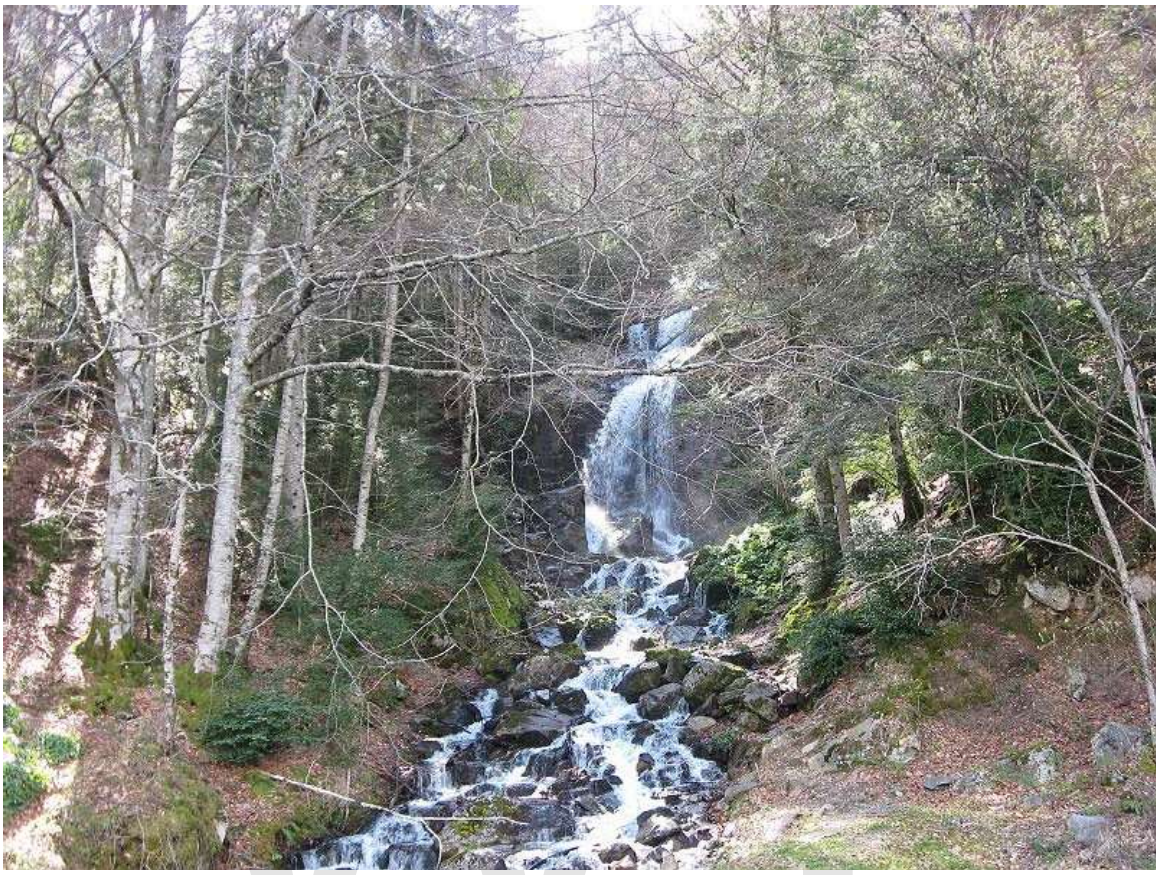
Chemistry

A forest stream in the winter near Erzhausen, Germany

Water chemistry between systems varies tremendously. The chemistry is foremost determined by inputs from the geology of its watershed, or catchment area, but can also be influenced by precipitation and the addition of pollutants from human sources. Large differences in chemistry do not usually exist within small lotic systems due to a high rate of mixing. In larger river systems, however, the concentrations of most nutrients, dissolved salts and pH decrease as distance increases from the river's source.

Oxygen is likely the most important chemical constituent of lotic systems, as all aerobic organisms require it for survival. It enters the water mostly via diffusion at the water-air interface. Oxygen's solubility in water decreases as water temperature increases. Fast, turbulent streams expose more of the water's surface area to the air and tend to have low temperatures and thus more oxygen than slow, backwaters. Oxygen is a byproduct of photosynthesis, so systems with a high abundance of aquatic algae and plants may also have high concentrations of oxygen during the day. These levels can decrease significantly during the night when primary producers switch to respiration. Oxygen can be limiting if circulation between the surface and deeper layers is poor, if the activity of lotic animals is very high, or if there is a large amount of organic decay occurring.

Substrate



Cascade in the Pyrénées

The inorganic substrate of lotic systems is composed of the geologic material present in the catchment that is eroded, transported, sorted and deposited by the current. Inorganic substrates are classified by size on the Wentworth scale, which ranges from boulders, to pebbles, to gravel, to sand and to silt. Typically, particle size decreases downstream with larger boulders and stones in more mountainous areas and sandy bottoms in lowland rivers. This is because the higher gradients of mountain streams facilitate a faster flow, moving smaller substrate materials further downstream for deposition. Substrate can also be organic and may include fine particles, autumn shed leaves, submerged wood, moss and more evolved plants. Substrate deposition is not necessarily a permanent event, as it can be subject to large modifications during flooding events.

Biota

Bacteria

Bacteria are present in large numbers in lotic waters. Free-living forms are associated with decomposing organic material, biofilm on the surfaces of rocks and vegetation, in between particles that compose the substrate and suspended in the water column. Other forms are also associated with the guts of lotic organisms as parasites or in commensal

relationships. Bacteria play a large role in energy recycling, which will be discussed in the Trophic Relationships section.

Primary producers

Periphyton

Common water hyacinth in flower

Algae, consisting of phytoplankton and periphyton, are the most significant sources of primary production in most streams and rivers. Phytoplankton float freely in the water column and thus are unable to maintain populations in fast flowing streams. They can, however, develop sizable populations in slow moving rivers and backwaters. Periphyton are typically filamentous and tufted algae that can attach themselves to objects to avoid being washed away by fast current. In places where flow rates are negligible or absent, periphyton may form a gelatinous, unanchored floating mat.

Plants exhibit limited adaptations to fast flow and are most successful in reduced currents. More primitive plants, such as mosses and liverworts attach themselves to solid objects. This typically occurs in colder headwaters where the mostly rocky substrate offers attachment sites. Some plants are free floating at the water's surface in dense mats like duckweed or water hyacinth. Others are rooted and may be classified as submerged or emergent. Rooted plants usually occur in areas of slackened current where fine-grained soils are found (Brown 1987). These rooted plants are flexible, with elongated leaves that offer minimal resistance to current.

Living in flowing water can be beneficial to plants and algae because the current is usually well aerated and it provides a continuous supply of nutrients. These organisms are limited by flow, light, water chemistry, substrate and grazing pressure. Algae and plants are important to lotic systems as sources of energy, for forming microhabitats that shelter other fauna from predators and the current and as a food resource (Brown 1987).

Insects and other invertebrates

Up to 90% of invertebrates in some lotic systems are insects. These species exhibit tremendous diversity and can be found occupying almost every available habitat, including the surfaces of stones, deep below the substratum, adrift in the current and in the surface film. Insects have developed several strategies for living in the diverse flows of lotic systems. Some avoid high current areas, inhabiting the substratum or the sheltered side of rocks. In stronger current, species have developed weighted cases, attachments to anchored pads of silk, recurved clinging claws, suction cup like devices and flattened, streamlined bodies (Hynes 1970; Brown 1987). Additional invertebrate taxa common to flowing waters include mollusks such as snails, limpets, clams, mussels, as well as crustaceans like crayfish and crabs. Like most of the primary consumers, lotic invertebrates often rely heavily on the current to bring them food and oxygen (Brown 1987). Invertebrates, especially insects, are important as both consumers and prey items in lotic systems.

Fish and other vertebrates

The brook trout is native to small streams, creeks, lakes and spring ponds

New Zealand longfin eels can weigh over 50 kilograms

Fishes are probably the best-known inhabitants of lotic systems. The ability of a fish species to live in flowing waters depends upon the speed at which it can swim and the duration that its speed can be maintained. This ability can vary greatly between species and is tied to the habitat in which it can survive. Continuous swimming expends a tremendous amount of energy and, therefore, fishes spend only short periods in full current. Instead, individuals remain close to the bottom or the banks, behind obstacles and sheltered from the current, swimming in the current only to feed or change locations. Some species have adapted to living only on the system bottom, never venturing into the open water flow. These fishes are dorso-ventrally flattened to reduce flow resistance and often have eyes on top of their heads to observe what is happening above them. Some also have sensory barrels positioned under the head to assist in the testing of substratum (Brown 1987).

Lotic systems typically connect to each other, forming a path to the ocean (spring → stream → river → ocean) and many fishes have life cycles that require stages in both fresh and salt water. Salmon, for example, are anadromous species that are born and develop in freshwater and then move to the ocean as adults. Eels are catadromous and are born and develop in the ocean and then move into freshwater as adults.

Other vertebrate taxa that inhabit lotic systems include amphibians, such as salamanders, reptiles (e.g. snakes, turtles, crocodiles and alligators) various bird species and mammals (e.g., otters, beavers, hippos and river dolphins). With the exception of a few species, these vertebrates are not tied to water as fishes are and spend part of their time in terrestrial habitats. Many fish species are important as consumers and as prey species to the larger vertebrates mentioned above.

Trophic relationships

Energy inputs

Pondweed is an autochthonous energy source

Leaf litter is an allochthonous energy source

Energy sources can be autochthonous or allochthonous.

- **Autochthonous** energy sources are those derived from within the lotic system. During photosynthesis, for example, primary producers form organic carbon compounds out of carbon dioxide and inorganic matter. The energy they produce is important for the community because it may be transferred to higher trophic levels via consumption. Additionally, high rates of primary production can introduce dissolved organic matter (DOM) to the waters. Another form of autochthonous energy comes from the decomposition of dead organisms and feces that originate within the lotic system. In this case, bacteria decompose the detritus or coarse particulate organic material (CPOM; >1 mm pieces) into fine organic particulate matter (FPOM; <1 mm pieces) and then further into inorganic compounds that are required for photosynthesis. This process is discussed in more detail below.

- **Allochthonous** energy sources are those derived from outside the lotic system, that is, from the terrestrial environment. Leaves, twigs, fruits, etc. are typical forms of terrestrial CPOM that have entered the water by direct litterfall or lateral leaf blow. In addition, terrestrial animal-derived materials, such as feces or carcasses that have been added to the system are examples of allochthonous

CPOM. The CPOM undergoes a specific process of degradation. Allan gives the example of a leaf fallen into a stream. First, the soluble chemicals are dissolved and leached from the leaf upon its saturation with water. This adds to the DOM load in the system. Next, microbes such as bacteria and fungi colonize the leaf, softening it as the mycelium of the fungus grows into it. The composition of the microbial community is influenced by the species of tree from which the leaves are shed (Rubbo and Kiesecker 2004). This combination of bacteria, fungi and leaf are a food source for shredding invertebrates, which leave only FPOM after consumption. These fine particles may be colonized by microbes again or serve as a food source for animals that consume FPOM. Organic matter can also enter the lotic system already in the FPOM stage by wind, surface runoff, bank erosion, or groundwater. Similarly, DOM can be introduced through canopy drip from rain or from surface flows.

Invertebrates

Invertebrates can be organized into many feeding guilds in lotic systems. Some species are shredders, which use large and powerful mouth parts to feed on non-woody CPOM and their associated microorganisms. Others are suspension feeders, which use their setae, filtering aparati, nets, or even secretions to collect FPOM and microbes from the water. These species may be passive collectors, utilizing the natural flow of the system, or they may generate their own current to draw water and also, FPOM in Allan. Members of the gatherer-collector guild actively search for FPOM under rocks and in other places where the stream flow has slackened enough to allow deposition. Grazing invertebrates utilize scraping, rasping and browsing adaptations to feed on periphyton and detritus. Finally, several families are predatory, capturing and consuming animal prey. Both the number of species and the abundance of individuals within each guild is largely dependent upon food availability. Thus, these values may vary across both seasons and systems.

Fish

Fish can also be placed into feeding guilds. Planktivores pick plankton out of the water column. Herbivore-detritovores are bottom-feeding species that ingest both periphyton and detritus indiscriminately. Surface and water column feeders capture surface prey (mainly terrestrial and emerging insects) and drift (benthic invertebrates floating downstream). Benthic invertebrate feeders prey primarily on immature insects, but will also consume other benthic invertebrates. Top predators consume fishes and/or large invertebrates. Omnivores ingest a wide range of prey. These can be floral, faunal and/or detrital in nature. Finally, parasites live off of host species, typically other fishes. Fish are flexible in their feeding roles, capturing different prey with regard to seasonal availability and their own developmental stage. Thus, they may occupy multiple feeding guilds in their lifetime. The number of species in each guild can vary greatly between systems, with temperate warm water streams having the most benthic invertebrate feeders and tropical systems having large numbers of detritus feeders due to high rates of allochthonous input.

Community patterns and diversity

Iguazu Falls - an extreme lotic environment

Local species richness

Large rivers have comparatively more species than small streams. Many relate this pattern to the greater area and volume of larger systems, as well as an increase in habitat diversity. Some systems, however, show a poor fit between system size and species richness. In these cases, a combination of factors such as historical rates of speciation and extinction, type of substrate, microhabitat availability, water chemistry, temperature and disturbance such as flooding seem to be important.

Resource partitioning

Although many alternate theories have been postulated for the ability of guild-mates to coexist, resource partitioning has been well documented in lotic systems as a means of reducing competition. The three main types of resource partitioning include habitat, dietary and temporal segregation.

Habitat segregation was found to be the most common type of resource partitioning in natural systems (Schoener, 1974). In lotic systems, microhabitats provide a level of physical complexity that can support a diverse array of organisms (Vincin and Hawknis, 1998). The separation of species by substrate preferences has been well documented for invertebrates. Ward (1992) was able to divide substrate dwellers into 6 broad assemblages, including those that live in: coarse substrate, gravel, sand, mud, woody debris and those associated with plants, showing one layer of segregation. On a smaller scale, further habitat partitioning can occur on or around a single substrate, such as a piece of gravel. Some invertebrates prefer the high flow areas on the exposed top of the gravel, while others reside in the crevices between one piece of gravel and the next, while still others live on the bottom of this gravel piece.

Dietary segregation is the second-most common type of resource partitioning. High degrees of morphological specializations or behavioral differences allow organisms to use specific resources. The size of nets built by some species of invertebrate suspension feeders, for example, can filter varying particle size of FPOM from the water (Edington et al. 1984). Similarly, members in the grazing guild can specialize in the harvesting of algae or detritus depending upon the morphology of their scraping apparatus. In addition, certain species seem to show a preference for specific algal species.

Temporal segregation is a less common form of resource partitioning, but it is nonetheless an observed phenomenon. Typically, it accounts for coexistence by relating it to differences in life history patterns and the timing of maximum growth among guild mates. Tropical fishes in Borneo, for example, have shifted to shorter life spans in response to the ecological niche reduction felt with increasing levels of species richness in their ecosystem (Watson and Balon 1984).

Persistence and succession

Over long time scales, there is a tendency for species composition in pristine systems to remain in a stable state. This has been found for both invertebrate and fish species. On shorter times scales, however, flow variability and unusual precipitation patterns decrease habitat stability and can all lead to declines in persistence levels. The ability to maintain this persistence over long time scales is related to the ability of lotic systems to return to the original community configuration relatively quickly after a disturbance (Townsend et al. 1987). This is one example of temporal succession, a site-specific change in a community involving changes in species composition over time. Another form of temporal succession might occur when a new habitat is opened up for colonization. In

these cases, an entirely new community that is well adapted to the conditions found in this new area can establish itself.

River continuum concept

Meandering stream in Waitomo, New Zealand

River Gryffe in Scotland

A rocky stream in the U.S. state of Hawaii

The River continuum concept (RCC) was an attempt to construct a single framework to describe the function of temperate lotic ecosystems from the source to the end and relate it to changes in the biotic community (Vannote et al. 1980). The physical basis for RCC is size and location along the gradient from a small stream eventually linked to a large river. Stream order is used as the physical measure of the position along the RCC.

According to the RCC, low ordered sites are small shaded streams where allochthonous inputs of CPOM are a necessary resource for consumers. As the river widens at mid-ordered sites, energy inputs should change. Ample sunlight should reach the bottom in these systems to support significant periphyton production. Additionally, the biological processing of CPOM (Coarse Particulate Organic Matter - larger than 1 mm) inputs at upstream sites is expected to result in the transport of large amounts of FPOM (Fine Particulate Organic Matter - smaller than 1 mm) to these downstream ecosystems. Plants should become more abundant at edges of the river with increasing river size, especially in lowland rivers where finer sediments have been deposited and facilitate rooting. The main channels likely have too much current and turbidity and a lack of substrate to support plants or periphyton. Phytoplankton should produce the only autochthonous inputs here, but photosynthetic rates will be limited due to turbidity and mixing. Thus, allochthonous inputs are expected to be the primary energy source for large rivers. This

FPOM will come from both upstream sites via the decomposition process and through lateral inputs from floodplains.

Biota should change with this change in energy from the headwaters to the mouth of these systems. Namely, shredders should prosper in low-ordered systems and grazers in mid-ordered sites. Microbial decomposition should play the largest role in energy production for low-ordered sites and large rivers, while photosynthesis, in addition to degraded allochthonous inputs from upstream will be essential in mid-ordered systems. As mid-ordered sites will theoretically receive the largest variety of energy inputs, they might be expected to host the most biological diversity (Vannote et al. 1980)

Just how well the RCC actually reflects patterns in natural systems is uncertain and its generality can be a handicap when applied to diverse and specific situations. The most noted criticisms of the RCC are: 1. It focuses mostly on macroinvertebrates, disregarding that plankton and fish diversity is highest in high orders; 2. It relies heavily on the fact that low ordered sites have high CPOM inputs, even though many streams lack riparian habitats; 3. It is based on pristine systems, which rarely exist today; and 4. It is centered around the functioning of temperate streams. Despite its shortcomings, the RCC remains a useful idea for describing how the patterns of ecological functions in a lotic system can vary from the source to the mouth.

Human impacts

Pollution

Pollutant sources of lotic systems are hard to control because they derive, often in small amounts, over a very wide area and enter the system at many locations along its length. Agricultural fields often deliver large quantities of sediments, nutrients and chemicals to nearby streams and rivers. Urban and residential areas can also add to this pollution when contaminants are accumulated on impervious surfaces such as roads and parking lots that then drain into the system. Elevated nutrient concentrations, especially nitrogen and phosphorus which are key components of fertilizers, can increase periphyton growth, which can be particularly dangerous in slow moving streams. Another pollutant, acid rain, forms from sulfur dioxide and nitrous oxide emitted from factories and power stations. These substances readily dissolve in atmospheric moisture and enter lotic systems through precipitation. This can lower the pH of these sites, affecting all trophic levels from algae to vertebrates (Brown 1987). Mean species richness and total species numbers within a system decrease with decreasing pH.

While direct pollution of lotic systems has been greatly reduced in the United States under the government's Clean Water Act, contaminants from diffuse, non-point sources, remain a large problem.

Flow modification

A weir on the River Calder, West Yorkshire

Dams alter the flow, temperature and sediment regime of lotic systems. Additionally, many rivers are dammed at multiple locations, amplifying the impact. Dams can cause enhanced clarity and reduced variability in stream flow, which is due to an increase in periphyton abundance. Invertebrates immediately below a dam can show reductions in species richness due to an overall reduction in habitat heterogeneity. Also, thermal changes can affect insect development, with abnormally warm winter temperatures obscuring cues to break egg diapause and overly cool summer temperatures leaving too few acceptable days to complete growth. Finally, dams fragment river systems, isolating previously continuous populations and preventing the migrations of anadromous and catadromous species.

Invasive species

Invasive species have been introduced to lotic systems through both purposeful events (e.g. stocking game and food species) as well as unintentional events (e.g. hitchhikers on boats or fishing waders). These organisms can affect natives via competition for prey or habitat, predation, habitat alteration, hybridization, or the introduction of harmful diseases and parasites. Once established, these species can be difficult to control or eradicate, particularly because of the connectivity of lotic systems. Invasive species can

be especially harmful in areas that have endangered biota, such as mussels in the Southeast United States, or those that have localized endemic species, like lotic systems west of the Rocky Mountains, where many species evolved in isolation.

Chapter- 5

Coral Reef

Coral reefs are underwater structures made from calcium carbonate secreted by corals. Corals are colonies of tiny living animals found in marine waters containing few nutrients. Most coral reefs are built from stony corals and are formed by polyps that live together in groups. The polyps secrete a hard carbonate exoskeleton which provides support and protection for the body of each polyp. Reefs grow best in warm, shallow, clear, sunny and agitated waters.

Often called "rainforests of the sea", coral reefs form some of the most diverse ecosystems on earth. They occupy less than one tenth of one percent of the world ocean surface, about half the area of France, yet they provide a home for twenty-five percent of all marine species, including fish,molluscs,worms, crustaceans, echinoderms, sponges, tunicates and other cnidarians. Paradoxically, coral reefs flourish even though they are surrounded by ocean waters that provide few nutrients. They are most commonly found at shallow depths in tropical waters, but deep water and cold water corals also exist on smaller scales in other areas.

Coral reefs deliver ecosystem services to tourism, fisheries and shoreline protection. The annual global economic value of coral reefs has been estimated at $30 billion. However, coral reefs are fragile ecosystems, partly because they are very sensitive to water temperature. They are under threat from climate change, ocean acidification, blast fishing, cyanide fishing for aquarium fish, overuse of reef resources and harmful land-use practices, including urban and agricultural runoff and water pollution, which can harm reefs by encouraging excess algae growth.

Reef structure

Types

The three principal reef types are:

- **Fringing reef** – a reef that is directly attached to a shore or borders it with an intervening shallow channel or lagoon
- **Barrier reef** – a reef separated from a mainland or island shore by a deep channel or lagoon

- **Atoll reef** – a more or less circular or continuous barrier reef extending all the way around a lagoon without a central island

A small atoll in the Maldives

Inhabited cay in the Maldives

Other reef types or variants are:

- **Patch reef** – an isolated, comparatively small reef outcrop, usually within a lagoon or embayment, often circular and surrounded by sand or seagrass. Patch reefs are common
- **Apron reef** – a short reef resembling a fringing reef, but more sloped; extending out and downward from a point or peninsular shore
- **Bank reef** – a linear or semi-circular shaped-outline, larger than a patch reef.
- **Ribbon reef** – a long, narrow, possibly winding reef, usually associated with an atoll lagoon
- **Table reef** – an isolated reef, approaching an atoll type, but without a lagoon.
- **Habili** - reef in the Red Sea that does not reach the surface near enough to cause visible surf, although it may a hazard to ships (from the Arabic for "unborn")
- **Microatolls** – certain species of corals form communities called microatolls. The vertical growth of microatolls is limited by average tidal height. By analysing growth morphologies, microatolls offer a low resolution record of patterns of sea level change. Fossilized microatolls can also be dated using radioactive carbon dating. Such methods have been used to reconstruct Holocene sea levels.

- **Cays** – small, low-elevation, sandy islands formed on the surface of a coral reef. Material eroded from the reef piles up on parts of the reef or lagoon, forming an area above sea level. Plants can stabilize cays enough to become habitable by

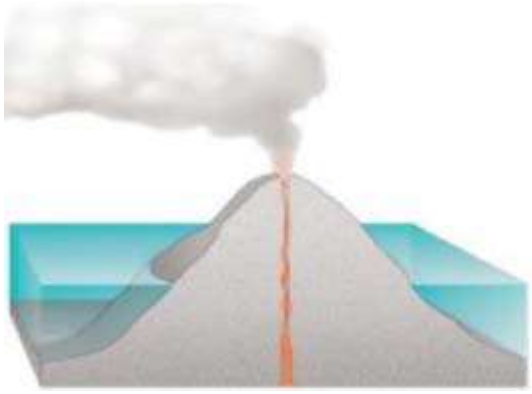
humans. Cays occur in tropical environments throughout the Pacific, Atlantic and Indian Oceans (including the Caribbean and on the Great Barrier Reef and Belize Barrier Reef), where they provide habitable and agricultural land for hundreds of thousands of people.

- When a coral reef cannot keep up with the sinking of a volcanic island, a **seamount** or **guyot** is formed. The tops of seamounts and guyots are below the surface. Seamounts are rounded at the top and guyots are flat. The flat top of the guyot, also called a *tablemount*, is due to erosion by waves, winds and atmospheric processes.

Formation

Most coral reefs were formed after the last glacial period when melting ice caused the sea level to rise and flood the continental shelves. This means that most coral reefs are less than 10,000 years old. As coral reef communities were established on the shelves, they built reefs that grew upwards, keeping pace with the rise in sea level. Reefs that didn't keep pace could become *drowned reefs*, covered by so much water that there was insufficient light for further survival. Coral reefs are also found in the deep sea away from the continental shelves, around oceanic islands and as atolls. The vast majority of these ocean coral islands are volcanic in origin. The few exceptions have tectonic origins where plate movements have lifted the deep ocean floor on the surface.

In 1842 in his first monograph, *The Structure and Distribution of Coral Reefs* Charles Darwin set out his theory of the formation of atoll reefs, an idea he conceived during the voyage of the *Beagle*. His theory was that atolls were formed by the uplift and subsidence of the Earth's crust under the oceans. Darwin's theory sets out a sequence of three stages in atoll formation. It starts with a fringing reef forming around an extinct volcanic island as the island and ocean floor subsides. As the subsidence continues, the fringing reef becomes a barrier reef and ultimately an atoll reef.



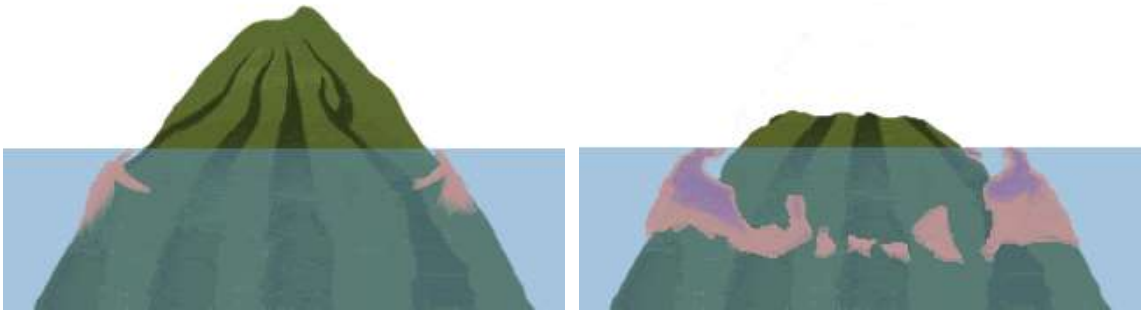
Darwin's theory starts with a volcanic island which becomes extinct

As the island and ocean floor subside, coral growth builds a fringing reef, often including a shallow lagoon between the land and the main reef

As the subsidence continues the fringing reef becomes a larger barrier reef further from the shore with a bigger and deeper lagoon inside

Ultimately the island sinks below the sea and the barrier reef becomes an atoll enclosing an open lagoon

Darwin predicted that underneath each lagoon would be a bed rock base, the remains of the original volcano. Subsequent drilling proved this correct. Darwin's theory followed from his understanding that coral polyps thrive in the clean seas of the tropics where the water is agitated, but can only live within a limited depth of water, starting just below low tide. Where the level of the underlying land stays the same, the corals grow around the coast to form what he called fringing reefs and can eventually grow out from the shore to become a barrier reef.



A fringing reef can take ten thousand years to form and an atoll can take up to 30 million years

Where the land is rising, fringing reefs can grow around the coast, but coral raised above sea level dies and becomes white limestone. If the land subsides slowly, the fringing reefs keep pace by growing upwards on a base of dead coral, forming a barrier reef enclosing a lagoon between the reef and the land. A barrier reef can encircle an island and once the island sinks below sea level a roughly circular atoll of growing coral continues to keep up with the sea level, forming a central lagoon. Barrier reefs and atolls don't usually form complete circles, but are broken in places by storms. Should the land subside too quickly or sea level rise too fast, the coral dies as it is below its habitable depth.

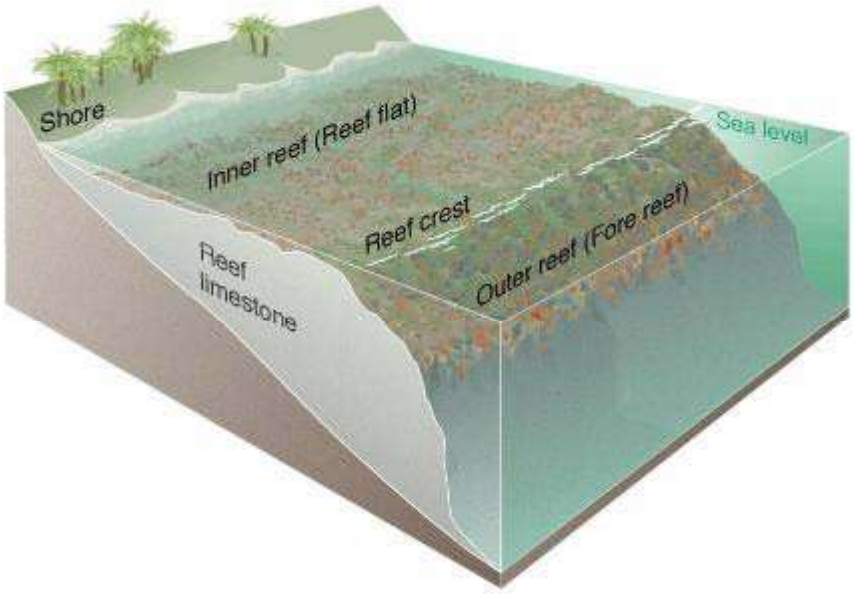
In general, the two main variables determining the geomorphology, or shape, of coral reefs are the nature of the underlying substrate on which they rest and the history of the change in sea level relative to that substrate.

As an example of how coral reefs have formed on continental shelves, the current living reef structure of the Great Barrier Reef began growing about 20,000 years ago. Sea level was then 120 metres (390 ft) lower than it is today. As sea level rose, the water and the corals encroached on what had been hills of the Australian coastal plain. By 13,000 years ago sea level had risen to 60 metres (200 ft) lower than at present and the hills of the coastal plains were, by then, continental islands. As the sea level rise continued, water topped most of the continental islands. The corals could then overgrow the hills, forming the present cays and reefs. Sea level on the Great Barrier Reef has not changed significantly in the last 6,000 years and the age of the present living reef structure is estimated to be between 6,000 and 8,000 years. Although the Great Barrier Reef formed along a continental shelf and not around a volcanic island, Darwin's principles apply. The Great Barrier Reef development stopped at the barrier reef stage, since Australia is not about to submerge. It formed the world's largest barrier reef, 300–1,000 metres (980–3,300 ft) from shore, stretching for 2,000 kilometres (1,200 mi).

Healthy coral reefs grow horizontally from 1 to 3 centimetres (0.39 to 1.2 in) per year and grow vertically anywhere from 1 to 25 centimetres (0.39 to 9.8 in) per year; however,

they grow only at depths shallower than 150 metres (490 ft) due to their need for sunlight and cannot grow above sea level.

Zones



The three major zones of a coral reef: the fore reef, reef crest and the back reef

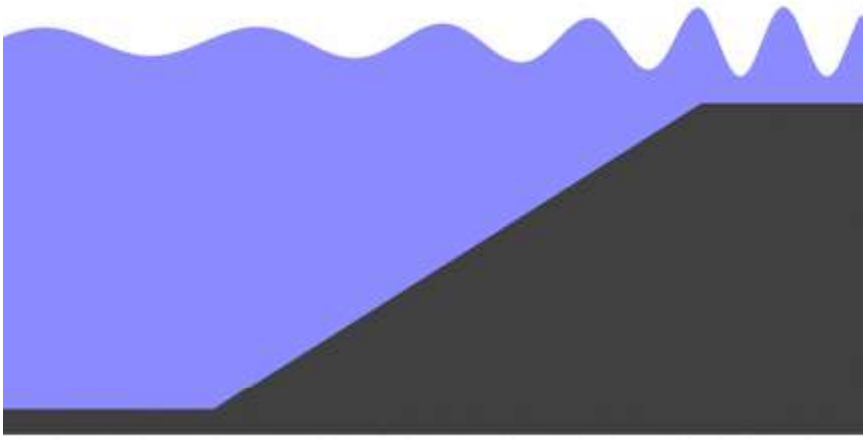
Coral reef ecosystems contain distinct zones that represent different kinds of habitats. Usually three major zones are recognized: the fore reef, reef crest and the back reef (frequently referred to as the reef lagoon).

All three zones are physically and ecologically interconnected. Reef life and oceanic processes create opportunities for exchange of seawater, sediments, nutrients and marine life among one another.

Thus, they are integrated components of the coral reef ecosystem, each playing a role in the support of the reefs' abundant and diverse fish assemblages.

Most coral reefs exist in shallow waters less than fifty metres deep. Some inhabit tropical continental shelves where cool, nutrient rich upwelling does not occur, such as Great Barrier Reef. Others are found in the deep ocean surrounding islands or as atolls, such as in the Maldives. The reefs surrounding islands form when islands subside into the ocean and atolls form when an island subsides below the surface of the sea.

Alternatively, Moyle and Cech distinguish six zones, though most reefs possess only some of the zones.



Water in the reef surface zone is often agitated. This diagram represents a reef on a continental shelf. The water waves at the left travel over the *off-reef floor* until they encounter the *reef slope* or *fore reef*. Then the waves pass over the shallow *reef crest*. When a wave enters shallow water it shoals, that is, it slows down and the wave height increases.

- **The reef surface** is the shallowest part of the reef. It is subject to the surge and the rise and fall of tides. When waves pass over shallow areas, they shoal, as shown in the diagram at the right. This means that the water is often agitated. These are the precise condition under which coral flourish. Shallowness means there is plenty of light for photosynthesis by the symbiotic zooxanthellae and agitated water promotes the ability of coral to feed on plankton. However other organisms must be able to withstand the robust conditions to flourish in this zone.

- **The off-reef floor** is the shallow sea floor surrounding a reef. This zone occurs by reefs on continental shelves. Reefs around tropical islands and atolls drop abruptly to great depths and don't have a floor. Usually sandy, the floor often supports seagrass meadows which are important foraging areas for reef fish.

- **The reef drop-off** is, for its first 50 metres, habitat for many reef fish who find shelter on the cliff face and plankton in the water nearby. The drop-off zone applies mainly to the reefs surrounding oceanic islands and atolls.

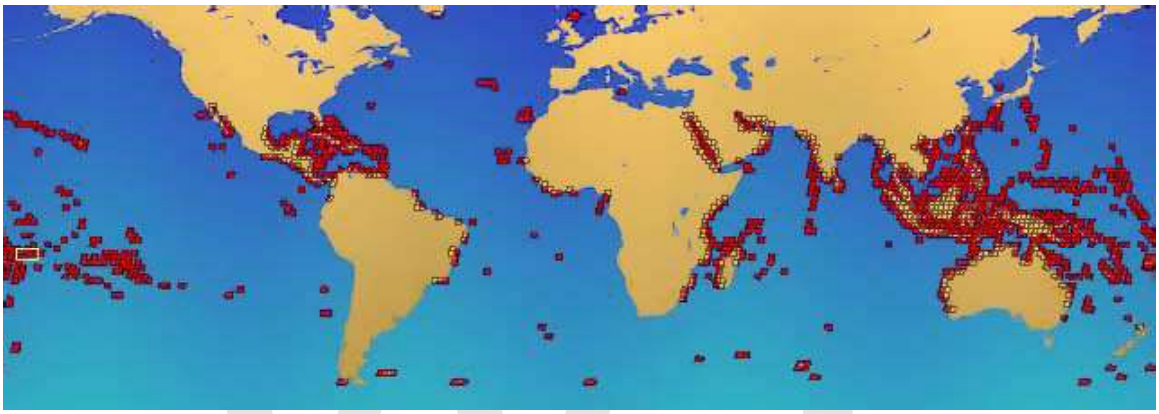
- **The reef face** is the zone above the reef floor or the reef drop-off. "It is usually the richest habitat. Its complex growths of coral and calcareous algae provide cracks and crevices for protection and the abundant invertebrates and epiphytic algae provide an ample source of food."

- **The reef flat** – sandy bottomed flat can be behind the main reef, containing chunks of coral. "The reef flat may be a protective area bordering a lagoon, or it may be a flat, rocky area between the reef and the shore. In the former case, the number of fish species living in the area often is the highest of any reef zone."

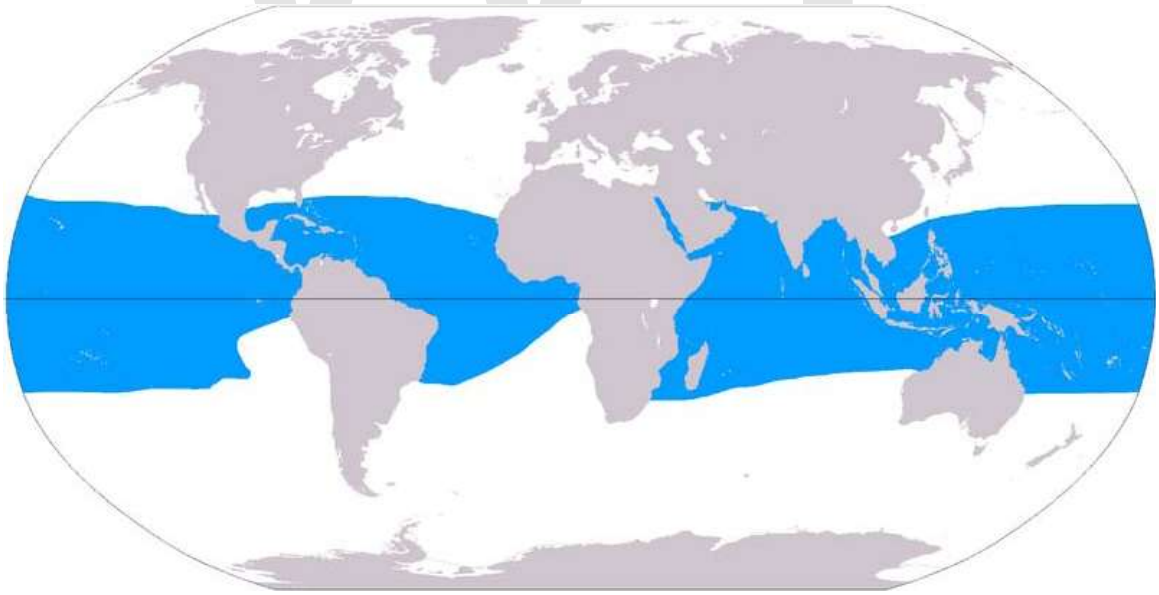
- **The reef lagoon** – "many coral reefs completely enclose an area, thereby creating a quiet-water lagoon that usually contains small patches of reef."

However, the "topography of coral reefs is constantly changing. Each reef is made up of irregular patches of algae, sessile invertebrates and bare rock an sand. The size, shape and relative abundance of these patches changes from year to year in response to the various factors that favour one type of patch over another. Growing coral, for example, produces constant change in the fine structure of reefs. On a larger scale, tropical storms may knock out large sections of reef and cause boulders on sandy areas to move."

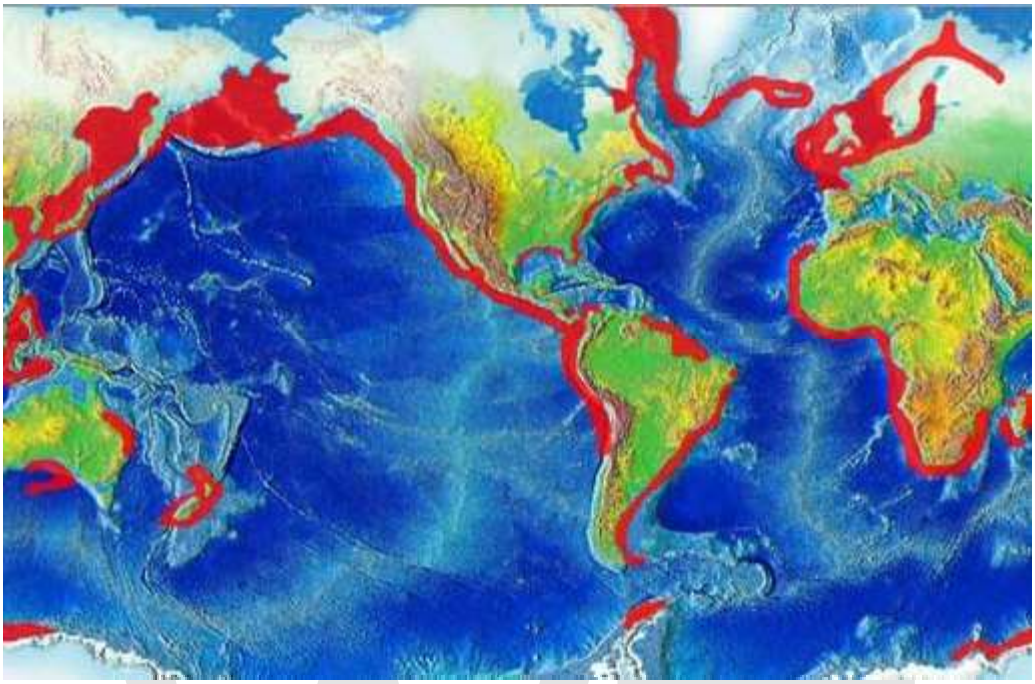
Distribution



Locations of coral reefs



Boundary for 20 °C isotherms. Most corals live within this boundary. Note the cooler waters caused by upwelling on the south west coast of Africa and off the coast of Peru.



This map shows areas of upwelling in red. Coral reefs are not found in coastal areas where colder and nutrient-rich upwellings occur

Coral reefs are estimated to cover 284,300 square kilometers (109,800 sq mi), which is just under one tenth of one percent of the oceans' surface area. The Indo-Pacific region (including the Red Sea, Indian Ocean, Southeast Asia and the Pacific) account for 91.9% of this total. Southeast Asia accounts for 32.3% of that figure, while the Pacific including Australia accounts for 40.8%. Atlantic and Caribbean coral reefs account for 7.6%.

Although corals exist both in temperate and tropical waters, shallow-water reefs form only in a zone extending from 30° N to 30° S of the equator. Tropical corals do not grow at depths of over 50 meters (160 ft). The optimum temperature for most coral reefs is 26–27 °C (79–81 °F) and few reefs exist in waters below 18 °C (64 °F). However reefs in the Persian Gulf have adapted to temperatures of 13 °C (55 °F) in winter and 38 °C (100 °F) in summer.

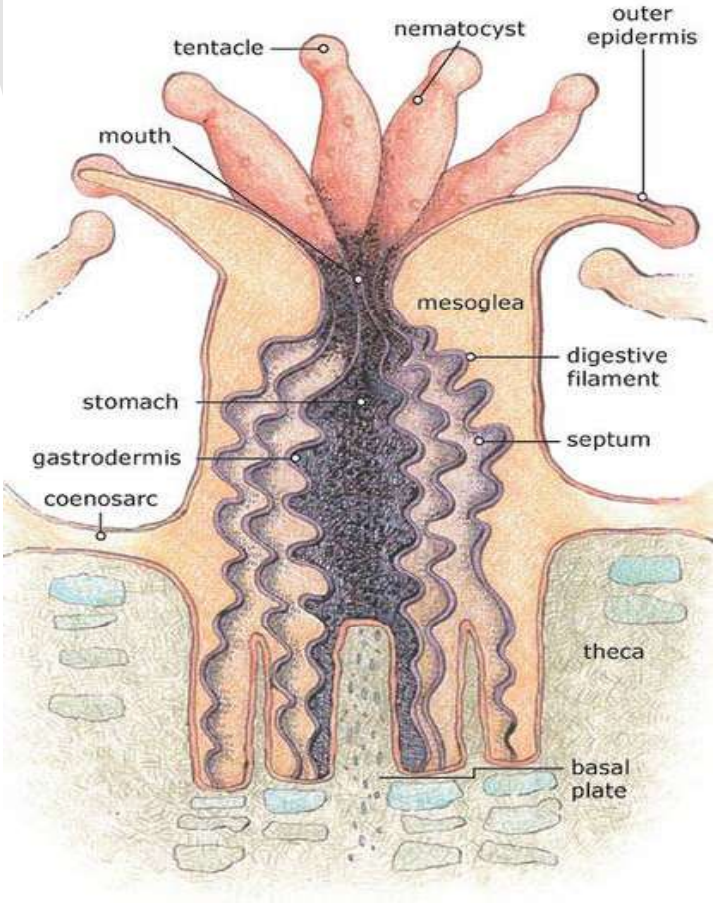
Deep water coral can exist at greater depths and colder temperatures. Although deep water corals can form reefs, very little is known about them.

Coral reefs are rare along the American west coast, as well as along the African west coast. This is due primarily to upwelling and strong cold coastal currents that reduce water temperatures in these areas (respectively the Peru, Benguela and Canary streams). Corals are seldom found along the coastline of South Asia from the eastern tip of India (Madras) to the border of Bangladesh and Myanmar. They are also rare along the coast around north-eastern South America and Bangladesh due to the freshwater release from the Amazon and Ganges Rivers respectively.

Principal coral reefs and reef areas

- The Great Barrier Reef - largest, comprising over 2,900 individual reefs and 900 islands stretching for over 2,600 kilometers (1,616 mi) off Queensland, Australia
- The Mesoamerican Barrier Reef System - second largest, stretching 1,000 kilometers (621 mi) from Isla Contoy at the tip of the Yucatán Peninsula down to the Bay Islands of Honduras
- The New Caledonia Barrier Reef - second longest double barrier reef, covering 1,500 kilometers (930 mi)
- The Andros, Bahamas Barrier Reef - third largest, following the east coast of Andros Island, Bahamas, between Andros and Nassau
- The Red Sea Coral Reef - located off the coast of Israel, Egypt, Sudan, Eritrea, Djibouti, Somalia, Jordan, Saudi Arabia and Yemen
- Pulley Ridge - deepest photosynthetic coral reef, Florida
- Numerous reefs scattered over the Maldives
- Ghe Raja Ampat Islands in Indonesia's West Papua province offer the highest known marine diversity.

Coral biology



Anatomy of a coral polyp

Live coral are small animals embedded in calcium carbonate shells. It is a mistake to think of coral as plants or rocks. Coral heads consist of accumulations of individual animals called polyps, arranged in diverse shapes. Polyps are usually tiny, but they can range in size from a pinhead to a foot across. Reef-building or hermatypic corals live only in the photic zone (above 50 m depth), the depth to which sufficient sunlight penetrates the water for photosynthesis to occur. Coral polyps do not themselves photosynthesize, but have a symbiotic relationship with single-celled organisms called zooxanthellae; these organisms live within the tissues of polyps and provide organic nutrients that nourish the polyp. Because of this relationship, coral reefs grow much faster in clear water, which admits more sunlight. Indeed, the relationship is responsible for coral reefs in the sense that without their symbionts, coral growth would be too slow for the corals to form significant reef structures. Corals get up to 90% of their nutrients from their zooxanthellae symbionts.

Reefs grow as polyps and other organisms deposit calcium carbonate,the basis of coral, as a skeletal structure beneath and around themselves, pushing the coral head's top upwards and outwards. Waves, grazing fish (such as parrotfish), sea urchins, sponges and other forces and organisms act as bioeroders, breaking down coral skeletons into fragments that settle into spaces in the reef structure or form sandy bottoms in associated reef lagoons. Many other organisms living in the reef community contribute skeletal calcium carbonate in the same manner. Coralline algae are important contributors to reef structure in those parts of the reef subjected to the greatest forces by waves (such as the reef front facing the open ocean). These algae deposit limestone in sheets over the reef surface, thereby strengthening it.

The colonies of the one thousand coral species assume a characteristic shape such as wrinkled brains, cabbages, table tops, antlers, wire strands and pillars.

Table coral

Close up of polyps arrayed on a coral, waving their tentacles. There can be thousands of polyps on a single coral branch.

Reproduction

Corals reproduce both sexually and asexually. Individual polyp uses both reproductive modes within its lifetime. Corals reproduce sexually by either internal or external fertilization. The reproductive cells are found on the mesentery membranes that radiate inward from the layer of tissue that lines the stomach cavity. Some mature adult corals are hermaphroditic; others are exclusively male or female. A few species change sex as they grow.

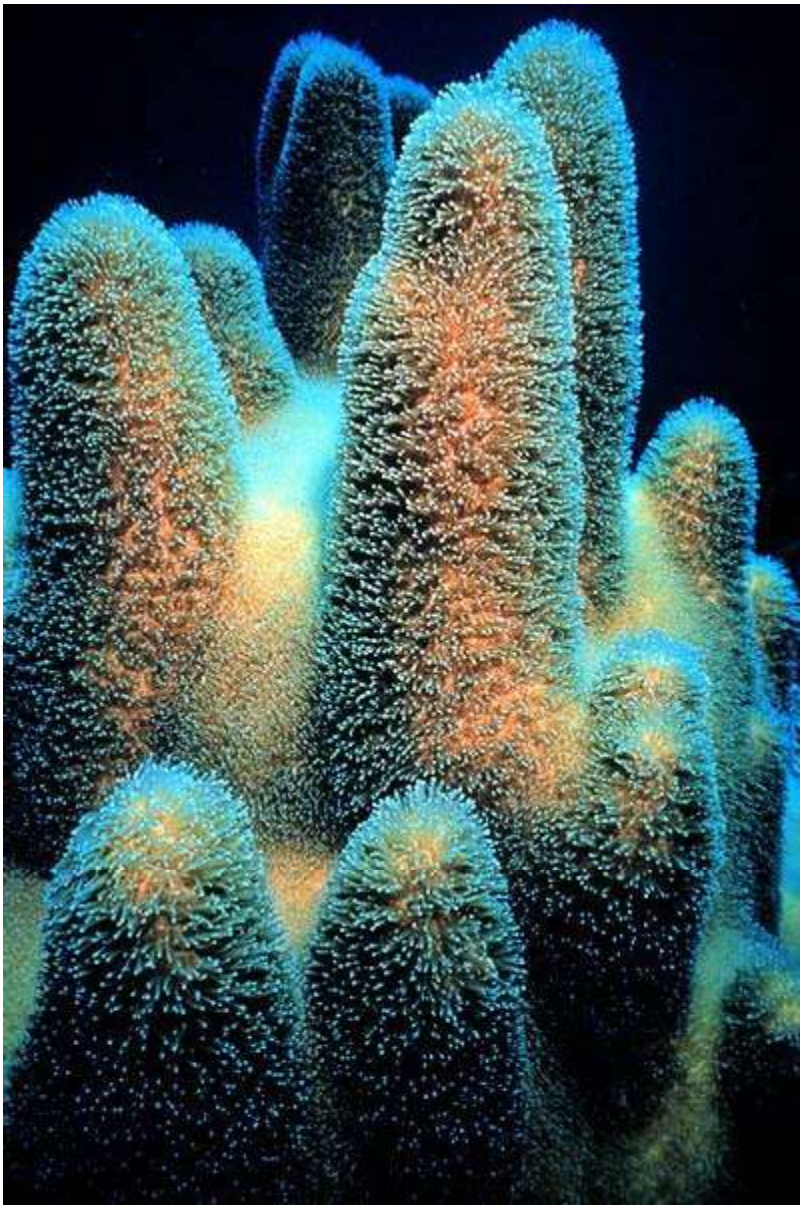
Internally fertilized eggs develop in the polyp for a period ranging from days to weeks. Subsequent development produces a tiny larva, known as a planula. Externally fertilized eggs develop during synchronized spawning. Polyps release eggs and sperm into the water en masse, simultaneously. Eggs disperse over a large area. The timing of spawning depends on time of year, water temperature and tidal and lunar cycles. Spawning is most successful when there is little variation between high and low tides. The less water movement, the better the chance for fertilization. Ideal timing occurs in the spring. Release of eggs or planula usually occurs at night and is sometimes in phase with the lunar cycle (3–6 days after a full moon). The period from release to settlement lasts only a few days, but some planulae can survive afloat for several weeks. They are vulnerable

to predation and environmental conditions. The lucky few who attach to substrate next confront competition for food and space.

Brain coral

Staghorn coral

Spiral wire coral



Pillar coral

Ecology

Darwin's paradox

Darwin's paradox

Coral... seems to proliferate when ocean waters are warm, poor, clear and agitated, a fact which Darwin had already noted when he passed through Tahiti in 1842.

This constitutes a fundamental paradox, shown quantitatively by the apparent impossibility of balancing input and output of the nutritive elements which control the coral polyp metabolism.

Recent oceanographic research has brought to light the reality of this paradox by confirming that the oligotrophy of the ocean euphotic zone persists right up to the swell-battered reef crest. When you approach the reef edges and atolls from the quasi-desert of the open sea, the near absence of living matter suddenly becomes a plethora of life, without transition. So why is there something rather than nothing and more precisely, where do the necessary nutrients for the functioning of this extraordinary coral reef machine come from ? — Francis Rougerie

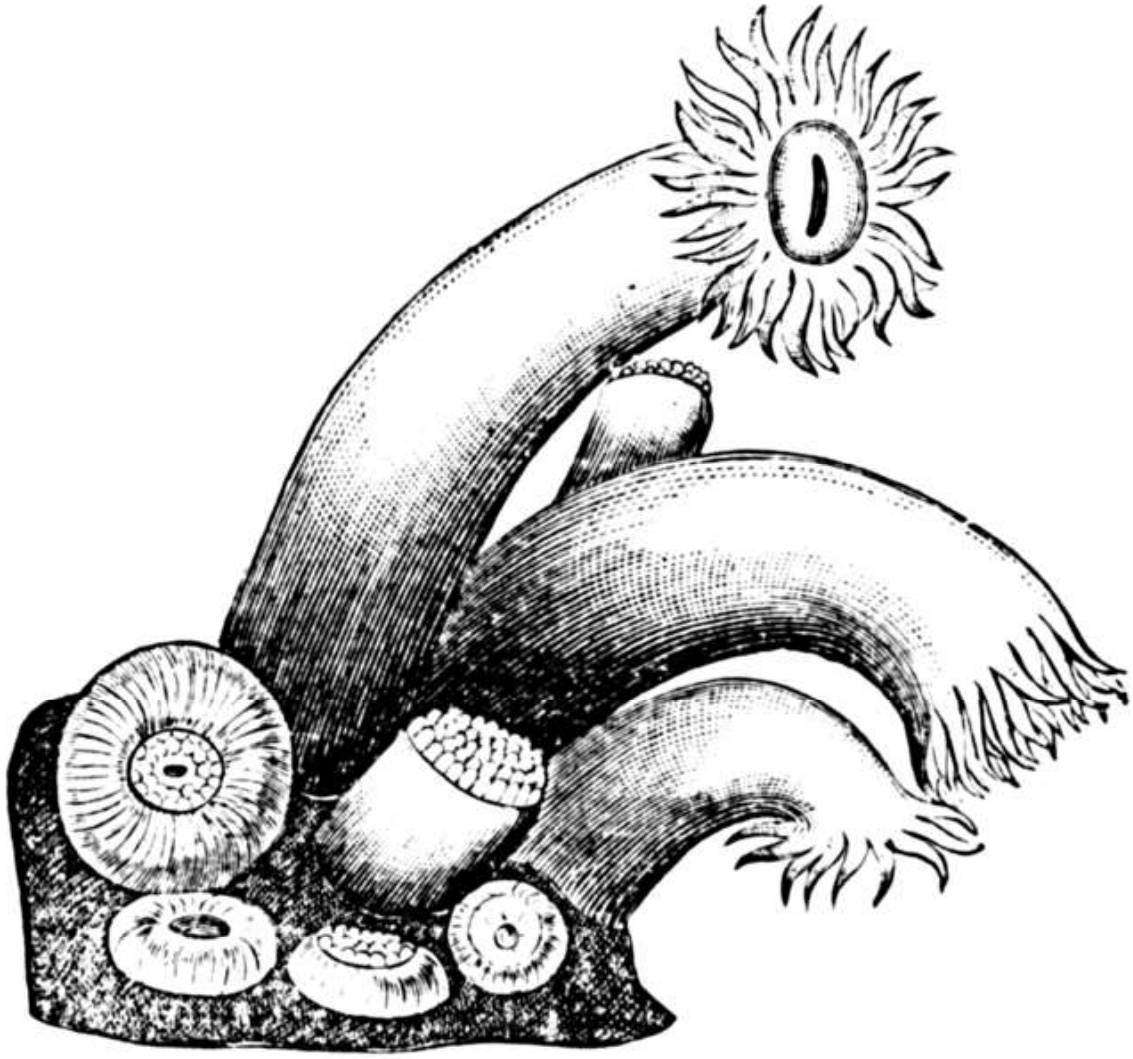
The nutrient paradox

During his voyage on the *Beagle*, Darwin described tropical coral reefs as oases in the desert of the ocean. He reflected on the paradox that tropical coral reefs, which are among the richest and most diverse ecosystems on earth, flourish surrounded by tropical ocean waters that provide hardly any nutrients.

Coral reefs cover less than one tenth of one percent of the surface of the world's ocean, yet they support over one-quarter of all marine species. This huge number of species results in complex food webs, with large predator fish eating smaller forage fish that eat yet smaller zooplankton and so on. However, all food webs eventually depend on plants, which are the primary producers. Coral reefs' primary productivity is very high, typically producting 5-10g C m^{-2} day^{-1} biomass.

One reason for the startling clarity of tropical waters is that they are deficient in nutrients and drifting plankton. Further, the sun shines year round in the tropics, warming the surface layer, making it less dense than subsurface layers. The warmer water is separated from the cooler water by a stable thermocline, where the temperature makes a rapid change. This keeps the warm surface waters floating above the cooler deeper waters. In most parts of the ocean there is little exchange between these layers. Organisms that die in aquatic environments generally sink to the bottom where they decompose. This decomposition releases nutrients in the form of nitrogen (N), phosphorus (P) and potassium (K). These nutrients are necessary for plant growth, but in the tropics they are not directly recycled back to the surface.

Plants form the base of the food chain and need sunlight and nutrients to grow. In the ocean these plants are mainly microscopic phytoplankton which drift in the water column. They need sunlight for photosynthesis, which powers carbon fixation, so they are found only relatively near the surface. But they also need nutrients. Phytoplankton rapidly use nutrients in the surface waters and in the tropics these nutrients are not usually replaced because of the thermocline.



Coral polyps

Solution: retention and recycling

Around coral reefs, lagoons fill in with material eroded from the reef and the island. They become havens for marine life, providing protection from waves and storms.

Most importantly, reefs recycle nutrients, which happens much less in the open ocean. In coral reefs and lagoons, producers include phytoplankton as well as seaweed and coralline algae, especially small types called turf algae, which pass nutrients to corals. The phytoplankton are eaten by fish and crustaceans, who also pass nutrients along the food web. Recycling ensures that fewer nutrients are needed overall to support the community.

Coral reefs support many symbiotic relationships. In particular, zooxanthellae provides energy to coral in the form of glucose, glycerol and amino acids. Zooxanthellae can

provide up to 90% of a coral's energy requirements. In return, as an example of mutualism, the coral shelter the zooxanthellae, averaging one million for every cubic centimetre of coral, with and provide a constant supply of the carbon dioxide it needs for photosynthesis.

The colour of corals depends on the type of zooxanthella they host

Corals also absorb nutrients, including inorganic nitrogen and phosphorus, directly from the water. Many corals extend their tentacles at night to catch zooplankton that brush them when the water is agitated. Zooplankton provide the polyp with nitrogen and the polyp shares some of the nitrogen with the zooxanthellae, which also require this element. The varying pigments in different species of zooxanthellae give corals their different colours. Coral which loses its zooxanthellae becomes white and is said to be bleached, a condition which unless corrected can kill the coral.

Sponges are another key to explaining Darwin's paradox. They live in crevices in the coral reefs. They are efficient filter feeders and in the Red Sea they consume about sixty percent of the phytoplankton that drifts by. The sponges eventually excrete nutrients in a form the corals can use.

Most coral polyps are nocturnal feeders. Here, in the dark, polyps have extended their tentacles to feed on zooplankton

The roughness of coral surfaces is the key to coral survival in agitated waters. Normally a boundary layer of still water surrounds a submerged object, which acts as a barrier. Waves breaking on the extremely rough edges of corals disrupt the boundary layer, allowing the corals access to nutrients. Turbulent water thereby promotes rapid reef growth and lots of branching. Without the nutritional gains brought by rough coral surfaces, even the most effective recycling would leave corals wanting in nutrients.

Cyanobacteria provide soluble nitrates for the reef via nitrogen fixation.

Coral reefs also often depend on surrounding habitats, such as seagrass meadows and mangrove forests, for nutrients. Seagrass and mangroves supply dead plants and animals which are rich in nitrogen and also serve to feed fish and animals from the reef by supplying wood and vegetation. Reefs in turn protect mangroves and seagrass from waves and produce sediment for the mangroves and seagrass to root in.

Biodiversity

Tube sponges attracting cardinal fishes, glassfishes and wrasses

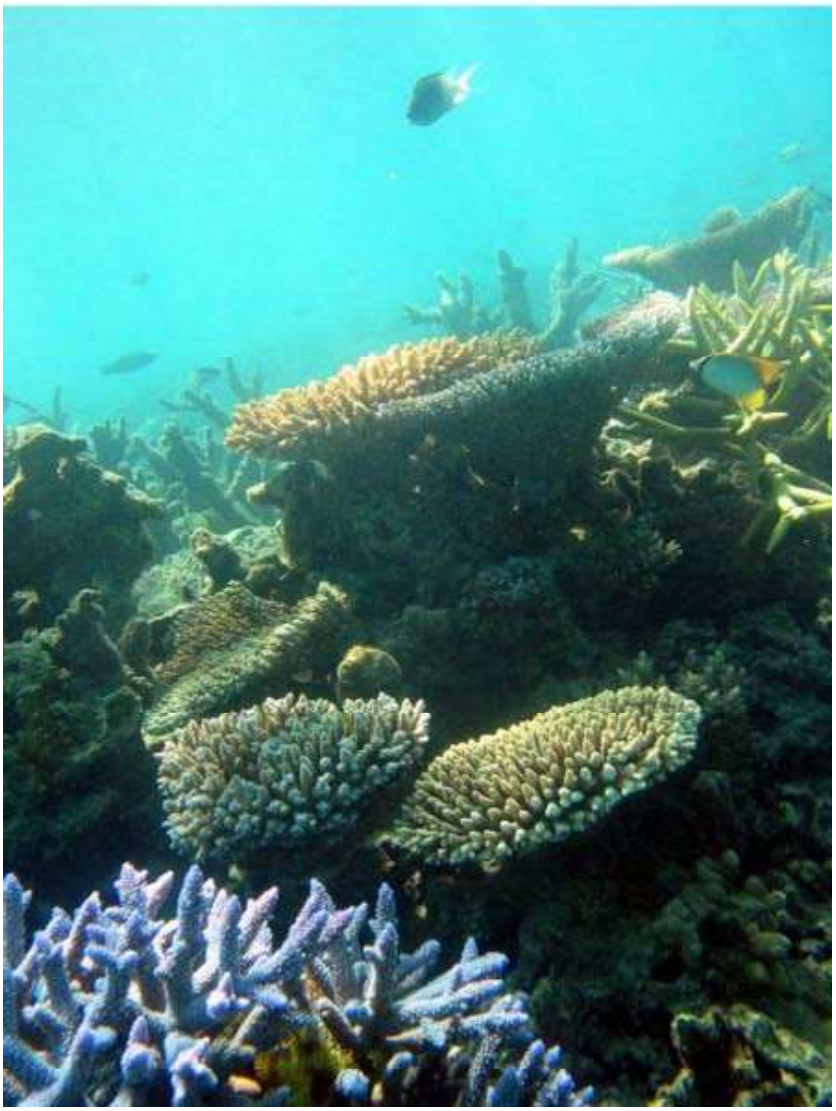
Reefs are home to a large variety of organisms, including fish, seabirds, sponges, Cnidarians (which includes some types of corals and jellyfish), worms, crustaceans (including shrimp, cleaner shrimp, spiny lobsters and crabs), molluscs (including cephalopods), echinoderms (including starfish, sea urchins and sea cucumbers), sea squirts, sea turtles and sea snakes. Aside from humans, mammals are rare on coral reefs, with visiting cetaceans such as dolphins being the main exception. A few of these varied species feed directly on corals, while others graze on algae on the reef.

Fish

Coral reefs are home to a wide variety of tropical or reef fish, among them are the following:

- Fish that influence the coral (such as *Labridae* and parrotfish) These types of fish feed either on small animals living near the coral, seaweed, or on the coral itself. Fish that feed on small animals include cleaner fish (these fish feed on organisms that inhabit larger fish), bullet fish and Balistidae (these eat sea urchins) while seaweed eating fish include the Pomacentridae (damselfishes). Serranidae cultivate the seaweed by removing creatures feeding on it (such as sea urchins) and they remove inedible seaweeds. Fish that eat coral itself include parrotfish and butterflyfish.

- Fish that cruise the boundaries of the reef or nearby seagrass meadows. These include predatory fish such as pompanos, groupers, Horse mackerels, certain types of shark, *Epinephelus marginatus*, barracudas and snappers). Herbivorous and plankton-eating fish also populate reefs. Seagrass-eating fish include Horse mackerel, snapper, Pagellus and Conodon. Plankton-eating fish include Caesio, manta ray, chromis, Holocentridae and pterapogon kauderni.



Organisms can cover every square inch of a coral reef

Fish that swim in coral reefs can be as colorful as the reef. Examples are the parrotfish, angelfish, damselfish, *Pomacanthus paru*, *Clinidae* and butterflyfish. At night, some change to a less vivid color. Besides colorful fish matching their environment, other fish (e.g., predatory and herbivorous fish such as *Lampanyctodes hectoris*, *Holocentridae* and *Pterapogon kauderni*) as well as aquatic animals (Comatulida, Crinoidea and Ophiuroidea) emerge and become active while others rest.

Other fish groups found on coral reefs include groupers, grunts and wrasses. Over 4,000 species of fish inhabit coral reefs. It has been suggested that the fish species that inhabit coral reefs are able to coexist in such high numbers because the reef is "full" in that any free living space is inhabited by the first planktonic fish larvae that find it in what has been termed "a lottery for living space".

Invertebrates

Sea urchins, Dotidae and sea slugs eat seaweed. Some species of sea urchins, such as *Diadema antillarum*, can play a pivotal part in preventing algae overrunning reefs. Nudibranchia and sea anemones eat sponges.

A number of invertebrates, collectively called **cryptofauna**, inhabit the coral skeletal substrate itself, either boring into the skeletons (through the process of bioerosion) or living in pre-existing voids and crevices. Those animals boring into the rock include sponges,bivalve mollusks and sipunculans. Those settling on the reef include many other species, particularly crustaceans and *polychaete* worms.

Algae

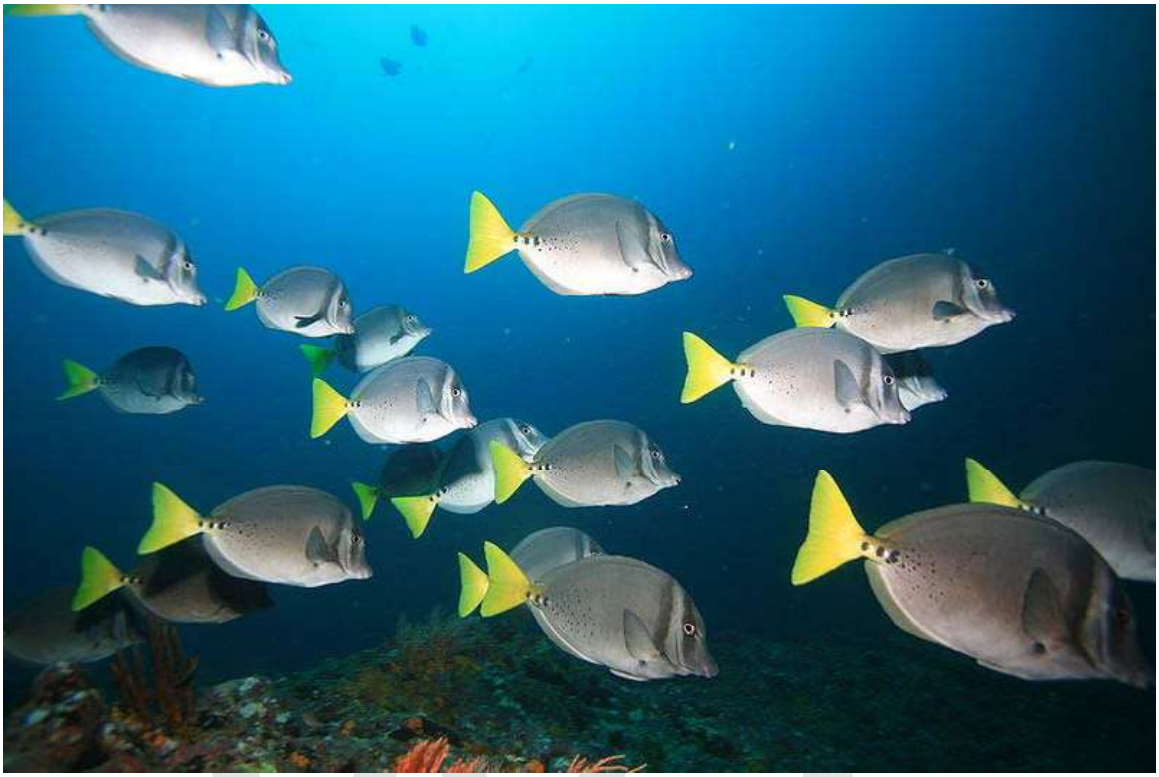
Researchers have found evidence of algae dominance in locations of healthy coral reefs. In surveys done around largely uninhabited US Pacific islands, algae inhabit a large percentage of surveyed coral locations. The algae population consists of turf algae, coralline algae and macroalgae.

Seabirds

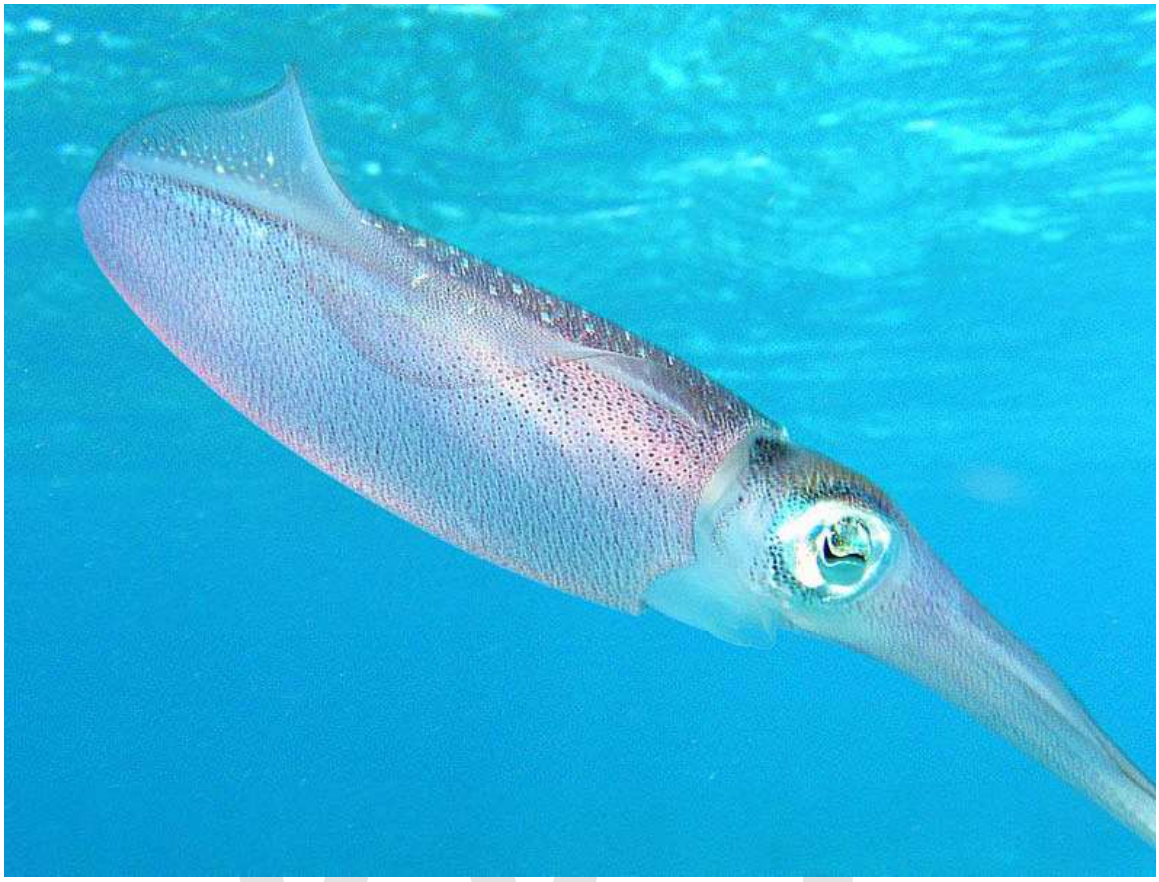
Coral reef systems provide important habitats for seabird species, some endangered. For example, Midway Atoll in Hawaii supports nearly three million seabirds, including two-thirds (1.5 million) of the global population of Laysan Albatross and one-third of the global population of black-footed albatross. Each seabird species has specific sites on the atoll where they nest. Altogether, 17 species of seabirds live on Midway. The short-tailed albatross is the rarest, with fewer than 2,200 surviving after excessive feather hunting in the late nineteenth century.

Other

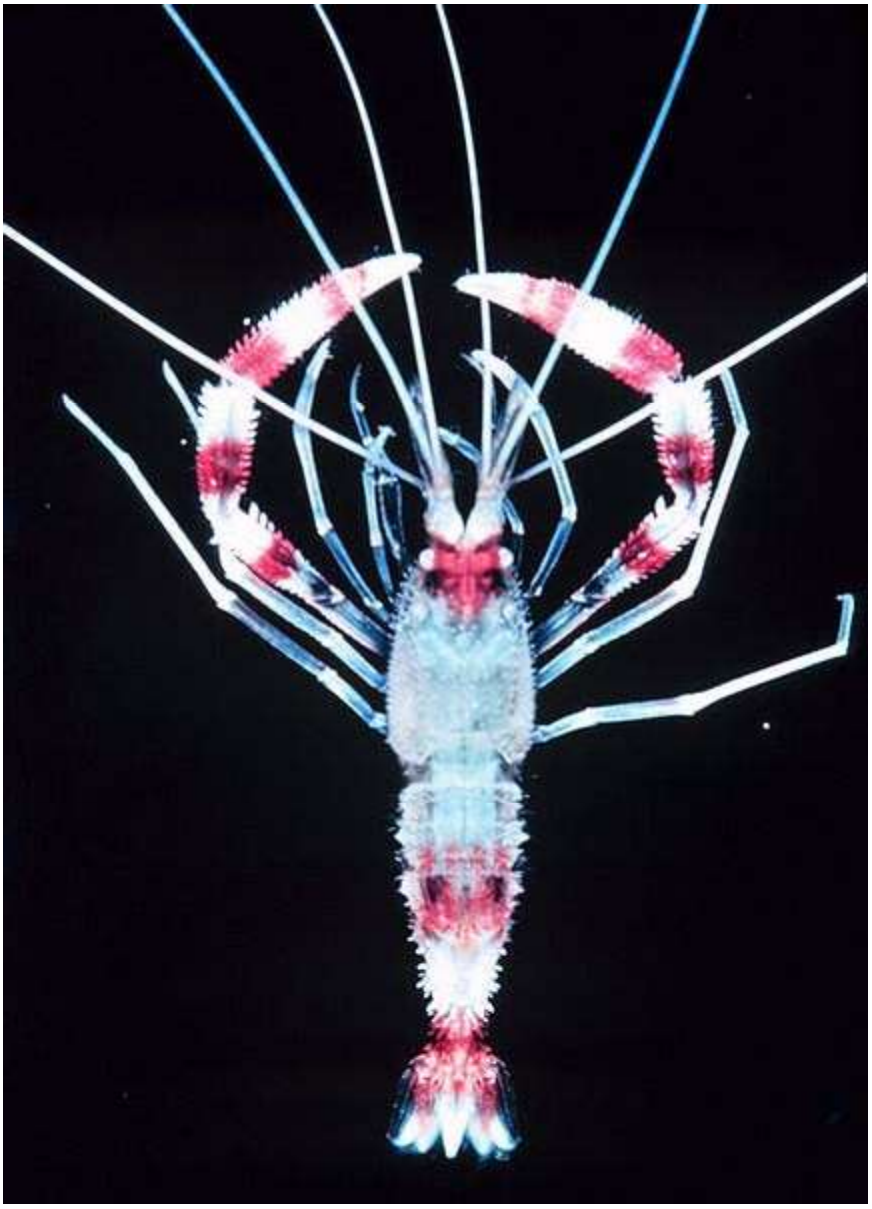
Sea snakes feed exclusively on fish and their eggs. Tropical birds such as herons, gannets, pelicans and boobies feed on reef fish. Some land based reptiles intermittently associate with reefs, such as monitor lizards, the marine crocodile and semi-aquatic snakes like *Laticauda colubrina*. Sea turtles eat sponges.



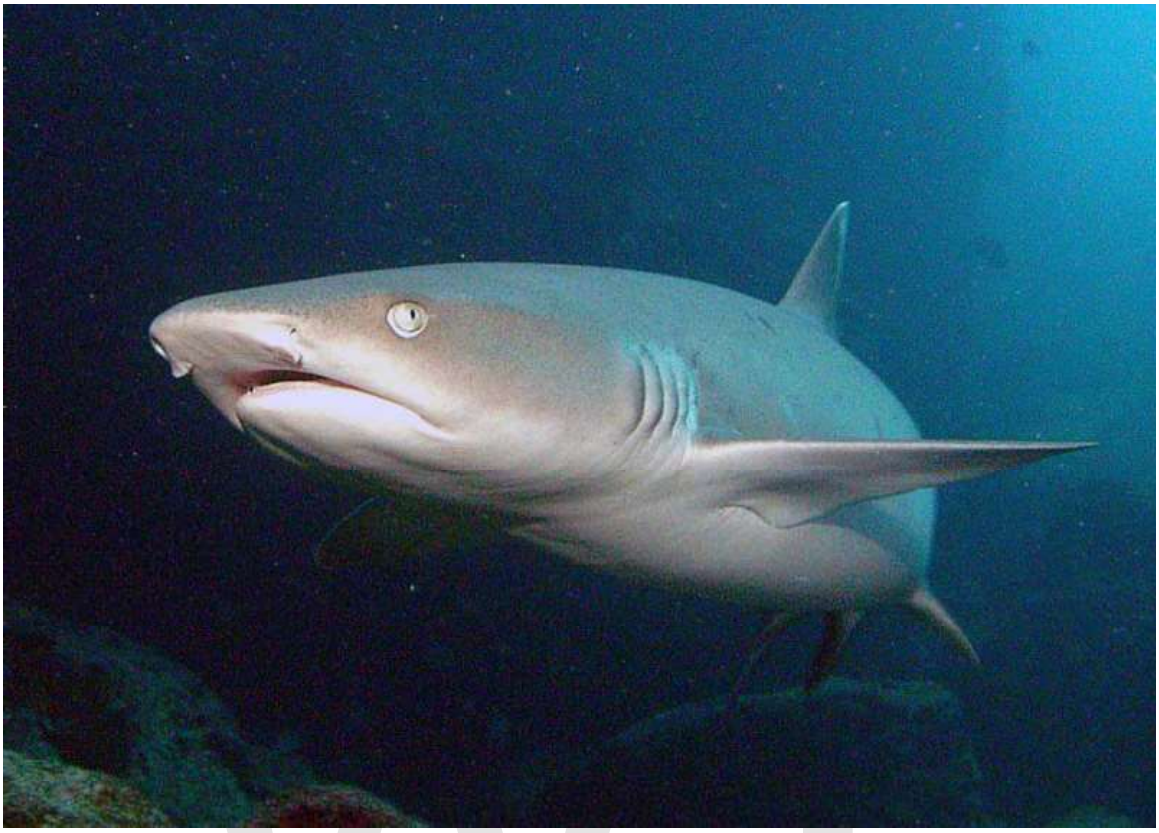
Schooling reef fish



Caribbean reef squid



Banded coral shrimp

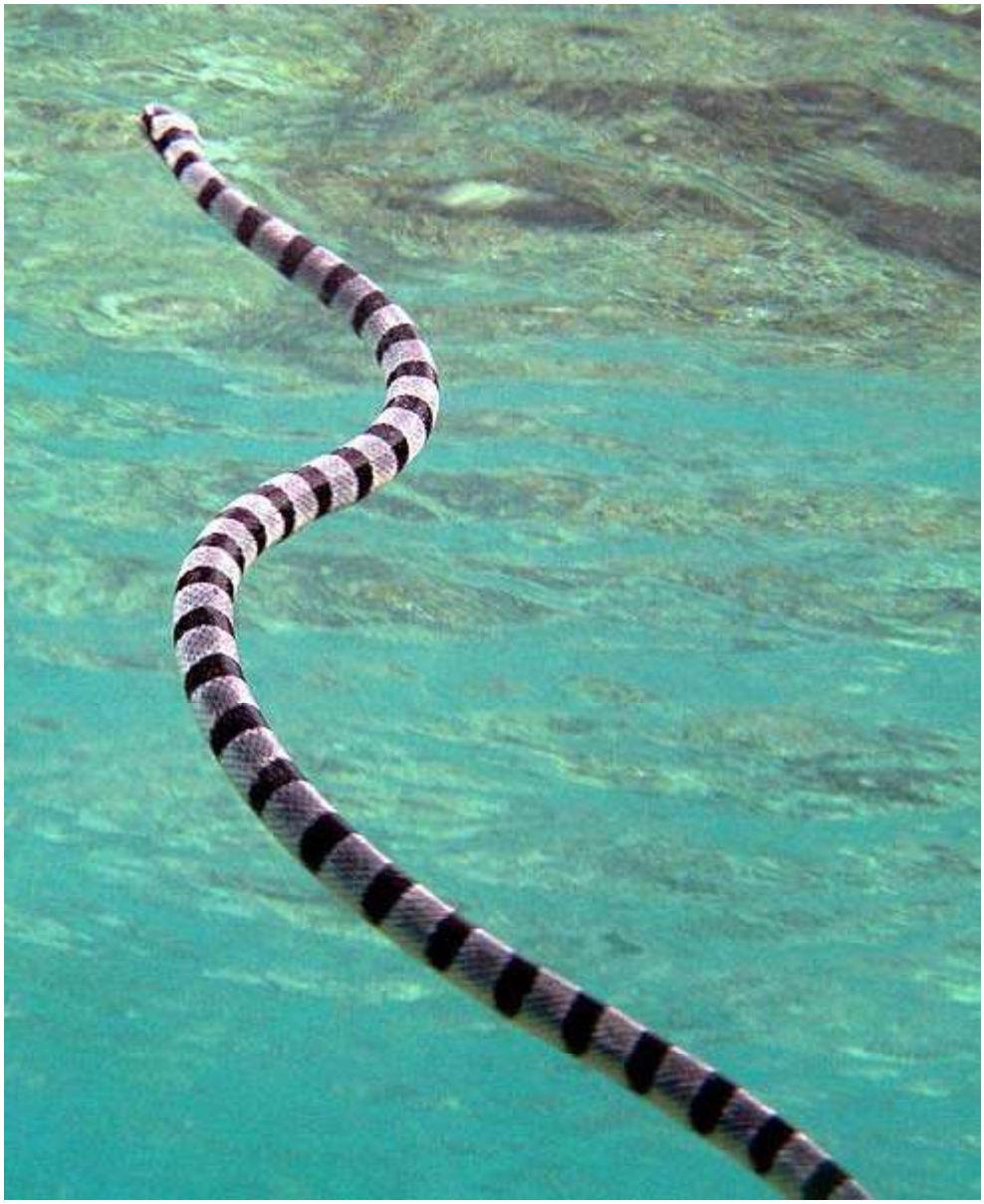


The whitetip reef shark almost exclusively inhabits coral reefs

Green turtle

Giant clam

Soft coral, cup coral, sponges and ascidians



Banded sea krait

Economic value

Coral reefs deliver ecosystem services to tourism, fisheries and coastline protection. The global economic value of coral reefs has been estimated at $30 billion. Coral reefs protect shorelines by absorbing wave energy and many small islands would not exist without their reef to protect them. According to the WWF, the economic cost over a 25 year period of destroying one kilometre of coral reef is somewhere between $137,000 and $1,200,000. About 6 million tons of fish are taken each year from coral reefs. Well managed coral reefs have an annual yield of 15 tons seafood on average per square kilometre. Southeast Asia's coral reef fisheries alone yield about $ 2.4 billion annually from seafood.

Threats

Island with fringing reef off Yap, Micronesia. Coral reefs are dying around the world

Coral reefs are dying around the world. In particular, coral mining, agricultural and urban runoff, pollution (organic and non-organic), overfishing, blast fishing, disease and the digging of canalS and access into islands and bays are serious threats to these ecosystems. A broader threat are sea temperature rise, sea level rise and pH changes from ocean acidification, all associated with greenhouse gas emissions. In El Nino-year 2010, preliminary reports show global coral bleaching reached its worst level since another El Nino year, 1998, when 16 percent of the world's reefs died As a result of excessive water temperature. In Indonesia's Aceh province, surveys showed some 80 percent of bleached corals died. In July, Malaysia closed several dive sites after virtually all the corals In some areas were damaged by bleaching.

In order to find answers for these problems, researchers study the various factors that impact reefs. The list of factors is long, including the ocean's role as a carbon dioxide sink, atmospheric changes, ultraviolet light, ocean acidification, biological virus, impacts of dust storms carrying agents to far flung reefs, pollutants, algal blooms and others. Reefs are threatened well beyond coastal areas.

General estimates show approximately 10% world's coral reefs are already dead. About 60% of the world's reefs are at risk due to destructive, human-related activities. The threat to the health of reefs is particularly strong in Southeast Asia, where 80% of reefs are endangered.

Protection

Coral reefs and fish in Papua New Guinea

Marine Protected Areas (MPAs) have become increasingly prominent for reef management. MPAs in Southeast Asia and elsewhere around the world attempt to promote responsible fishery management and habitat protection. Much like national parks and wild life refuges, MPAs prohibit potentially damaging extraction activities. The objectives of MPAs are both social and biological, including reef restoration, aesthetics, increased and protected biodiversity and economic benefits. Conflicts surrounding MPAs involve lack of participation, clashing views and perceptions of effectiveness and funding.

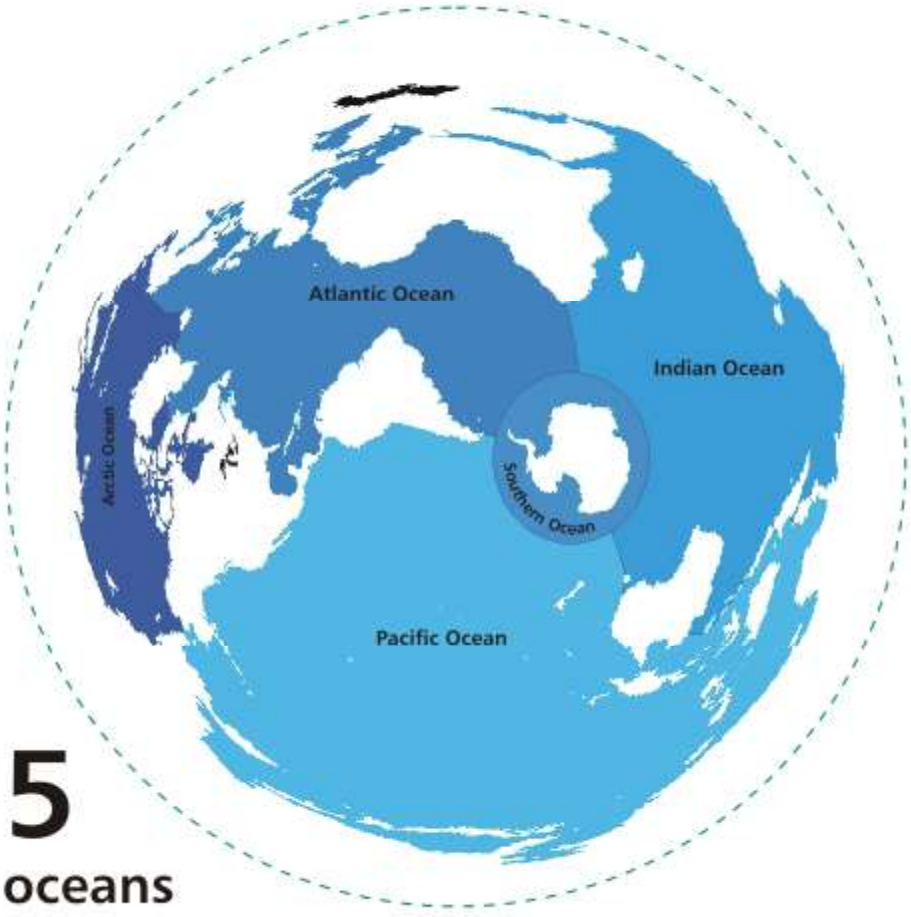
Biosphere reserves are other protected areas that may protect reefs. Also, Marine parks, as well as world heritage sites can protect reefs. World heritage designation can also play a vital role. For example Belize's Barrier reef, Chagos archipelago, Sian Ka'an, the Galapagos islands, Great Barrier Reef, Henderson Island, Palau and Papahānaumokuākea Marine National Monument have been designated as world heritage sites.

In Australia, the Great Barrier Reef is protected by the Great Barrier Reef Marine Park Authority and is the subject of much legislation, including a Biodiversity Action Plan.

Inhabitants of Ahus Island, Manus Province, Papua New Guinea, have followed a generations-old practice of restricting fishing in six areas of their reef lagoon. Their cultural traditions allow line fishing but not net and spear fishing. The result is that both the biomass and individual fish sizes are significantly larger in these areas than in places where fishing is unrestricted.

Chapter- 6

Introduction to Marine Biology



World Marine Environment

Marine biology is the scientific study of organisms in the ocean or other marine or brackish bodies of water. Given that in biology many phyla, families and genera have some species that live in the sea and others that live on land, marine biology classifies species based on the environment rather than on taxonomy. Marine biology differs from

marine ecology as marine ecology is focused on how organisms interact with each other and the environment, and biology is the study of the animal itself.

Marine life is a vast resource, providing food, medicine, and raw materials, in addition to helping to support recreation and tourism all over the world. At a fundamental level, marine life helps determine the very nature of our planet. Marine organisms contribute significantly to the oxygen cycle, and are involved in the regulation of the Earth's climate. Shorelines are in part shaped and protected by marine life, and some marine organisms even help create new land.

Marine biology covers a great deal, from the microscopic, including most zooplankton and phytoplankton to the huge cetaceans (whales) which reach up to a reported 48 meters (125 feet) in length.

The habitats studied by marine biology include everything from the tiny layers of surface water in which organisms and abiotic items may be trapped in surface tension between the ocean and atmosphere, to the depths of the oceanic trenches, sometimes 10,000 meters or more beneath the surface of the ocean. It studies habitats such as coral reefs, kelp forests, tidepools, muddy, sandy and rocky bottoms, and the open ocean (pelagic) zone, where solid objects are rare and the surface of the water is the only visible boundary.

A large amount of all life on Earth exists in the oceans. Exactly how large the proportion is unknown, since many ocean species are still to be discovered. While the oceans comprise about 71% of the Earth's surface, due to their depth they encompass about 300 times the habitable volume of the terrestrial habitats on Earth.

Many species are economically important to humans, including food fish. It is also becoming understood that the well-being of marine organisms and other organisms are linked in very fundamental ways. The human body of knowledge regarding the relationship between life in the sea and important cycles is rapidly growing, with new discoveries being made nearly every day. These cycles include those of matter (such as the carbon cycle) and of air (such as Earth's respiration, and movement of energy through ecosystems including the ocean). Large areas beneath the ocean surface still remain effectively unexplored.

Subfields

The marine ecosystem is large, and thus there are many subfields of marine biology. Most involve studying specializations of particular animal groups, such as phycology, invertebrate zoology and ichthyology.

Other subfields study the physical effects of continual immersion in sea water and the ocean in general, adaptation to a salty environment, and the effects of changing various oceanic properties on marine life. A subfield of marine biology studies the relationships

between oceans and ocean life, and global warming and environmental issues (such as carbon dioxide displacement).

Recent marine biotechnology has focused largely on marine biomolecules, especially proteins, that may have uses in medicine or engineering. Marine environments are the home to many exotic biological materials that may inspire biomimetic materials.

Related fields

Marine biology is a branch of oceanography and is closely linked to biology. It also encompasses many ideas from ecology. Fisheries science and marine conservation can be considered partial offshoots of marine biology (as well as environmental studies).

Distribution factors

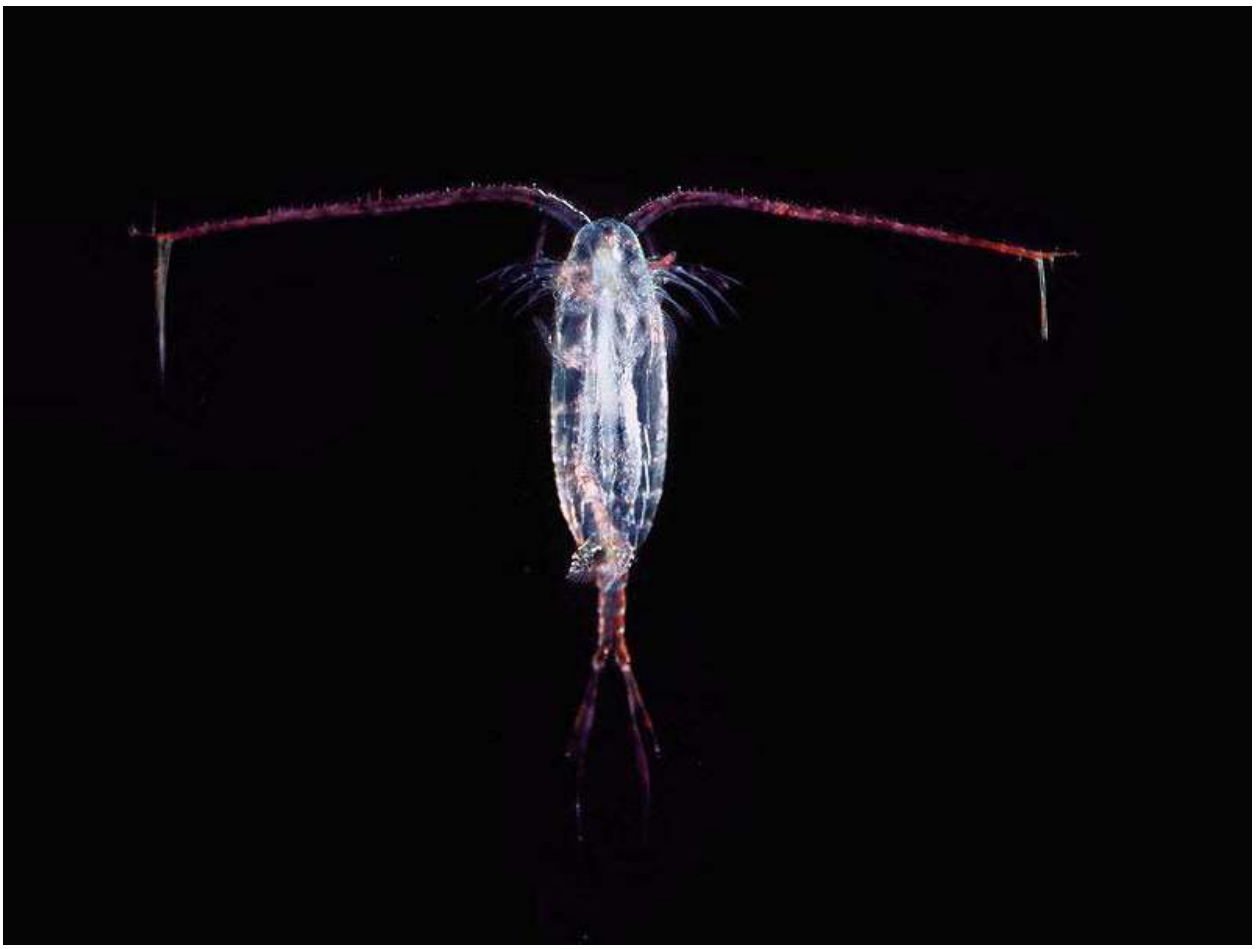
An active research topic in marine biology is to discover and map the life cycles of various species and where they spend their time. Marine biologists study how the ocean currents, tides and many other oceanic factors affect ocean lifeforms, including their growth, distribution and well-being. This has only recently become technically feasible with advances in GPS and newer underwater visual devices.

Most ocean life breeds in specific places, nests or not in others, spends time as juveniles in still others, and in maturity in yet others. Scientists know little about where many species spend different parts of their life cycles. For example, it is still largely unknown where sea turtles and some sharks travel. Tracking devices do not work for some life forms, and the ocean is not friendly to technology. This is important to scientists and fishermen because they are discovering that by restricting commercial fishing in one small area they can have a large impact in maintaining a healthy fish population in a much larger area far away.

Chapter- 7

Lifeforms in Marine Biology

1. Microscopic life



A copepod

Microscopic life undersea is incredibly diverse and still poorly understood. For example, the role of viruses in marine ecosystems is barely being explored even in the beginning of the 21st century.

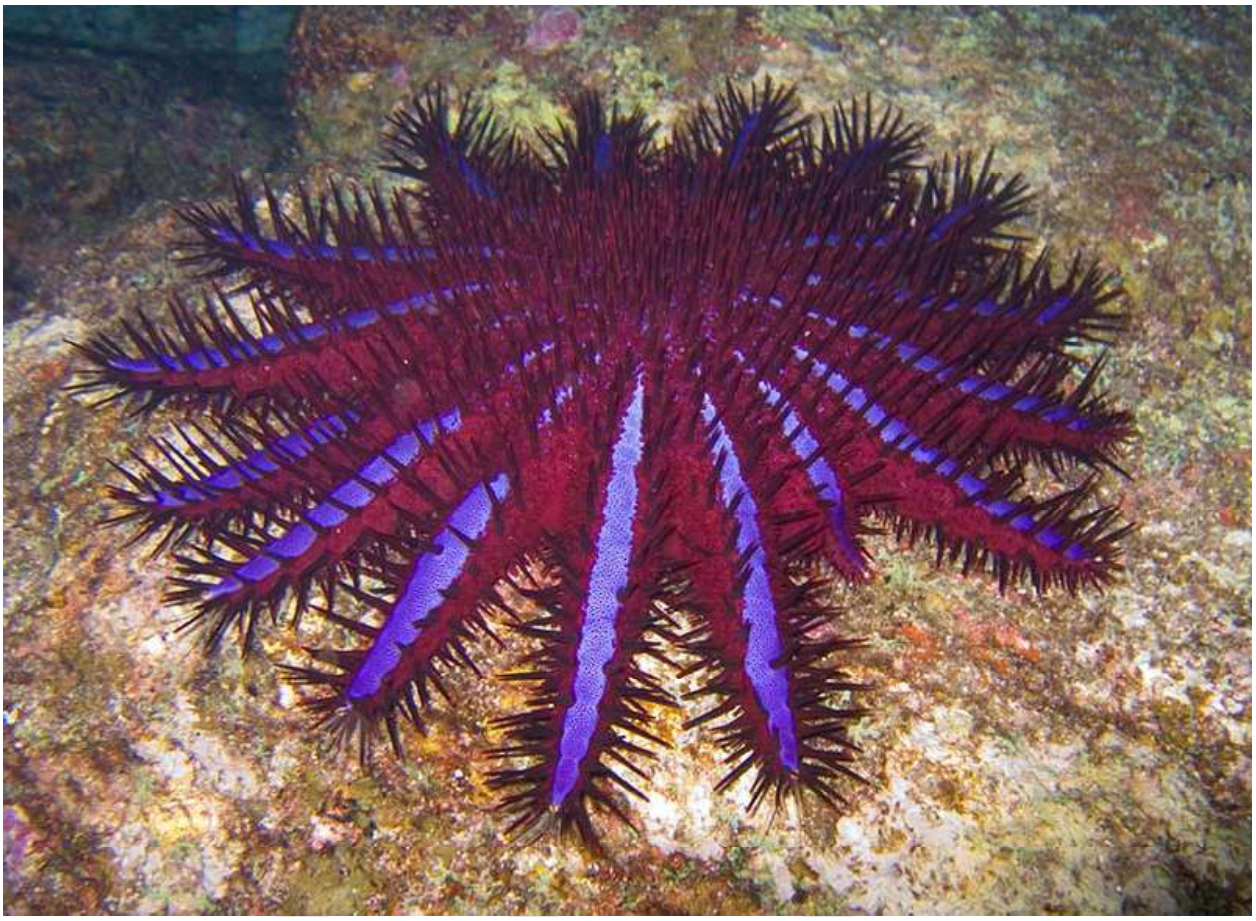
The role of phytoplankton is better understood due to their critical position as the most numerous primary producers on Earth. Phytoplankton are categorized into cyanobacteria (also called blue-green algae/bacteria), various types of algae (red, green, brown, and yellow-green), diatoms, dinoflagellates, euglenoids, coccolithophorids, cryptomonads, chrysophytes, chlorophytes, prasinophytes, and silicoflagellates.

Zooplankton tend to be somewhat larger, and not all are microscopic. Many Protozoa are zooplankton, including dinoflagellates, zooflagellates, foraminiferans, and radiolarians. Some of these (such as dinoflagellates) are also phytoplankton; the distinction between plants and animals often breaks down in very small organisms. Other zooplankton include cnidarians, ctenophores, chaetognaths, molluscs, arthropods, urochordates, and annelids such as polychaetes. Many larger animals begin their life as zooplankton before they become large enough to take their familiar forms. Two examples are fish larvae and sea stars (also called starfish).

2. Plants and Algae

Plant life is widespread and very diverse under the sea. Microscopic photosynthetic algae contribute a larger proportion of the worlds photosynthetic output than all the terrestrial forests combined. Most of the niche occupied by sub plants on land is actually occupied by macroscopic algae in the ocean, such as *Sargassum* and kelp, which are commonly known as seaweeds that create kelp forests. The non algae plants that survive in the sea are often found in shallow waters, such as the seagrasses (examples of which are eelgrass, *Zostera*, and turtle grass, *Thalassia*). These plants have adapted to the high salinity of the ocean environment. The intertidal zone is also a good place to find plant life in the sea, where mangroves or cordgrass or beach grass might grow. Microscopic algae and plants provide important habitats for life, sometimes acting as hiding and foraging places for larval forms of larger fish and invertebrates.

3. Marine invertebrates



A crown-of-thorns starfish

As on land, invertebrates make up a huge portion of all life in the sea. Invertebrate sea life includes Cnidaria such as jellyfish and sea anemones; Ctenophora; sea worms including the phyla Platyhelminthes, Nemertea, Annelida, Sipuncula, Echiura, Chaetognatha, and Phoronida; Mollusca including shellfish, squid, octopus; Arthropoda including Chelicerata and Crustacea; Porifera; Bryozoa; Echinodermata including starfish; and Urochordata including sea squirts or tunicates.

4. Marine reptile

Sea turtle

Marine reptiles are reptiles which have become secondarily adapted for an aquatic or semi-aquatic life in a marine environment.

The earliest marine reptiles arose in the Permian period during the Paleozoic era. During the Mesozoic era, many groups of reptiles became adapted to life in the seas, including such familiar clades as the ichthyosaurs, plesiosaurs (these two orders were once thought united in the "Enalosauria", now known to be an unnatural group), placodonts, and mosasaurs.

After the mass extinction at the end of the Cretaceous period, marine reptiles were less numerous. Extant marine reptiles include marine iguanas, sea snakes, sea turtles, and some species of crocodiles.

Some marine reptiles, such as ichthyosaurs and mosasaurs, rarely ventured onto land and gave birth in the water. Others, such as sea turtles, and saltwater crocodiles, return to shore to lay their eggs. Some marine reptiles also occasionally rest and bask on land.

5. Marine mammal

A Humpback whale (*Megaptera novaeangliae*), a member of order Cetacea

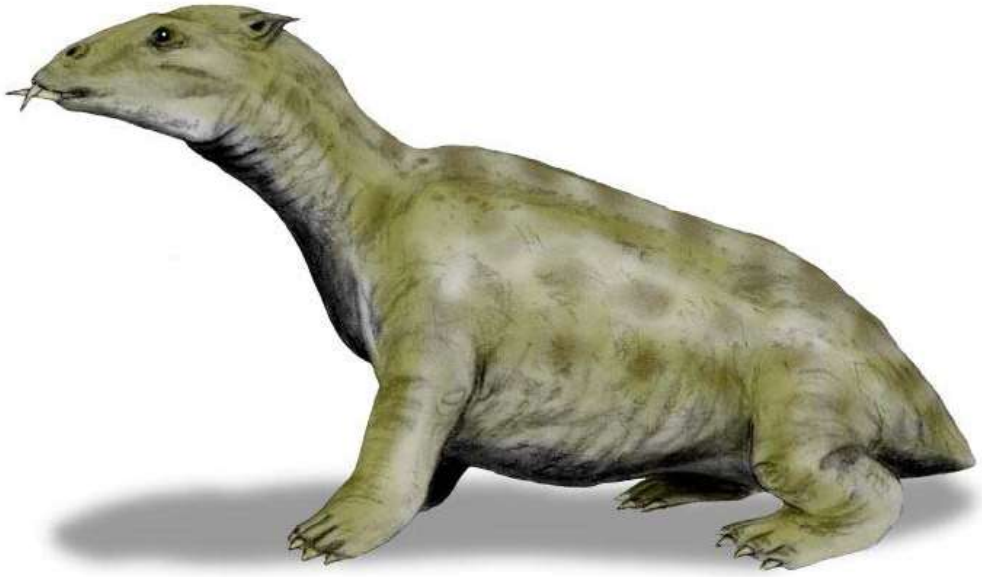
A Leopard seal (*Hydrurga leptonyx*), a member of suborder Pinnipedia of order Carnivora

A West Indian Manatee (*Trichechus manatus*), a member of order Sirenia

A Sea Otter (*Enhydra lutris*), a member of family Mustelidae

A Polar bear (*Ursus maritimus*), a member of family Ursidae

California sea lions, members of the family Otariidae



Desmostylus

Marine mammals are a diverse group of 120 species of mammal that are primarily ocean-dwelling or depend on the ocean for food. They include the cetaceans (whales, dolphins, and porpoises), the sirenians (manatees and dugong), the pinnipeds (true seals, eared seals and walrus), and several otters (the sea otter and marine otter). The polar bear, while not fully aquatic, is also usually considered a marine mammal because it lives on sea ice for most or all of the year.

Marine mammals evolved from land dwelling ancestors and share several adaptive features for life at sea such as generally large size, hydrodynamic body shapes, modified appendages and various thermoregulatory adaptations. Whales are the largest mammals ever. Different species are, however, adapted to marine life to varying degrees. The most fully adapted are the cetaceans and the sirenians, which cannot live on land.

Despite the fact that marine mammals are highly recognizable charismatic megafauna, many populations are vulnerable or endangered due to a history of commercial use for blubber, meat, ivory and fur. Most species are currently in protection from commercial use.

Groups

There are some 120 extant species of marine mammals, generally sub-divided into the five groups bold-faced below. Each group descended from a different land-based ancestor. The morphological similarities between these diverse groups are a result of convergent and parallel evolution. For example, although whales and seals have some similarities in shape, whales are more closely related to deer than they are to seals.

- **Order Sirenia**: Sirenians, belonging to Afrotheria, a group that includes elephants and hyraxes
    - family Trichechidae: manatees (3 species, however, only one is actually a marine mammal)
    - family Dugongidae: dugong (1 species)
- **Order Cetacea**: Cetaceans, belonging to Cetartiodactyla, a group that includes hippopotamuses, deer, and pigs.
    - Suborder Mysticeti: Baleen whales (14 or 15 species)
    - Suborder Odontoceti: Toothed whales (around 73 species)
- **Order Carnivora**,
    - **superfamily Pinnipedia**, belonging to Caniformia descended from a bear-like ancestor.
        - family Phocidae: true seals (around 20 species)
        - family Otariidae: eared seals (around 16 species)
        - family Odobenidae: walrus (1 species)
    - **family Mustelidae**, belonging to Caniformia and most closely related to other otters and weasels
        - sea otter (*Enhydra lutris*)
        - marine otter (*Lontra felina*)
    - **family Ursidae**, belonging to Caniformia

        - polar bear (*Ursus maritimus*), most closely related to other bears, particularly the brown bear
- **Order** Desmostylia
- **Order** Pilosa
    - *Thalassocnus*

Several groups of marine mammals existed in the past that are not alive today. In addition to the ancestors of the modern day whales, seals, and manatees, there existed desmostylians, cousins of the manatees, and *Kolponomos*, a genus of clam-eating marine bears not related to the modern polar bear.

Adaptations

Since mammals originally evolved on land, their spines are optimized for running, allowing for up-and-down but only little sideways motion. Therefore, marine mammals typically swim by moving their spine up and down. By contrast, fish normally swim by moving their spine sideways. For this reason, fish mostly have vertical caudal (tail) fins, while marine mammals have horizontal caudal fins.

Some of the primary differences between marine mammals and other marine life are:

- Marine mammals breathe air, while most other marine animals extract oxygen from water.
- Marine mammals have hair. Cetaceans have little or no hair, usually a very few bristles retained around the head or mouth. All members of the Carnivora have a coat of fur or hair, but it is far thicker and more important for thermoregulation in sea otters and polar bears than in seals or sea lions. Thick layers of fur contribute to drag while swimming, and slow down a swimming mammal, giving it a disadvantage in speed.
- Marine mammals have thick layers of blubber used to insulate their bodies and prevent heat loss. Sea otters and polar bears are exceptions, relying more on fur and behavior to stave off hypothermia.
- Marine mammals give birth. Most marine mammals give birth to one calf or pup at a time.
- Marine mammals feed off milk as young. Maternal care is extremely important to the survival of offspring that need to develop a thick insulating layer of blubber. The milk from the mammary glands of marine mammals often exceeds 40-50% fat content to support the development of blubber.
- Marine mammals maintain a high internal body temperature. Unlike most other marine life, marine mammals carefully maintain a core temperature much higher than their environment. Blubber, thick coats of fur, bubbles of air between skin and water, countercurrent exchange, and behaviors such as hauling out, are all adaptations that aid marine mammals in retention of body heat.

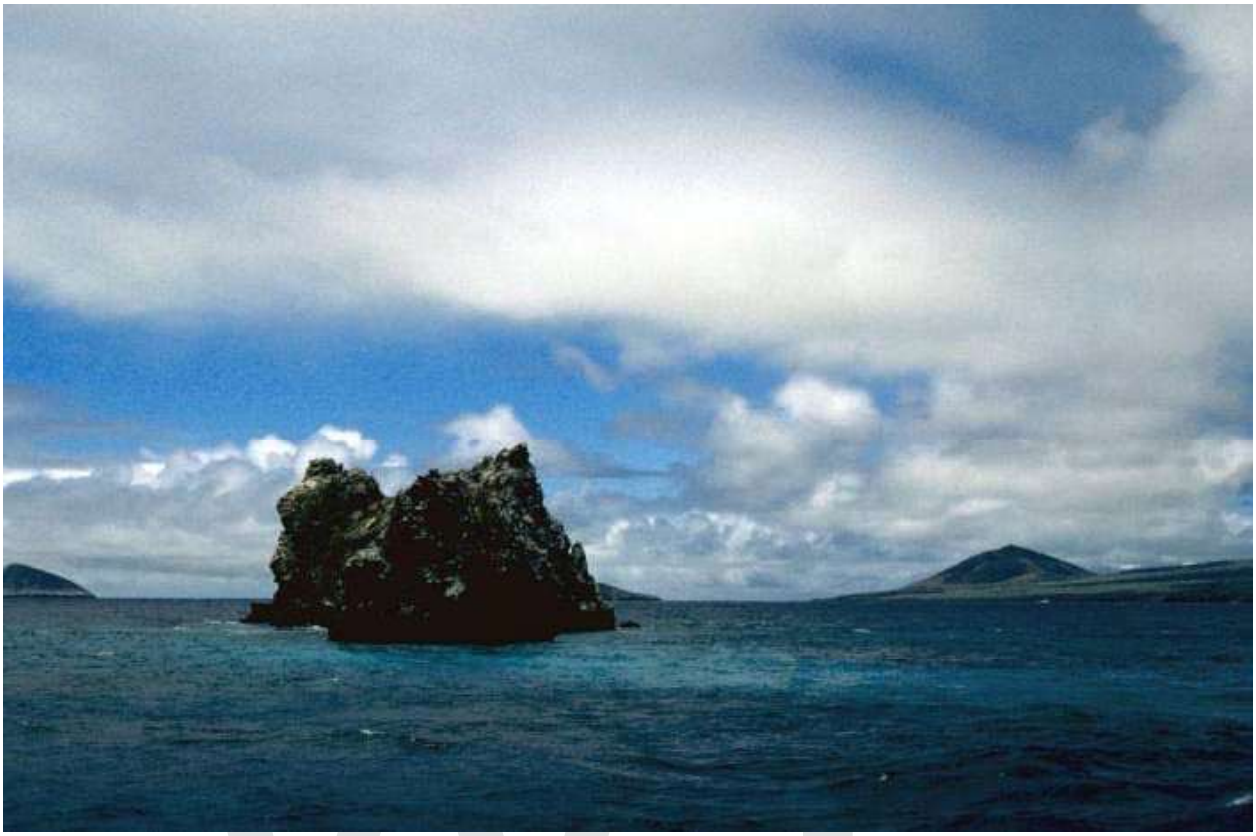
The polar bear spends a large portion of its time in a marine environment, albeit a frozen one. When it does swim in the open sea it is extremely proficient and has been shown to cover 74 km in a day. For these reasons, some scientists regard it as a marine mammal.

Chapter- 8

Oceanic Habitats

1. Reef

Pamalican island with surrounding reef, Sulu Sea, Philippines



A reef surrounding an islet

In nautical terminology, a **reef** is a rock, sandbar, or other feature lying beneath the surface of the water (six fathoms or less at low water).

Many reefs result from abiotic processes—deposition of sand, wave erosion planning down rock outcrops, and other natural processes—but the best-known reefs are the coral reefs of tropical waters developed through biotic processes dominated by corals and calcareous algae. Artificial reefs such as shipwrecks are sometimes created to enhance physical complexity on generally featureless sand bottoms in order to attract a diverse assemblage of organisms, especially fish.

Biotic reef

Coral Reefs in a beach in the city of Recife(reef), Brazil

There are a number of biotic reef types, including oyster reefs, but the most massive and widely distributed are tropical coral reefs. Although corals are major contributors to the framework and bulk material comprising a coral reef, the organisms most responsible for reef growth against the constant assault from ocean waves are calcareous algae, especially, although not entirely, species of coralline algae.

These biotic reef types take on additional names depending upon how the reef lies in relation to the land, if any. Reef types include fringing reef, Barrier reefs, as well as atolls. A fringing reef is a reef that is attached to an island. A barrier reef forms a calcareous barrier around an island resulting in a lagoon between the shore and the reef. An atoll is a ring reef with no land present. The reef front (ocean side) is a high energy locale whereas the internal lagoon will be at a lower energy with fine grained sediments.

Geologic reef

Definition

Archeocyathids, the first reef building organisms, from the Poleta formation in the Death Valley area

Geologists define reefs and related terms (for example, bioherm, biostrome, carbonate mound) using the factors of depositional relief, internal structure, and biotic composition. There is no consensus on one universally applicable definition. A useful definition distinguishes reefs from mounds as follows. Both are considered to be varieties of organosedimentary buildups: sedimentary features, built by the interaction of organisms and their environment, that have synoptic relief and whose biotic composition differs from that found on and beneath the surrounding sea floor. Reefs are held up by a macroscopic skeletal framework. Coral reefs are an excellent example of this kind. Corals and calcareous algae grow on top of one another and form a three-dimensional framework that is modified in various ways by other organisms and inorganic processes. By contrast, mounds lack a macroscopic skeletal framework. Mounds are built by microorganisms or by organisms that don't grow a skeletal framework. A microbial mound might be built exclusively or primarily by cyanobacteria. Excellent examples of biostromes formed by cyanobacteria occur in the Great Salt Lake of Utah (USA), and in Shark Bay, Western Australia.

Cyanobacteria do not have skeletons and individuals are microscopic. Cyanobacteria encourage the precipitation or accumulation of calcium carbonate and can produce distinct sediment bodies in composition that have relief on the seafloor. Cyanobacterial mounds were most abundant before the evolution of shelly macroscopic organisms, but they still exist today (stromatolites are microbial mounds with a laminated internal structure). Bryozoans and crinoids, common contributors to marine sediments during the Mississippian (for example), produced a very different kind of mound. Bryozoans are small and the skeletons of crinoids disintegrate. However, bryozoan and crinoid meadows can persist over time and produce compositionally distinct bodies of sediment with depositional relief.

The Proterozoic Belt Supergroup contains evidence of possible microbial mat and dome structures similar to stromatolite reef complexes.

Geologic reef structures

Reefs off Vanatinai in the Louisiade Archipelago

Ancient reefs buried within stratigraphic sections are of considerable interest to geologists because they provide paleo-environmental information about the location in Earth's history. In addition, reef structures within a sequence of sedimentary rocks provide a discontinuity which may serve as a trap or conduit for fossil fuels or mineralizing fluids to form petroleum or ore deposits.

Corals, including some major extinct groups Rugosa and Tabulata, have been important reef builders through much of the Phanerozoic since the Ordovician Period. However, other organism groups, such as calcifying algae, especially members of the red algae Rhodophyta, and mollusks (especially the rudist bivalves during the Cretaceous Period) have created massive structures at various times. During the Cambrian Period, the conical or tubular skeletons of Archaeocyatha, an extinct group of uncertain affinities (possibly sponges), built reefs. Other groups, such as the Bryozoa have been important interstitial organisms, living between the framework builders. The corals which build reefs today, the Scleractinia, arose after the Permian–Triassic extinction event that wiped out the earlier rugose corals (as well as many other groups), and became increasingly important reef builders throughout the Mesozoic Era. They may have arisen from a rugose coral ancestor. Rugose corals built their skeletons of calcite and have a different symmetry from that of the scleractinian corals, whose skeletons are aragonite. However, there are some unusual examples of well preserved aragonitic rugose corals in the late Permian. In addition, calcite has been reported in the initial post-larval calcification in a few scleractinian corals. Nevertheless, scleractinian corals (which arose in the middle Triassic) may have arisen from a non-calcifying ancestor independent of the rugosan corals (which disappeared in the late Permian).

2. Deep sea and trenches

The deepest recorded oceanic trenches measure to date is the Mariana Trench, near the Philippines, in the Pacific Ocean at 10,924 m (35,838 ft). At such depths, water pressure is extreme and there is no sunlight, but some life still exists. Small flounder (family Soleidae) fish and shrimp were seen by the American crew of the bathyscaphe *Trieste* when it dove to the bottom in 1960.

Other notable oceanic trenches include Monterey Canyon, in the eastern Pacific, the Tonga Trench in the southwest at 10,882 m (35,702 ft), the Philippine Trench, the Puerto Rico Trench at 8,605 m (28,232 ft), the Romanche Trench at 7,760 m (24,450 ft), Fram Basin in the Arctic Ocean at 4,665 m (15,305 ft), the Java Trench at 7450 m (24,442 ft), and the South Sandwich Trench at 7,235 m (23,737 ft).

In general, the deep sea is considered to start at the aphotic zone, the point where sunlight loses its power of transference through the water. Many life forms that live at these depths have the ability to create their own light a unique evolution known as bio-luminescence.

Marine life also flourishes around seamounts that rise from the depths, where fish and other sea life congregate to spawn and feed. Hydrothermal vents along the mid-ocean ridge spreading centers act as oases, as do their opposites, cold seeps. Such places support unique biomes and many new microbes and other lifeforms have been discovered at these locations.

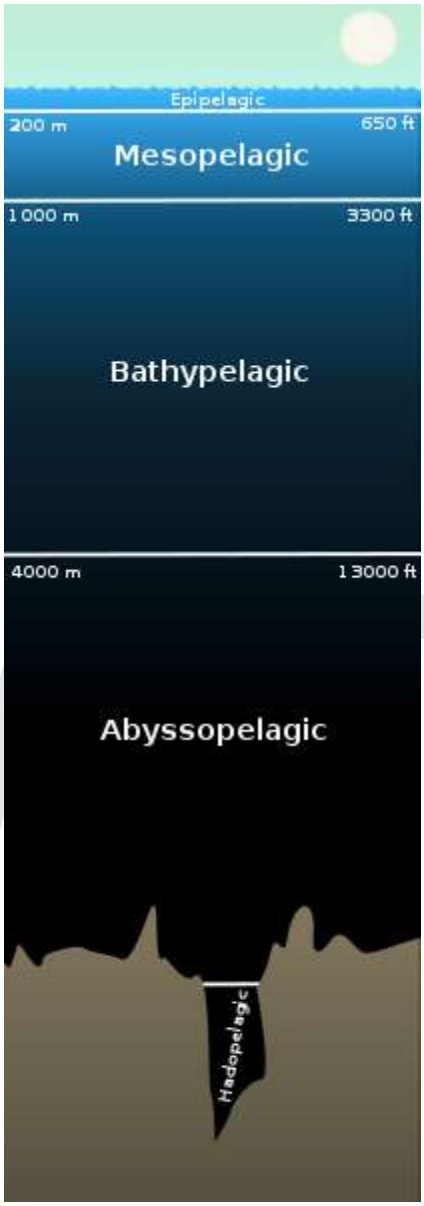
3. Pelagic zone

Any water in the sea that is not close to the bottom or near to the shore is in the **pelagic zone**. The word *pelagic* comes from the Greek πέλαγος or *pélagos*, which means "open sea." The pelagic zone can be thought of in terms of an imaginary cylinder or water column that goes from the surface of the sea almost to the bottom, as shown in the diagram below. Conditions change deeper down the water column; the pressure increases, the temperature drops and there is less light. Depending on the depth, scientists further subdivide the water column, rather like the Earth's atmosphere is divided into different layers.

The pelagic zone occupies 1,370 million cubic kilometres (330 million cubic miles) and has a vertical range up to 11 kilometres (6.8 miles). Fish that live in the pelagic zone are called pelagic fish. Pelagic life decreases with increasing depth. It is affected by light levels, pressure, temperature, salinity, the supply of dissolved oxygen and nutrients, and the submarine topography. In deep water, the pelagic zone is sometimes called the **open-ocean zone** and can be contrasted with water that is near the coast or on the continental shelf. However in other contexts, coastal water that is not near the bottom is still said to be in the pelagic zone.

The pelagic zone can be contrasted with the benthic and demersal zones at the bottom of the sea. The benthic zone is the ecological region at the very bottom of the sea. It includes the sediment surface and some sub-surface layers. Marine organisms living in this zone, such as clams and crabs, are called benthos. The demersal zone is just above the benthic zone. It can be significantly affected by the seabed and the life that lives there. Fish that live in the demersal zone are called **demersal fish**. Demersal fish can be divided into benthic fish, which are denser than water so they can rest on the bottom, and benthopelagic fish, which swim in the water column just above the bottom. Demersal fish are also known as bottom feeders and groundfish.

Depth and layers



A scale diagram of the layers of the pelagic zone

Depending on how deep the sea is, there can be up to five horizontal layers in the ocean. From the top down, they are:

Epipelagic (sunlit)

From the surface (MSL) down to around 200 m (650 ft).

This is the illuminated zone at the surface of the sea where there is enough light for photosynthesis. Nearly all primary production in the ocean occurs here. Consequently, plants and animals are largely concentrated in this zone.

Examples of organisms living in this zone are plankton, floating seaweed, jellyfish, tuna, many sharks, and dolphins.

Mesopelagic (twilight)

From 200 m down to around 1,000 m (3,300 ft).

The name for this zone stems from Greek μέσον, *middle*.

Although some light penetrates this second layer, it is insufficient for photosynthesis. At about 500 m the water also becomes depleted of oxygen. Still, life copes, with gills that are more efficient or by minimizing movement.

Examples of animals that live here are: swordfish, squid, wolffish and some species of cuttlefish. Many organisms that live in this zone are bioluminescent. Some creatures living in the mesopelagic zone will rise to the epipelagic zone at night in order to feed.

Bathypelagic (midnight)

From 1,000 m down to around 4,000 m (13,000 ft).

The name stems from the Greek βαθύς (bathýs), meaning *deep*.

At this depth the ocean is pitch black, apart from occasional bioluminescent organisms, such as lanternfish. There is no living plant-life.

Most animals living here survive by consuming the detritus falling from the zones above, which is known as "marine snow", or, like the marine hatchetfish, by preying on other inhabitants of this zone.

Other examples of this zone's inhabitants are giant squid, smaller squids & dumbo octopodes. The giant squid is hunted here by deep-diving sperm whales.

Abyssopelagic (lower midnight)

From 4,000 m down to above the ocean floor.

The name is derived from the Greek ἄβυσσος (*ábyssos*), *abyss*, meaning bottomless (a holdover from the times when the deep ocean was believed to be bottomless). Very few creatures are sufficiently adapted to survive in the cold temperatures and incredible pressures found at this depth. Among the species found in this zone are several species of squid; echinoderms including the basket star, swimming cucumber, and the sea pig; and marine arthropods including the sea spider. Many of the species living at these depths have evolved to be transparent and eyeless as a result of the total lack of light in this zone.

Hadopelagic

The deep water in ocean trenches.

The name is derived from the Greek Ἅδης (*Haidēs*), *Hades*, the classical Greek underworld. This zone is mostly unknown, and very few species are known to live here (in the open areas). However, many organisms live in hydrothermal vents in this and other zones. Some define the hadopelagic as waters below 6,000 m (19,685 ft), whether in a trench or not.

The bathypelagic, abyssopelagic, and hadopelagic zones are very similar in character, and some marine biologists combine them into a single zone or consider the latter two to be the same. The abyssal plain is covered with soft sludge covered by the dead organisms from above.

Pelagic ecology

The pelagic sooty tern spends months at a time flying at sea, returning to land only for breeding

Pelagic birds

Pelagic birds, also called **oceanic birds**, are birds that live on the open sea, rather than around waters adjacent to land or around inland waters. Pelagic birds feed on planktonic crustaceans, squid and forage fish. Examples are the Atlantic puffin, macaroni penguins, sooty terns, shearwaters, and procellariiforms such as the albatross, procellariids and petrels.

The term seabird includes birds which live around the sea adjacent to land, as well as pelagic birds.

Pelagic fish

Pelagic fish are fish that live in the water column of coastal, ocean and lake waters, but not on the bottom of the sea or the lake. They can be contrasted with demersal fish, which live on or near the bottom, and reef fish which are associated with coral reefs.

These fish are often migratory forage fish, which feed on plankton, and the larger fish that follow and feed on the forage fish. Examples of migratory forage fish are herring, anchovies, capelin and menhaden. Examples of larger pelagic fish which predate the forage fish are billfish, tuna and oceanic sharks.

4. Intertidal zone

The rocky shoreline of Newport, Rhode Island showing a clear line where high tide occurs

The **intertidal zone** (also known as the foreshore and seashore and sometimes referred to as the littoral zone) is the area that is exposed to the air at low tide and underwater at high tide (for example, the area between tide marks). This area can include many different types of habitats, including steep rocky cliffs, sandy beaches, or wetlands (e.g., vast mudflats). The area can be a narrow strip, as in Pacific islands that have only a narrow tidal range, or can include many meters of shoreline where shallow beach slope interacts with high tidal excursion.

Organisms in the intertidal zone are adapted to an environment of harsh extremes. Water is available regularly with the tides but varies from fresh with rain to highly saline and dry salt with drying between tidal inundations. The action of waves can dislodge residents in the littoral zone. With the intertidal zone's high exposure to the sun the temperature range can be anything from very hot with full sun to near freezing in colder climates. Some microclimates in the littoral zone are ameliorated by local features and larger plants such as mangroves. Adaption in the littoral zone is for making use of

nutrients supplied in high volume on a regular basis from the sea which is actively moved to the zone by tides. Edges of habitats, in this case land and sea, are themselves often significant ecologies, and the littoral zone is a prime example.

A typical rocky shore can be divided into a spray zone or splash zone (also known as the supratidal zone), which is above the spring high-tide line and is covered by water only during storms, and an intertidal zone, which lies between the high and low tidal extremes. Along most shores, the intertidal zone can be clearly separated into the following subzones: high tide zone, middle tide zone, and low tide zone.

Zonation

Tide pools at Pillar Point showing zonation on the edge of the rock ledge

A rock, seen at low tide, exhibiting typical intertidal zonation, Kalaloch, Washington, western USA

Marine biologists and others divide the intertidal region into three zones (low, middle, and high), based on the overall average exposure of the zone. The low intertidal zone, which borders on the shallow subtidal zone, is only exposed to air at the lowest of low tides and is primarily marine in character. The mid intertidal zone is regularly exposed and submerged by average tides. The high intertidal zone is only covered by the highest of the high tides, and spends much of its time as terrestrial habitat. The high intertidal zone borders on the swash zone (the region above the highest still-tide level, but which receives wave splash). On shores exposed to heavy wave action, the intertidal zone will be influenced by waves, as the spray from breaking waves will extend the intertidal

Depending on the substratum and topography of the shore, additional features may be noticed. On rocky shores, tide pools form at lowis trapped in hollows. Under certain conditions, such as those at Morecambe Bay, quicksand may form.

Low tide zone (lower littoral)

This subregion is mostly submerged - it is only exposed at the point of low tide and for a longer period of time during extremely low tides. This area is teeming with life; the most notable difference with this subregion to the other three is that there is much more marine vegetation, especially seaweeds. There is also a great biodiversity. Organisms in this zone generally are not well adapted to periods of dryness and temperature extremes. Some of the organisms in this area are abalone, anemones, brown seaweed, chitons, crabs, green algae, hydroids, isopods, limpets, mussels, nudibranchs, sculpin, sea cucumber, sea lettuce, sea palms, sea stars, sea urchins, shrimp, snails, sponges, surf grass, tube worms, and whelks. Creatures in this area can grow to larger sizes because there is more available energy in the localised ecosystem and because marine vegetation can grow to much greater sizes than in the other three intertidal subregions due to the better water coverage: the water is shallow enough to allow plenty of light to reach the vegetation to allow substantial photosynthetic activity, and the salinity is at almost normal levels. This area is also protected from large predators such as large fish because of the wave action and the water still being relatively shallow.

Ecology

A California tide pool in the low tide zone

The intertidal region is an important model systems for the study of ecology, especially on wave-swept rocky shores. The region contains a high diversity of species, and the different zones caused by the physics of the tides causes species ranges to be compressed into very narrow bands. This makes it relatively simple to study species across their entire cross-shore range, something that can be extremely difficult in, for instance, terrestrial habitats that can stretch thousands of kilometers. Communities on wave-swept shores also have high turnover due to disturbance, so it is possible to watch ecological succession over years rather than decades.

Since the foreshore is alternately covered by the sea and exposed to the air, organisms living in this environment must have adaptions for both wet and dry conditions. Hazards include being smashed or carried away by rough waves, exposure to dangerously high temperatures, and desiccation. Typical inhabitants of the intertidal rocky shore include sea anemones, barnacles, chitons, crabs, isopods, mussels, seastars, and many marine gastropod mollusks such as limpets, whelks etc.

Legal issues

As with the dry sand part of a beach, legal and political disputes can arise over the ownership and use of the foreshore. One recent example is the New Zealand foreshore and seabed controversy. In legal discussions the foreshore is often referred to as the *wet-sand area*.

For privately-owned beaches in the United States, some states such as Massachusetts use the low water mark as the dividing line between the property of the State and that of the beach owner. Other states such as California use the high water mark.

In the UK, the foreshore is generally deemed to be owned by the Crown although there are notable exceptions, especially what are termed *several fisheries* which can be historic deeds to title, dating back to King John's time or earlier, and the Udal Law, which applies generally in Orkney and Shetland.

Additional images

Mussels in the intertidal zone in Cornwall, England.

Barnacles and limpets in the intertidal zone near Newquay, Cornwall.

A tidal pool in the intertidal zone during low tide, Sunrise-on-Sea, South Africa.

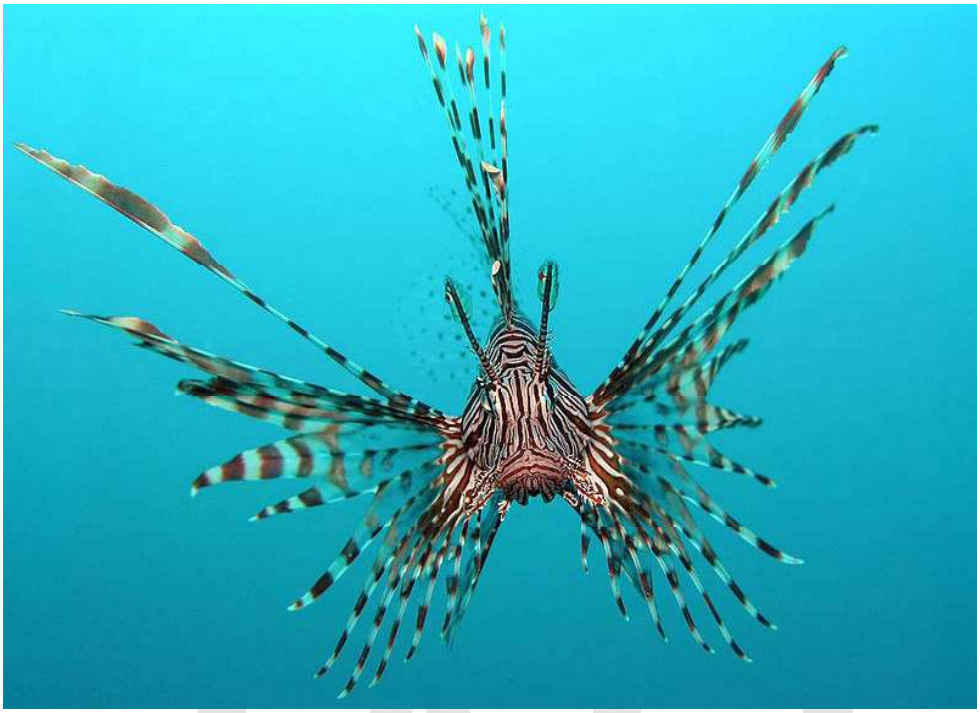
Unexplained crumbs of sand which appear to have been deposited around stone by escaping air.

Chapter- 9

Fish

Fishes
Fossil range: Ordovician–Neogene

A giant grouper at the Georgia Aquarium, seen swimming among schools of other fish



The ornate lionfish as seen from a head-on view

Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
(unranked)	Craniata

Included groups

Jawless fishes
†Armoured fishes
Cartilaginous fishes
Ray-finned fishes
Lobe-finned fishes

Excluded groups

Tetrapods

A **fish** is any aquatic vertebrate animal that is covered with scales, and equipped with two sets of paired fins and several unpaired fins. Most fish are "cold-blooded", or ectothermic, allowing their body temperatures to vary as ambient temperatures change. Fish are abundant in most bodies of water. They can be found in nearly all aquatic environments, from high mountain streams (e.g., char and gudgeon) to the abyssal and even hadal depths of the deepest oceans (e.g., gulpers and anglerfish). At 31,500 species, fish exhibit greater species diversity than any other class of vertebrates.

Food prepared from animals classified as fish is also referred to as fish, and is an important human food source. Commercial and subsistence fishers "hunt" fish in wild fisheries or "farm" them in ponds or in cages in the ocean. They are also caught by

recreational fishers and raised by fishkeepers, and are exhibited in public aquaria. Fish have had a role in culture through the ages, serving as deities, religious symbols, and as the subjects of art, books and movies.

Diversity of fish

Fish come in many shapes and sizes. This is a sea dragon, a close relative of the seahorse. They are camouflaged to look like floating seaweed.

Fish are very **diverse** and are categorized in many ways. This article is an overview of some of the more common types of fish. Although most fish species have probably been discovered and described, about 250 new ones are still discovered every year. According to FishBase, 31,500 species of fish had been described by January 2010. That is more than the combined total of all other vertebrates: mammals, amphibians, reptiles and birds.

By species

Fish systematics is the formal description and organisation of fish taxa into systems. It is complex and still evolving. Controversies over "arcane, but important, details of classification are still quietly raging."

The term "fish" describes any non-tetrapod chordate, (i.e., an animal with a backbone), that has gills throughout life and has limbs, if any, in the shape of fins. Unlike groupings such as birds or mammals, fish are not a single clade but a paraphyletic collection of taxa, including jawless, cartilaginous and skeletal types.

Jawless fish

Jawless fish are the most primitive fish. There is current debate over whether these are really fish at all. They have no jaw, no scales, no paired fins, and no bony skeleton. Their skin is smooth and soft to the touch, and they are very flexible. Instead of a jaw, they possess an oral sucker. They use this to fasten on to other fish, and then use their rasp-like teeth to grind through their host's skin into the viscera. Jawless fish inhabit both fresh and salt water environments. Some are anadromous, moving between both fresh and salt water habitats.

Extant jawless fish are either lamprey or hagfish. Juvenile lamprey feed by sucking up mud containing micro-organisms and organic debris. The lamprey has well developed eyes, while the hagfish has only primitive eyespots. The hagfish coats itself and carcasses it finds with noxious slime to deter predators, and periodically ties itself into a knot to scrape the slime off. It is the only invertebrate fish and the only animal which has a skull but no vertebral column. It has four hearts, two brains, and a paddle-like tail.

Lampreys attached to a lake trout

Mouth of a sea lamprey

Pacific hagfish resting on bottom at 280 m

Stir-fried hagfish, from Korean cuisine

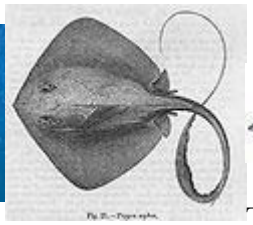
Cartilaginous fish

Cartilaginous fish have a cartilaginous skeleton. However, their ancestors were bony animals, and were the first fish to develop paired fins. Cartilaginous fish don't have swim bladders. Their skin is covered in denticles, that are as rough as sandpaper. Because cartilaginous fish do not have bone marrow, the spleen and special tissue around the gonads produces red blood cells. Some cartilaginous fishes possess an organ called Leydig's Organ which also produces red blood cells.

There are over 980 species of cartilaginous fish. They include sharks, rays and chimaera.

Tiger shark

Whale shark



Stingray

This elephant fish is a chimaera

Bony fish

Bony fish include the lobe finned fish and the ray finned fish. The lobe finned fish is the class of fleshy finned fishes, consisting of lungfish, and coelacanths. They are bony fish with fleshy, lobed paired fins, which are joined to the body by a single bone. These fins evolved into the legs of the first tetrapod land vertebrates, amphibians. Ray finned fishes are so-called because they possess lepidotrichia or "fin rays", their fins being webs of skin supported by bony or horny spines ("rays").

There are three types of ray finned fishes: the chondrosteans, holosteans, and teleosts. The chondrosteans and holosteans are primitive fishes sharing a mixture of characteristics of teleosts and sharks. In comparison with the other chondrosteans, the holosteans are closer to the teleosts and further from sharks.

Lungfish can breathe in air as well as water

Model of a coelacanth, thought until 1938 to be extinct. They are deep blue.

This Atlantic sturgeon is a chondrostean

This bowfin is a holostean

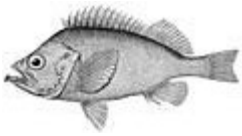
Teleosts

Teleosts are the most advanced or "modern" fishes. They are overwhelmingly the dominant class of fishes (or for that matter, vertebrates) with nearly 30,000 species, covering about 96 percent of all extant fish species. They are ubiquitous throughout fresh water and marine environments from the deep sea to the highest mountain streams. Included are nearly all the important commercial and recreational fishes.

Teleosts have a movable maxilla and premaxilla and corresponding modifications in the jaw musculature. These modifications make it possible for teleosts to protrude their jaws outwards from the mouth. The caudal fin is homocercal, meaning the upper and lower

lobes are about equal in size. The spine ends at the caudal peduncle, distinguishing this group from those in which the spine extends into the upper lobe of the caudal fin.

Striped marlin are teleosts



Rose fish are also teleosts

Eels are teleosts too

So are seahorses

By size

The smallest species is *Paedocypris progenetica*, a type of minnow. It is also the smallest vertebrate. The smallest mature female had a standard length of 7.9 millimeters (0.3 in). The largest individual is 10.3 millimeters (0.4 in). They live in the dark–colored peat swamps of the Indonesian island of Sumatra.

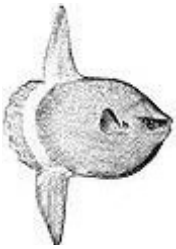
Other contenders for smallest fish are the male anglerfish, *Photocorynus spiniceps*, and the stout infantfish, a type of goby. According to the Guinness Book of World Records, the sinarapan, another type of goby, is the world's smallest commercially harvested fish. Found in the Philippines, they have an average length of 12.5 millimeters (0.5 in), and are threatened by overfishing.

The largest is the whale shark. It is a slow moving filter feeding shark with a maximum published length of 20 meters (66 ft) and a maximum weight of 34 tonnes. Whale sharks can live up to 70 years.

The heaviest bony fish is the ocean sunfish. It can weigh up to 2,300 kg (5,100 lb). It is found in all warm and temperate oceans. The longest bony fish is the king of herrings. Its total length can reach 11 metres (36 ft), and it can weigh up to 272 kilograms (600 lb). It is a rarely seen oarfish found in all the world's oceans, at depths of between 20 metres (66 ft) and 1,000 metres (3,300 ft).

Some of the smallest fishes are minnow-type fishes, including the smallest of all, *Paedocypris progenetica*.

The whale shark is the largest living fish (human shown for comparison)



The ocean sunfish is the heaviest bony

The king of herrings is the longest bony fish

By life span

Some of the shortest-lived species are gobies, which are small coral reef–dwelling fish. Some of the longest-lived are rockfish.

The shortest lived is the seven-figure pygmy goby, which lives for at most 59 days. This is the shortest lifespan for any vertebrate. Short lived fish have particular value in genetic studies on aging. In particular, the ram cichlid is used in laboratory studies because of its ease of breeding and predictable aging pattern.

The longest–lived fish is the 205 years reported for the rougheye rockfish, *Sebastes aleutianus*, found offshore in the North Pacific at 25–900 metres (14–490 fathoms). This fish exhibits negligible senescence.

There are stories about Japanese Koi goldfish passed from generation to generation for 300 years. Scientists are sceptical. Counting growth lines on the scales of fish confined to ponds or bowls is unreliable, since they lay down extra lines. The maximum reliably reported age for a goldfish is 41 years

The longest living commercial fish may be the orange roughy, with a maximum reported age of 149 years. One of the longest living sport fish is the Atlantic tarpon, with a maximum reported age of 55 years."

Some of the longest living fish are living fossils, such as the green sturgeon. This species is among the longest living species found in freshwater, with a maximum reported age of 60 years. They are also among the largest fish species found in freshwater, with a maximum reported length of 2.5 meters (8 ft) and a maximum reported weight of {{kg to lb}159}}. Another living fossil is the Australian lungfish. One individual has lived in an aquarium for 75 years, and is the oldest fish in captivity. According to fossil records, the Australian lungfish has hardly changed for 380 million years.

Among gobies, small coral reef-dwelling fish, are some of the shortest lived fishes with the seven-figure pygmy goby living at most for 59 days.

Among rockfish are some of the longest living fishes with the rougheye rockfish living for 205 years.

The oldest fish in captivity (at least 75 years) is an Australian lungfish

The orange roughy may be the longest lived commercial fish, at 149 years

By habitat

There is 10,000 times more saltwater in the oceans than there is freshwater in the lakes and rivers. However, only 58 percent of extant fish species are saltwater. A disproportionate 41 percent are freshwater fish (the remaining one percent are anadromous). This diversity in freshwater species is, perhaps, not surprising, since the thousands of separate lake habitats promote speciation.

Habitat	Area	Volume	Depth	Species		Fish biomass
	million km^2	million cu km	(mean)	count	percent	million tonnes
Saltwater	361	1370.8	3.8 km	18,000	58	800-2,000
Freshwater	1.5	0.13	87 m	13,000	41	

Fish can also be demersal or pelagic. Demersal fish live on or near the bottom of oceans and lakes, while pelagic fish inhabit the water column away from the bottom. Habitats can also be vertically stratified. Epipelagic fish occupy sunlit waters down to 200 metres (110 fathoms), mesopelagic fish occupying deeper twilight waters down to 1,000 meters (3,281 ft), and bathypelagic fish inhabiting the cold and pitch black depths below.

Most oceanic species (78 percent, or 44 percent of all fish species), live near the shoreline. These coastal fish live on or above the relatively shallow continental shelf. Only 13 percent of all fish species live in the open ocean, off the shelf. Of these, 1 percent are epipelagic, 5 percent are pelagic, and 7 percent are deep water.

Fish are found in nearly every aquatic habitat. Most fish, whether by species count or abundance, live in warmer environments with relatively stable temperatures. However, some species can survive temperatures up to 44.6 °C (112.3 °F), while others can cope with salinity greater than 10 percent. The world's deepest living fish, *Abyssobrotula galatheae*, a species of cusk eel, lives in the Puerto Rico Trench at a depth of 8,372 meters (27,467 ft). At the other extreme, the Tibetan stone loach lives at altitudes over 5,200 meters (17,060 ft) in the Himalayas.

Some marine pelagic fish range over vast areas, such as the blue shark that lives in all oceans. At the other extreme are fish confined to single, small living spaces, such as isolated cave fish like *Lucifuga* in the Bahamas and Cuba, or equally isolated desert pupfish living in small desert spring systems in Mexico and the southwest U.S., or bythitid vent fish like *Thermichthys hollisi*, living around thermal vents 2,400 metres (1,300 fathoms) down.

The blue shark ranges across all oceans

The blind cave fish live in caves

By breeding behavior

Grouper are protogynous hermaphrodites, who school in *harems* of three to fifteen females. When no male is available, the most aggressive and largest females shift sex to male, probably as a result of behavioral triggers.

In very deep waters, it is not easy for a fish to find a mate. There is no light, so some species depend on bioluminescence. Others are hermaphrodites, which doubles their chances of producing both eggs and sperm when an encounter does occur. The female anglerfish releases pheromones to attract tiny males. When a male finds her, he bites on to her and never lets go. When a male of the anglerfish species *Haplophryne mollis* bites into the skin of a female, he release an enzyme that digests the skin of his mouth and her body, fusing the pair to the point where the two circulatory systems join up. The male then atrophies into nothing more than a pair of gonads. This extreme sexual dimorphism ensures that, when the female is ready to spawn, she has a mate immediately available.

Some sharks, such as hammerheads are able to breed parthogenetically.

Female groupers change their sex to male if no male is available.

Male toadfish "sing" at up to 100 decibels with their swim bladders to attract mates.

Female *Haplophryne mollis* anglerfish trailing atrophied males she encountered.

By brooding behavior

Fish adopt a variety of strategies for nurturing their brood. Sharks, for example, variously follow three protocols with their brood. Most sharks, including lamniformesare ovoviviparous, bearing their young after they nourish themselves after hatching and before birth, by consuming the remnants of the yolk and other available nutrients. Some such as hammerheads are viviparous, bearing their young after nourishing hatchlings internally, analgously to mammalian gestation. Finally catsharks and others are, oviparous, laying their eggs to hatch in the water.

Some animals, predominantly fish such as cardinalfish practice mouthbrooding, caring for their offspring by holding them in the mouth of a parent for extended periods of time. Mouthbrooding has evolved independently in several different families of fish.

Others, such as seahorse males, practice pouch-brooding, analogous to Australia's kangaroos, nourishing their offspring in a pouch in which the female lays them.

A female *Cyphotilapia frontosa* mouthbrooding fry which can be seen looking out her mouth

The chain catshark is oviparous, laying its eggs to hatch in the water.

The great white shark is ovoviviparous, gestating eggs in the uterus for 11 months before giving birth.

The scalloped hammerhead is viviparous, bearing its young after nourishing hatchlings internally

By feeding behaviour

There are three basic methods by which food is gathered into the mouths of fish: by suction feeding, by ram feeding, and by manipulation or biting. Nearly all fish species use one of these styles, and most use two.

Early fish lineages had inflexible jaws limited to little more than opening and closing. Modern telosts have evolved protusible jaws that can reach out to engulf prey. An extreme example is the protusible jaw of the slingjaw wrasse. Its mouth extends into a tube half as long as its body, and with a strong suction it catches prey. The equipment tucks away under its body when it is not in use.

In practice, feeding modes lie on a spectrum, with suction and ram feeding at the extremes. Many fish capture their prey using both suction pressure combined with a forward motion of the body or jaw.

The cookiecutter shark is a small dogfish which derives its name from the way it removes small circular plugs, looking as though cut with a cookie cutter, from the flesh and skin of cetaceans and larger fish, including other sharks. The cookiecutter attaches to its larger prey with its suctorial lips, and then protrudes its teeth to remove a symmetrical scoop of flesh.

A pomfret with bite wounds from a cookiecutter shark.

Striped bass eat smaller fish

Chinese algae eaters are kept in aquaria to

The Emperor angelfish feeds on

control algae. coral sponges

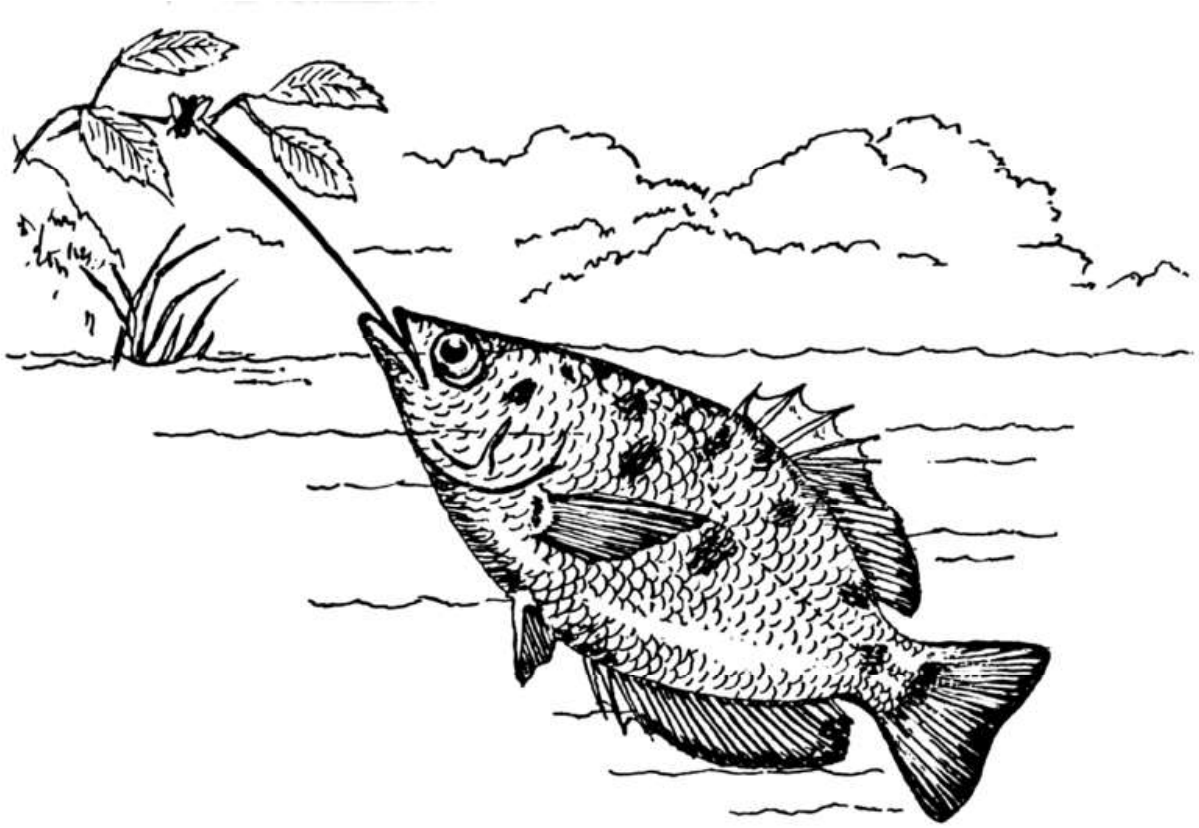
Most fish are food opportunists, or generalists. They eat whatever is most easily available. For example, the blue shark feeds on dead whales and nearly everything else that wriggles: other fish, cephalopods, gastropods, ascidians, crustaceans. Ocean sunfish prefer jellyfish.

Silver arowana leap two metres out of the water to capture prey.

Schooling herrings ram feed on copepods

The mangrove jack eats crustaceans

Many puffer fish species crush the shells of molluscs



Archerfish shooting down an insect using a jet of water

Other fish have developed extreme specializations. Silver arowana, also called *monkey fish*, can leap two meters out of the water to capture prey. They usually swim near the surface of the water waiting for potential prey. Their main diet consist of crustaceans,

insects, smaller fishes and other animals that float on the water surface, for which its draw-bridge-like mouth is exclusively adapted for feeding. The remains of small birds, bats, and snakes have also been found in their stomachs.

Archerfish prey on land–based insects and other small animals by literally shooting them down with water droplets from their specialized mouths. Archerfish are remarkably accurate; adults almost always hit the target on the first shot. They can bring down insects such as grasshoppers, spiders and butterflies on a branch of an overhanging tree, 3 m above the water's surface. This is partially due to good eyesight, but also the ability to compensate for light refraction when aiming. Triggerfish also use jets of water, to uncover sand dollars buried in sand or overturn sea urchins.

Triggerfish use a jet of water to uncover sand dollars buried in sand.

The bucktoothed tetra eats scales off other fishes (lepidophagy)

These two small wrasses are cleaner fish, and eat parasites off other fish.

Doctor fish nibbling on the diseased skin of patients

Doctor fish (*nibble fish*) live and breed in the outdoor pools of some Turkish spas, where they feed on the skin of patients with psoriasis. The fish are like cleaner fish in that they only consume the affected and dead areas of the skin, leaving the healthy skin to recover.

By locomotion

The slowest-moving fishes are the sea horses. The slowest of these, the dwarf seahorse, attains about five feet per hour.

The fasted sprinter is the Indo-Pacific sailfish. It has been recorded in a burst of over 110 kilometres per hour (68 mph), equivalent to 12 to 15 times its own length per second. The wahoo is perhaps the fastest fish for its size, attaining a speed of 19 lengths per second, reaching 78 kilometres per hour (48 mph).

The shortfin mako shark is fast enough and agile enough to chase down and kill an adult swordfish, but they don't always win. Sometimes in the struggle with a shark a swordfish can kill it by ramming it in the gills or belly. The shortfin mako's speed has been recorded at 50 kilometres per hour (31 mph), and there are reports that it can achieve bursts of up to 74 kilometres per hour (46 mph). It can jump up to 9 meters (30 ft) in the air. Due to its speed and agility, this high-leaping fish is sought as game worldwide. This shark is highly migratory. Its exothermic constitution partly accounts for its relatively great speed.

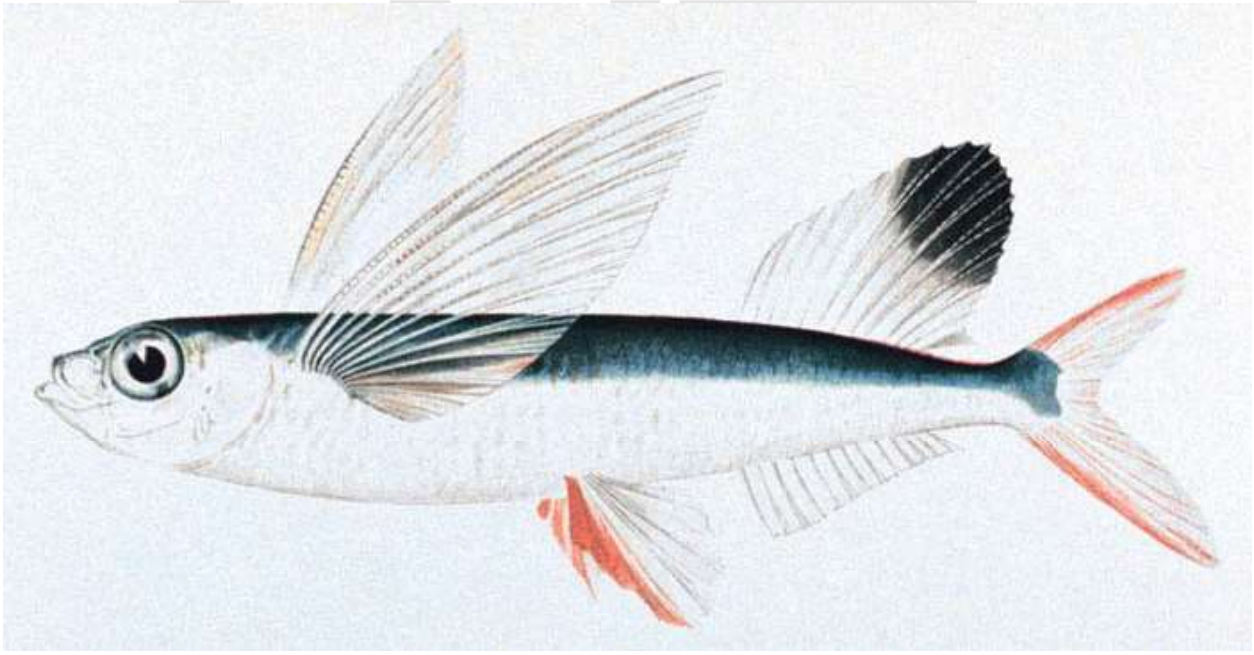
The northern bluefin tuna is capable of sustained high speed cruising, and maintains high muscle temperatures so it can can cruise in arctic waters.

The slowest fishes are the seahorses, and the tiny dwarf seahorse is the slowest of all

The fasted sprinter is the Indo-Pacific sailfish

The northern bluefin tuna is capable of sustained high speed cruising.

Flying fish taking off into a glide



Flying fish

A number of species jump while swimming near the surface, skimming the water. Flying fish have unusually large pectoral fins, which enable the fish to take short gliding flights above the surface of the water, in order to escape from predators. Their glides are typically around 50 meters (160 ft), but they can use updrafts at the leading edge of waves to cover distances of at least 400 meters (1,300 ft). In May 2008, a flying fish was filmed off the coast of Japan. The fish spent 45 seconds aloft, and was able to stay aloft by occasionally beating the surface of the water with its caudal (tail) fin. The previous record was 42 seconds.

The mudskipper is a type of walking fish

Walking fish are often amphibious and can travel over land for extended periods of time. Able to spend longer times out of water, these fish may use a number of means of locomotion, including springing, snake-like lateral undulation, and tripod-like walking. The mudskipper is probably the best land-adapted of contemporary fish and is able to spend days moving about out of water and can even climb mangroves, although to only modest heights. There are some species of fish that can "walk" along the sea floor but not on land. One such animal is the flying gurnard, which can walk on the sea floor.

By toxicity

Toxic fish produce strong poisons in their bodies. Both poisonous fish and venomous fish, contain toxins, but deliver them differently.

Venomous fish bite, sting, or stab, causing an envenomation. Venomous fish don't necessarily cause poisoning if they are eaten, since the digestive system often destroys the venom. By contrast, the digestive system does not destroy poisonous fish toxins, making them poisonous to eat.

The most poisonous fish is the puffer fish. It is the second most poisonous vertebrate after the golden dart frog. It paralyzes the diaphragm muscles of human victims, who can die from suffocation. In Japan, skilled chefs use parts of a closely related species, the

blowfish to create a delicacy called "fugu", including just enough toxin for that "special flavour".

The spotted trunkfish is a reef fish which secretes a colourless ciguatera toxin from glands on its skin when touched. The toxin is only dangerous when ingested, so there's no immediate harm to divers. However, predators as large as nurse sharks can die as a result of eating a trunkfish.

The giant moray is a reef fish at the top of the food chain. Like many other apex reef fish, it is likely to cause ciguatera poisoning if eaten. Outbreaks of ciguatera poisoning in the 11th to 15th centuries from large, carnivorous reef fish, caused by harmful algal blooms, could be a reason why Polynesians migrated to Easter Island, New Zealand, and possibly Hawaii.

The puffer fish is the most poisonous fish in the world

The spotted trunkfish secretes a ciguatera toxin from glands on its skin

Like many other apex reef fish, the giant moray can cause ciguatera poisoning if eaten.

A 2006 study found that there are at least 1200 species of venomous fish. There are more venomous fish than venomous snakes. In fact, there are more venomous fish than the combined total of all other venomous vertebrates. Venomous fish are found in almost all habitats around the world, but mostly in tropical waters. They wound over 50,000 people every year.

They carry their venom in venom glands and use various delivery systems, such as spines or sharp fins, barbs, spikes and fangs. Venomous fish tend to be either very visible, using flamboyant colors to warn enemies, or skilfully camouflaged and maybe buried in the sand. Apart from the defense or hunting value, venom help bottom dwelling fish by killing the bacteria that try to invade their skin. Few of these venoms have been studied. They are yet to be tapped resource for bioprospecting to find drugs with medical uses.

Head on view of the beautiful lionfish, a venomous coral reef fish

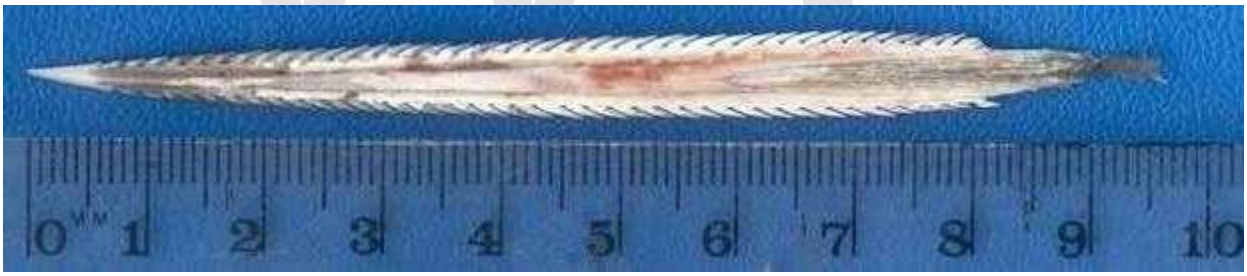
The stargazer *Uranoscopus sulphureus*.

The most venomous known
fish is the reef stonefish.

The most venomous fish is the reef stonefish. It has a remarkable ability to camouflage itself amongst rocks. It is an ambush predator that sits on the bottom waiting for prey to approach. Instead of swimming away if disturbed, it erects 13 venomous spines along its back. For defense, it can shoot venom from each or all of these spines. Each spine is like a hypodermic needle, delivering the venom from two sacs attached to the spine. The stonefish has control over whether to shoot its venom, and does so when provoked or frightened. The venom results in severe pain, paralysis and tissue death, and can be fatal if not treated. Despite its formidable defenses, stonefish have predators. Some bottom feeding rays and sharks with crushing teeth feed on them, as does the Stokes' seasnake

Unlike stonefish, lionfish can only release venom when something strikes its spines. Although not native to the U.S. coast, lionfish have appeared around Florida and have spread up the coast to New York. They are attractive aquarium fish, sometimes used to stock ponds, and may have been washed into the sea during a hurricane. Lionfish can aggressively dart at scuba divers and attempt to puncture their facemask with their venomous spines.

The stargazer buries itself and can deliver electric shocks as well as venom. It is a delicacy in some cultures (cooking destroys the venom), and can be found for sale in some fish markets with the electric organ removed. They have been called "the meanest things in creation"



A stingray's stinger

Stingray envenomations can occur to people who wade in shallow water and tread on them. This can be avoided by shuffling through the sand or stamping on the bottom, as the rays detect this and swim away. The stinger usually breaks off in the wound. It is barbed, so it can easily penetrate but not so easily be removed. The stinger causes local trauma from the cut itself, pain and swelling from the venom, and possible later infection from bacteria. Occasionally severed arteries or death can result.

Treatment for venom stings usually includes the application of heat, using water at temperatures of about 45 °C (113 °F), since heat breaks down most complex venom proteins.

By human use

Predator fish size up schooling forage fish

Fish are sought by humans for their value as commercial food fish, recreational sport fish, decorative aquarium fish and in tourism, attracting snorkelers and SCUBA divers.

Throughout human history, important fisheries have been based on forage fish. Forage fish are small fish which are eaten by larger predators. They usually school together for protection. Typical ocean forage fish feed near the bottom of the food chain on plankton, often by filter feeding. They include the family Clupeidae (herrings, sardines, menhaden, hilsa, shad and sprats), as well as anchovies, capelin and halfbeaks. Important herring fisheries have existed for centuries in the North Atlantic and the North Sea. Likewise, important traditional for anchovy and sardine fisheries have operated in the Pacific, the Mediterranean, and the southeast Atlantic. The world annual catch of forage fish in recent years has been around 25 million tonnes, or one quarter of the world's total catch.

Higher in the food chain, Gadidae (cod, pollock, haddock, saithe, hake and whiting also support important fisheries. Concentrated initially in the North Sea, Atlantic cod was one

of Europe's oldest fisheries, later extending to the Grand Banks, Declining numbers led to international "cod wars" and eventually the virtual abandonment of these fisheries. These days the Alaska pollock supports an important fishery in the Bering Sea and the north Pacific, yielding about 6 million tonnes, while cod amounts to about 9 million tonnes.

Yellowfin tuna are now being fished as a replacement for the depleted Southern bluefin tuna.

These schooling anchovy are forage fish

Atlantic cod fisheries have collapsed

Alaska pollock

Koi (and goldfish) have been kept in decorative ponds for centuries in China and Japan

- Food fish, Oily fish, whitefish
- Farmed fish

- fish used for medicinal purposes

Recreational and sport fishing is big business U.S. saltwater fishers spend about $30 billion annually and support 350,000 jobs. Some of the more popular recreational and sport fish include bass, marlin, porgie, shad, mahi-mahi, smelt whiting, swordfish, and walleye.

Fishkeeping is another popular pastime, and there is a large international trade for aquarium fish.

Snorkeling and SCUBA diving attract millions of people to beaches, coral reefs, lakes, and other water bodies to view fish and other marine life.

By vulnerability

- resilience

Other types

Four-eyed fish

Four-eyed fish have eyes raised above the top of the head and divided in two different parts, so that they can see below and above the water surface at the same time. Four-eyed fish actually have only two eyes, but their eyes are specially adapted for their surface-dwelling lifestyle. The eyes are positioned on the top of the head, and the fish floats at the water surface with only the lower half of each eye underwater. The two halves are divided by a band of tissue and the eye has two pupils, connected by part of the iris. The upper half of the eye is adapted for vision in air, the lower half for vision in water. The lens of the eye also changes in thickness top to bottom to account for the difference in the refractive indices of air versus water. These fish spend most of their time at the surface of the water. Their diet mostly consists of the terrestrial insects which are available at the surface.

Fish hold the records for the relative brain weights of vertebrates. Most vertebrate species have similar brain-to-body weight ratios. The deep sea bathopelagic cusk-eel *Acanthonus armatus*, has the smallest ratio of all known vertebrates. At the other extreme, the elephantnose fish, an African freshwater fish, has the largest ratio of all known vertebrates.

Sarpa salpa, a species of bream are recognizable by the golden stripes running the length of its body and can induce LSD-like hallucinations if it is eaten. These widely distributed coastal fish became a recreational drug during the Roman Empire, and are called "the fish that make dreams" in Arabic. Other hallucinogenic fish are *Siganus spinus*, called "the fish that inebriates" in Reunion Island, and *Mulloidichthys samoensis*, called "the chief of ghosts" in Hawaii.

Taxonomy

Fish are a paraphyletic group: that is, any clade containing all fish also contains the tetrapods, which are not fish. For this reason, groups such as the "Class Pisces" seen in older reference works are no longer used in formal classifications.

Fish are classified into the following major groups:

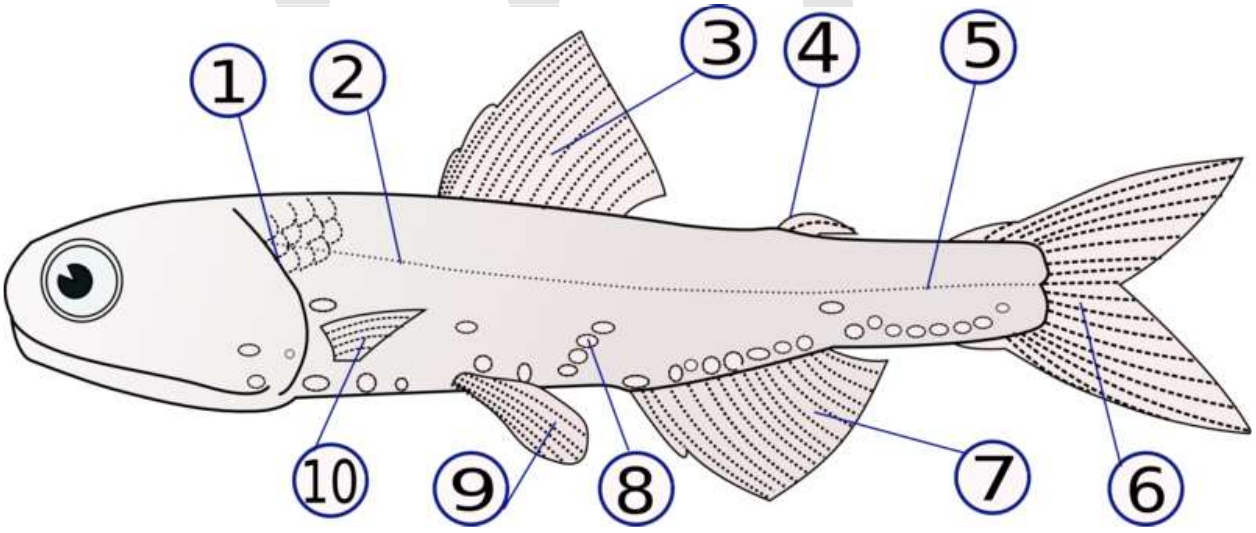
- Subclass Pteraspidomorphi (early jawless fish)
- Class Thelodonti
- Class Anaspida
- (unranked) Cephalaspidomorphi (early jawless fish)
    - (unranked) Hyperoartia or Petromyzontida
        - Petromyzontidae (lampreys)
    - Class Galeaspida
    - Class Pituriaspida
    - Class Osteostraci
- Infraphylum Gnathostomata (jawed vertebrates)
    - Class Placodermi (armoured fishes, extinct)
    - Class Chondrichthyes (cartilaginous fish)
    - Class Acanthodii (spiny sharks, extinct)

- Superclass Osteichthyes (bony fish)
  - Class Actinopterygii (ray-finned fish)
    - Subclass Chondrostei
      - Order Acipenseriformes (sturgeons and paddlefishes)
      - Order Polypteriformes (reedfishes and bichirs).
    - Subclass Neopterygii
      - Infraclass Holostei (gars and bowfins)
      - Infraclass Teleostei (many orders of common fishes)
  - Class Sarcopterygii (lobe-finned fish)
    - Subclass Coelacanthimorpha (coelacanths)
    - Subclass Dipnoi (lungfish)

Some palaeontologists contend that because Conodonta are chordates, they are primitive fish.

The various fish groups account for more than half of vertebrate species. There are almost 28,000 known extant species, of which almost 27,000 are bony fish, with 970 sharks, rays, and chimeras and about 108 hagfishes and lampreys. A third of these species fall within the nine largest families; from largest to smallest, these families are Cyprinidae, Gobiidae, Cichlidae, Characidae, Loricariidae, Balitoridae, Serranidae, Labridae, and Scorpaenidae. About 64 families are monotypic, containing only one species. The final total of extant species may grow to exceed 32,500.

Anatomy



The anatomy of *Lampanyctodes hectoris*
(1) – operculum (gill cover), (2) – lateral line, (3) – dorsal fin, (4) – fat fin, (5) – caudal peduncle, (6) – caudal fin, (7) – anal fin, (8) – photophores, (9) – pelvic fins (paired), (10) – pectoral fins (paired)

Respiration

Most fish exchange gases using gills on either side of the pharynx. Gills consist of threadlike structures called filaments. Each filament contains a capillary network that provides a large surface area for exchanging oxygen and carbon dioxide. Fish exchange gases by pulling oxygen-rich water through their mouths and pumping it over their gills. In some fishes, capillary blood flows in the opposite direction to the water, causing counter current exchange. The gills push the oxygen-poor water out through openings in the sides of the pharynx. Some fishes, like sharks and lampreys, possess multiple gill openings. However, most fishes have a single gill opening on each side. This opening is hidden beneath a protective bony cover called an operculum.

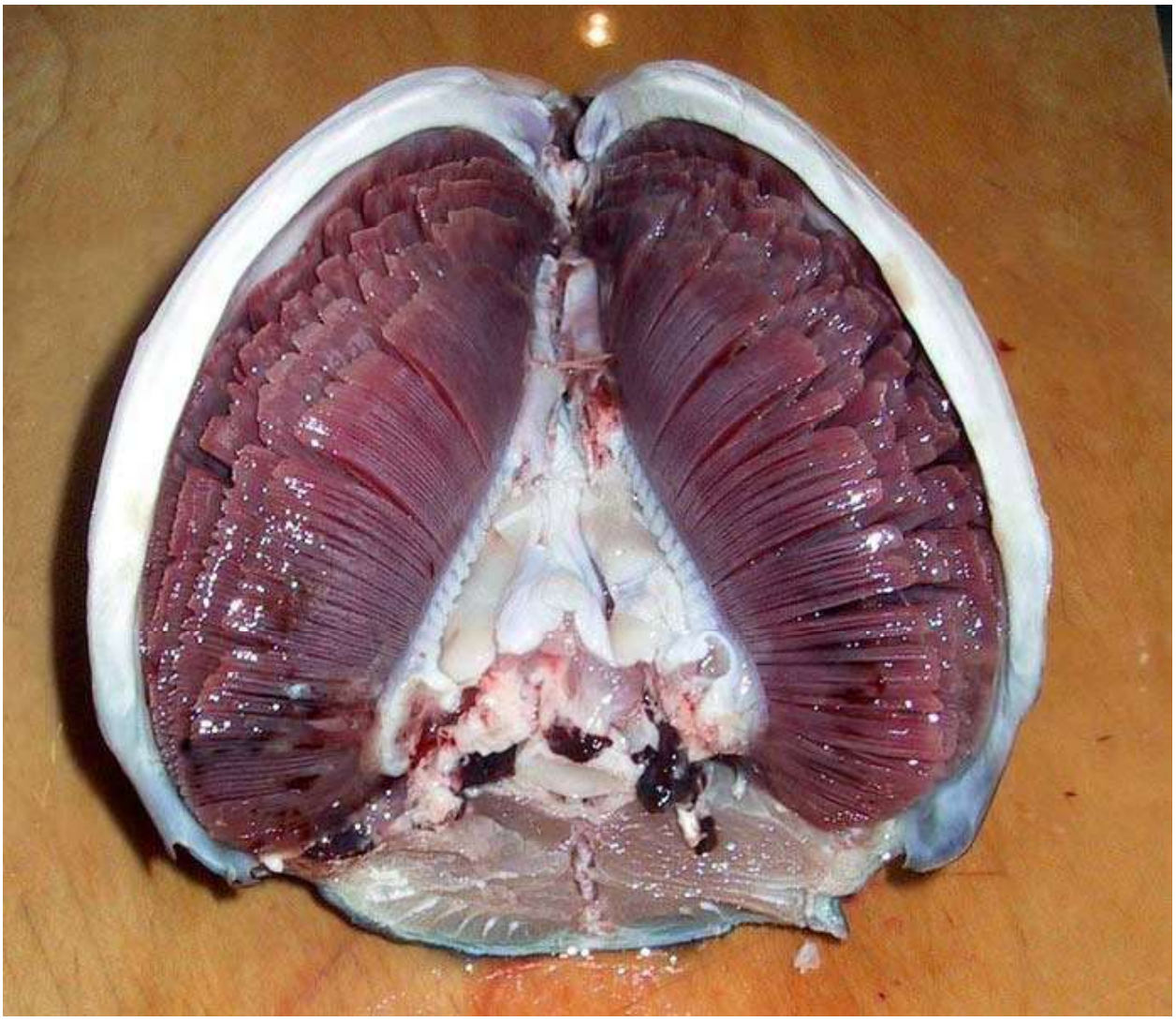
Juvenile bichirs have external gills, a very primitive feature that they share with larval amphibians.

Swim bladder of a Rudd (Scardinius erythrophthalmus)

Many fish can breathe air via a variety of mechanisms. The skin of anguillid eels may absorb oxygen. The buccal cavity of the electric eel may breathe air. Catfishes of the families Loricariidae, Callichthyidae, and Scoloplacidae absorb air through their digestive tracts. Lungfish and bichirs have paired lungs similar to those of tetrapods and must surface to gulp fresh air through the mouth and pass spent air out through the gills. Gar and bowfin have a vascularized swim bladder that functions in the same way. Loaches, trahiras, and many catfish breathe by passing air through the gut. Mudskippers breathe by absorbing oxygen across the skin (similar to frogs). A number of fishes have evolved so-called **accessory breathing organs** that extract oxygen from the air. Labyrinth fish (such as gouramis and bettas) have a labyrinth organ above the gills that performs this function. A few other fish have structures resembling labyrinth organs in form and function, most notably snakeheads, pikeheads, and the Clariidae catfish family.

Breathing air is primarily of use to fish that inhabit shallow, seasonally variable waters where the water's oxygen concentration may seasonally decline. Fishes dependent solely on dissolved oxygen, such as perch and cichlids, quickly suffocate, while air-breathers survive for much longer, in some cases in water that is little more than wet mud. At the most extreme, some air-breathing fish are able to survive in damp burrows for weeks

without water, entering a state of aestivation (summertime hibernation) until water returns.



Tuna gills inside of the head. The fish head is oriented snout-downwards, with the view looking towards the mouth.

Fish can be divided into **obligate air breathers** and **facultative air breathers**. Obligate air breathers, such as the African lungfish, *must* breathe air periodically or they suffocate. Facultative air breathers, such as the catfish *Hypostomus plecostomus*, only breathe air if they need to and will otherwise rely on their gills for oxygen. Most air breathing fish are facultative air breathers that avoid the energetic cost of rising to the surface and the fitness cost of exposure to surface predators.

Circulation

Fish have a closed-loop circulatory system. The heart pumps the blood in a single loop throughout the body. In most fish, the heart consists of four parts, including two chambers and an entrance and exit. The first part is the sinus venosus, a thin-walled sac that collects blood from the fish's veins before allowing it to flow to the second part, the atrium, which is a large muscular chamber. The atrium serves as a one-way antechamber, sends blood to the third part, ventricle. The ventricle is another thick-walled, muscular chamber and it pumps the blood, first to the fourth part, bulbous arteriosus, a large tube, and then out of the heart. The bulbus arteriosus connects to the aorta, through which blood flows to the gills for oxygenation.

Digestion

Jaws allow fish to eat a wide variety of food, including plants and other organisms. Fish ingest food through the mouth and break it down in the esophagus. In the stomach, food is further digested and, in many fish, processed in finger-shaped pouches called pyloric caeca, which secrete digestive enzymes and absorb nutrients. Organs such as the liver and pancreas add enzymes and various chemicals as the food moves through the digestive tract. The intestine completes the process of digestion and nutrient absorption.

Excretion

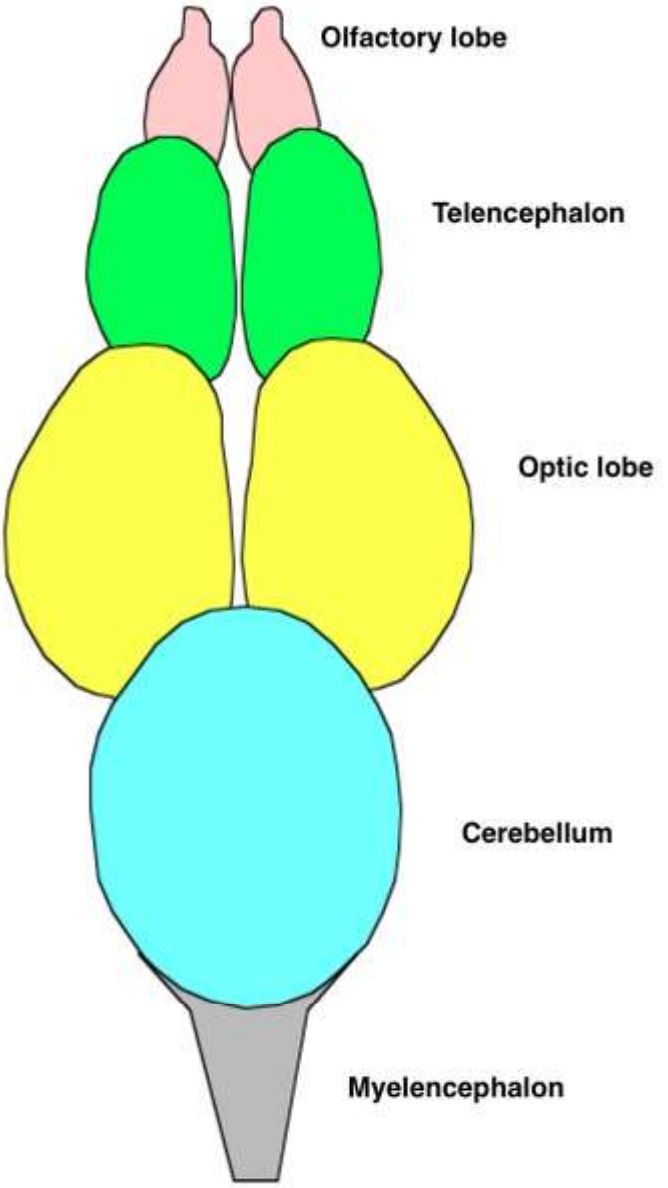
As with many aquatic animals, most fish release their nitrogenous wastes as ammonia. Some of the wastes diffuse through the gills. Blood wastes are filtered by the kidneys.

Saltwater fish tend to lose water because of osmosis. Their kidneys return water to the body. The reverse happens in freshwater fish: they tend to gain water osmotically. Their kidneys produce dilute urine for excretion. Some fish have specially adapted kidneys that vary in function, allowing them to move from freshwater to saltwater.

Scales

The scales of fish originate from the mesoderm (skin); they may be similar in structure to teeth.

Sensory and nervous system



Dorsal view of the brain of the rainbow trout

Central nervous system

Fish typically have quite small brains relative to body size compared with other vertebrates, typically one-fifteenth the brain mass of a similarly sized bird or mammal. However, some fish have relatively large brains, most notably mormyrids and sharks, which have brains about as massive relative to body weight as birds and marsupials.

Fish brains are divided into several regions. At the front are the olfactory lobes, a pair of structures that receive and process signals from the nostrils via the two olfactory nerves.

The olfactory lobes are very large in fishes that hunt primarily by smell, such as hagfish, sharks, and catfish. Behind the olfactory lobes is the two-lobed telencephalon, the structural equivalent to the cerebrum in higher vertebrates. In fishes the telencephalon is concerned mostly with olfaction. Together these structures form the **forebrain**.

Connecting the forebrain to the **midbrain** is the diencephalon (in the diagram, this structure is below the optic lobes and consequently not visible). The diencephalon performs functions associated with hormones and homeostasis. The pineal body lies just above the diencephalon. This structure detects light, maintains circadian rhythms, and controls color changes.

The midbrain or mesencephalon contains the two optic lobes. These are very large in species that hunt by sight, such as rainbow trout and cichlids.

The **hindbrain** or metencephalon is particularly involved in swimming and balance. The cerebellum is a single-lobed structure that is typically the biggest part of the brain. Hagfish and lampreys have relatively small cerebellae, while the mormyrid cerebellum is massive and apparently involved in their electrical sense.

The **brain stem** or myelencephalon is the brain's posterior. As well as controlling some muscles and body organs, in bony fish at least, the brain stem governs respiration and osmoregulation.

Sense organs

Most fish possess highly developed sense organs. Nearly all daylight fish have color vision that is at least as good as a human's. Many fish also have chemoreceptors that are responsible for extraordinary senses of taste and smell. Although they have ears, many fish may not hear very well. Most fish have sensitive receptors that form the lateral line system, which detects gentle currents and vibrations, and senses the motion of nearby fish and prey. Some fish, such as catfish and sharks, have organs that detect low-level electric current. Other fish, like the electric eel, can produce electric current.

Fish orient themselves using landmarks and may use mental maps based on multiple landmarks or symbols. Fish behavior in mazes reveals that they possess spatial memory and visual discrimination.

Fish locomotion

The prevailing type of **fish locomotion** is swimming in water. In addition, some fish can "walk", i.e., move over land, burrow in mud, and glide through the air.

Swimming

Fish swim by exerting force against the surrounding water. There are exceptions, but this is normally achieved by the fish contracting muscles on either side of its body in order to generate waves of flexion that travel the length of the body from nose to tail, generally getting larger as they go along. The vector forces exerted on the water by such motion cancel out laterally, but generate a net force backwards which in turn pushes the fish forward through the water.

Most fishes generate thrust using lateral movements of their body & caudal fin. But there are also a huge number of species that move mainly using their median and paired fins. The latter group profits from the gained manoeuvrability that is needed when living in coral reefs for example. But they can't swim as fast as fish using their bodies & caudal fins.

Body/caudal fin propulsion

There are four groups that differ in the fraction of their body that is displaced laterally:

Anguilliform locomotion

In some long, slender fish – eels, for example – there is little increase in the amplitude of the flexion wave as it passes along the body.

Sub-carangiform locomotion

Here, there is a more marked increase in wave amplitude along the body with the vast majority of the work being done by the rear half of the fish. In general, the fish body is stiffer, making for higher speed but reduced maneuverability. Trout use sub-carangiform locomotion.

Carangiform locomotion

Fish in this group are stiffer and faster-moving than the previous groups. The vast majority of movement is concentrated in the very rear of the body and tail. Carangiform swimmers generally have rapidly oscillating tails.

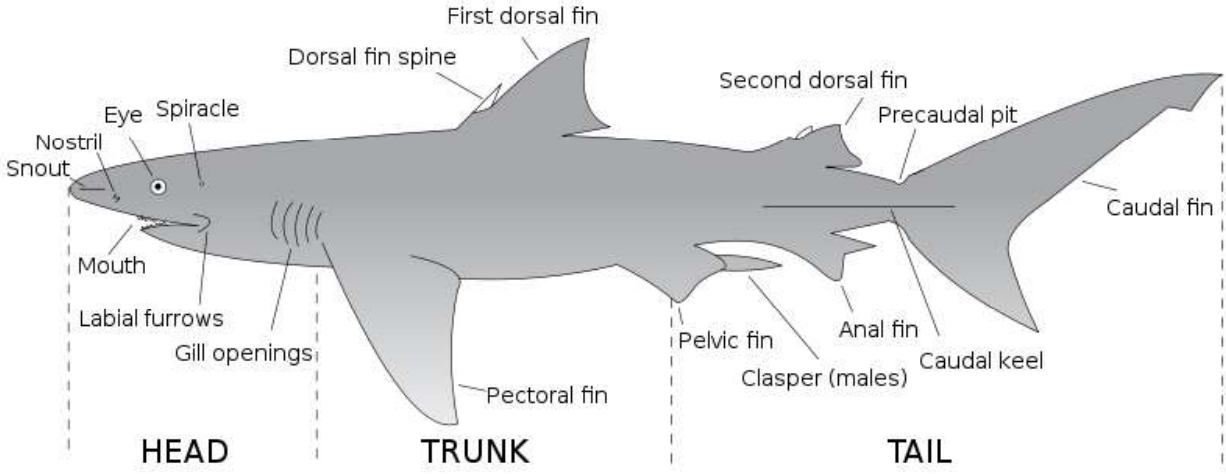
Thunniform locomotion

The final group is reserved for the high-speed long-distance swimmers, like tuna (new research shows that the thunniform locomotion is an autapomorphy of the tunas). Here, virtually all the lateral movement is in the tail and the region connecting the main body to the tail (the peduncle). The tail itself tends to be large and crescent shaped.

Median/paired fin propulsion

Not all fish fit comfortably in the above groups. Ocean sunfish, for example, have a completely different system, and many small fish use their pectoral fins for swimming as well as for steering and dynamic lift. Fish with electric organs, such as those in Gymnotiformes, swim by undulating their fins while keeping the body still, presumably so as not to disturb the electric field that they generate.

Dynamic lift



Bone and muscle tissues of fish are denser than water. To maintain depth some fish increase buoyancy by means of a gas bladder or by storing oils or lipids. Fish without these features use dynamic lift instead. It is done using their pectoral fins in a manner similar to the use of wings by aeroplanes and birds. As these fish swim, their pectoral fins are positioned to create lift which allows the fish to maintain a certain depth.

Sharks are a notable example of fish that depend on dynamic lift; notice their well-developed pectoral fins.

The two major drawbacks of this method are that these fish must stay moving to stay afloat and that they are incapable of swimming backwards or hovering.

Burrowing

Many fishes, particularly eel-shaped fishes such as true eels, moray eels, and spiny eels, are capable of burrowing through sand or mud. Ophichthids are capable of digging backwards using a sharpened tail.

Flying

Homeothermy

A 3-tonne (3.0 LT; 3.3 ST) great white shark off Isla Guadalupe

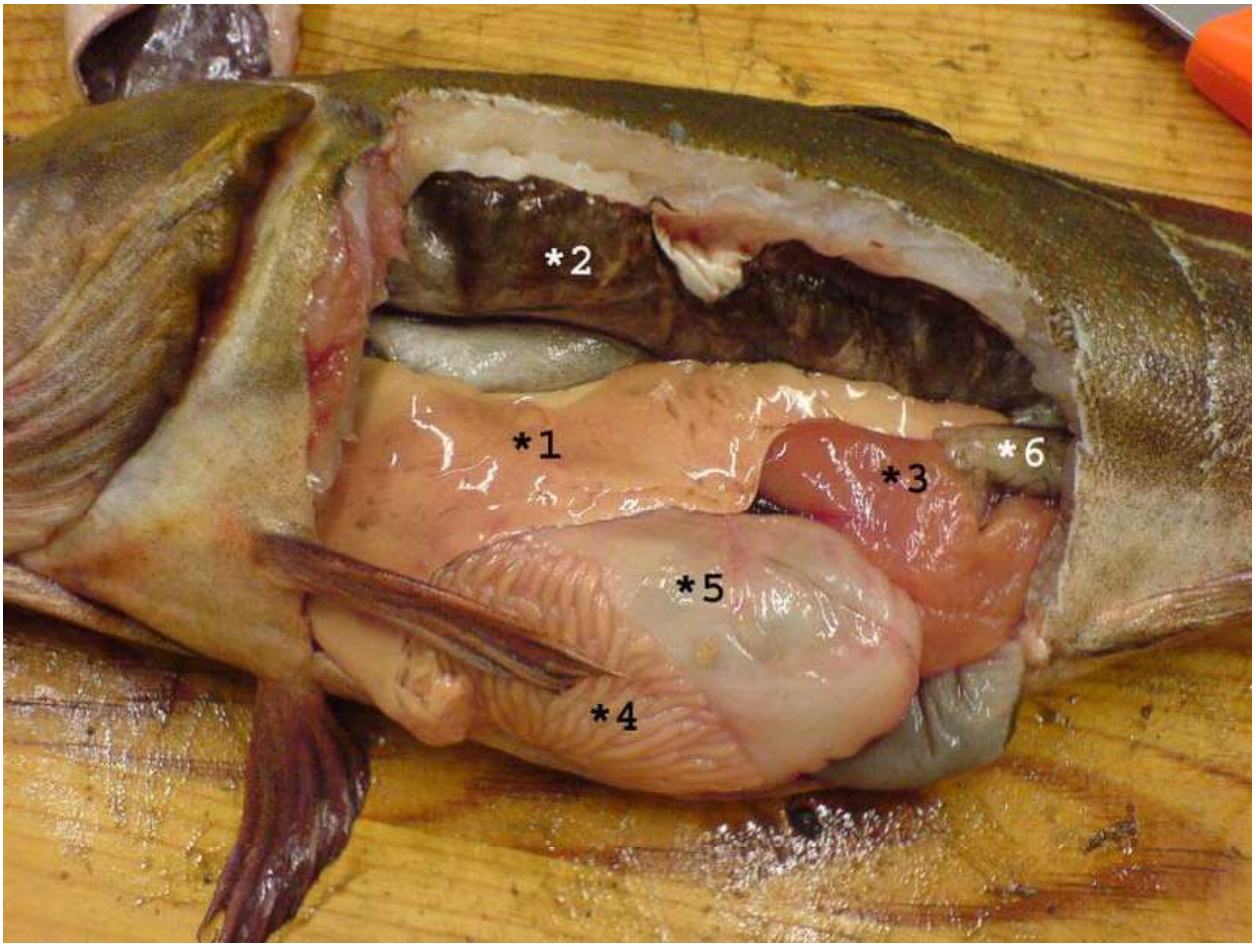
Although most fish are exclusively aquatic and ectothermic, there are exceptions to both cases.

Fish from multiple groups can live out of the water for extended time periods. Amphibious fish such as the mudskipper can live and move about on land for up to several days.

Certain species of fish maintain elevated body temperatures. Endothermic teleosts (bony fishes) are all in the suborder Scombroidei and include the billfishes, tunas, and one species of "primitive" mackerel (*Gasterochisma melampus*). All sharks in the family Lamnidae – shortfin mako, long fin mako, white, porbeagle, and salmon shark – are endothermic, and evidence suggests the trait exists in family Alopiidae (thresher sharks). The degree of endothermy varies from the billfish, which warm only their eyes and brain, to bluefin tuna and porbeagle sharks who maintain body temperatures elevated in excess of 20 °C above ambient water temperatures. Endothermy, though metabolically costly, is thought to provide advantages such as increased muscle strength, higher rates of central nervous system processing, and higher rates of digestion.

Reproductive system

Organs



Organs: 1. Liver, 2. Gas bladder, 3. Roe, 4. Pyloric caeca, 5. Stomach, 6. Intestine

Fish reproductive organs include testes and ovaries. In most species, gonads are paired organs of similar size, which can be partially or totally fused. There may also be a range of secondary organs that increase reproductive fitness.

In terms of spermatogonia distribution, the structure of teleosts testes has two types: in the most common, spermatogonia occur all along the seminiferous tubules, while in Atherinomorph fishes they are confined to the distal portion of these structures. Fishes can present cystic or semi-cystic spermatogenesis in relation to the release phase of germ cells in cysts to the seminiferous tubules lumen.

Fish ovaries may be of three types: gymnovarian, secondary gymnovarian or cystovarian. In the first type, the oocytes are released directly into the coelomic cavity and then enter the ostium, then through the oviduct and are eliminated. Secondary gymnovarian ovaries shed ova into the coelom from which they go directly into the oviduct. In the third type, the oocytes are conveyed to the exterior through the oviduct. Gymnovaries are the primitive condition found in lungfish, sturgeon, and bowfin. Cystovaries characterize most teleosts, where the ovary lumen has continuity with the oviduct. Secondary gymnovaries are found in salmonids and a few other teleosts.

Oogonia development in teleosts fish varies according to the group, and the determination of oogenesis dynamics allows the understanding of maturation and fertilization processes. Changes in the nucleus, ooplasm, and the surrounding layers characterize the oocyte maturation process.

Postovulatory follicles are structures formed after oocyte release; they do not have endocrine function, present a wide irregular lumen, and are rapidly reabsorbed in a process involving the apoptosis of follicular cells. A degenerative process called follicular atresia reabsorbs vitellogenic oocytes not spawned. This process can also occur, but less frequently, in oocytes in other development stages.

Some fish are hermaphrodites, having both testes and ovaries either at different phases in their life cycle or, as in hamlets, have them simultaneously.

Reproductive method

Over 97% of all known fishes are oviparous, that is, the eggs develop outside the mother's body. Examples of oviparous fishes include salmon, goldfish, cichlids, tuna, and eels. In the majority of these species, fertilization takes place outside the mother's body, with the male and female fish shedding their gametes into the surrounding water. However, a few oviparous fishes practice internal fertilization, with the male using some sort of intromittent organ to deliver sperm into the genital opening of the female, most notably the oviparous sharks, such as the horn shark, and oviparous rays, such as skates. In these cases, the male is equipped with a pair of modified pelvic fins known as claspers.

Marine fish can produce high numbers of eggs which are often released into the open water column. The eggs have an average diameter of 1 millimetre (0.039 in).




Egg of lampreyEgg of catshark (mermaids' purse)Egg of bullhead sharkEgg of chimaera

The newly hatched young of oviparous fish are called larvae. They are usually poorly formed, carry a large yolk sac (for nourishment) and are very different in appearance from juvenile and adult specimens. The larval period in oviparous fish is relatively short (usually only several weeks), and larvae rapidly grow and change appearance and structure (a process termed metamorphosis) to become juveniles. During this transition larvae must switch from their yolk sac to feeding on zooplankton prey, a process which depends on typically inadequate zooplankton density, starving many larvae.

In ovoviviparous fish the eggs develop inside the mother's body after internal fertilization but receive little or no nourishment directly from the mother, depending instead on the yolk. Each embryo develops in its own egg. Familiar examples of ovoviviparous fishes include guppies, angel sharks, and coelacanths.

Some species of fish are viviparous. In such species the mother retains the eggs and nourishes the embryos. Typically, viviparous fishes have a structure analogous to the placenta seen in mammals connecting the mother's blood supply with that of the embryo. Examples of viviparous fishes include the surf-perches, splitfins, and lemon shark. Some viviparous fishes exhibit oophagy, in which the developing embryos eat other eggs produced by the mother. This has been observed primarily among sharks, such as the shortfin mako and porbeagle, but is known for a few bony fish as well, such as the halfbeak *Nomorhamphus ebrardtii*. Intrauterine cannibalism is an even more unusual mode of vivipary, in which the largest embryos eat weaker and smaller siblings. This behavior is also most commonly found among sharks, such as the grey nurse shark, but has also been reported for *Nomorhamphus ebrardtii*.

Aquarists commonly refer to ovoviviparous and viviparous fishes as livebearers.

Immune system

Immune organs vary by type of fish. In the jawless fish (lampreys and hagfishes), true lymphoid organs are absent. These fish rely on regions of lymphoid tissue within other organs to produce immune cells. For example, erythrocytes, macrophages and plasma cells are produced in the anterior kidney (or pronephros) and some areas of the gut (where granulocytes mature.) They resemble primitive bone marrow in hagfish. Cartilaginous fish (sharks and rays) have a more advanced immune system. They have three specialized organs that are unique to chondrichthyes; the epigonal organs (lymphoid tissue similar to mammalian bone) that surround the gonads, the Leydig's organ within

the walls of their esophagus, and a spiral valve in their intestine. These organs house typical immune cells (granulocytes, lymphocytes and plasma cells). They also possess an identifiable thymus and a well-developed spleen (their most important immune organ) where various lymphocytes, plasma cells and macrophages develop and are stored. Chondrostean fish (sturgeons, paddlefish and bichirs) possess a major site for the production of granulocytes within a mass that is associated with the meninges (membranes surrounding the central nervous system.) Their heart is frequently covered with tissue that contains lymphocytes, reticular cells and a small number of macrophages. The chondrostean kidney is an important hemopoietic organ; where erythrocytes, granulocytes, lymphocytes and macrophages develop.

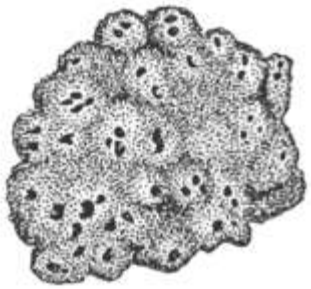
Like chondrostean fish, the major immune tissues of bony fish (or teleostei) include the kidney (especially the anterior kidney), which houses many different immune cells. In addition, teleost fish possess a thymus, spleen and scattered immune areas within mucosal tissues (e.g. in the skin, gills, gut and gonads). Much like the mammalian immune system, teleost erythrocytes, neutrophils and granulocytes are believed to reside in the spleen whereas lymphocytes are the major cell type found in the thymus. In 2006, a lymphatic system similar to that in mammals was described in one species of teleost fish, the zebrafish. Although not confirmed as yet, this system presumably will be where naive (unstimulated) T cells accumulate while waiting to encounter an antigen.

Diseases

Like other animals, fish suffer from diseases and parasites. To prevent disease they have a variety of defenses. *Non-specific* defenses include the skin and scales, as well as the mucus layer secreted by the epidermis that traps and inhibits the growth of microorganisms. If pathogens breach these defenses, fish can develop an inflammatory response that increases blood flow to the infected region and delivers white blood cells that attempt to destroy pathogens. Specific defenses respond to particular pathogens recognised by the fish's body, i.e., an immune response. In recent years, vaccines have become widely used in aquaculture and also with ornamental fish, for example furunculosis vaccines in farmed salmon and koi herpes virus in koi.

Some species use cleaner fish to remove external parasites. The best known of these are the Bluestreak cleaner wrasses of the genus *Labroides* found on coral reefs in the Indian and Pacific Oceans. These small fish maintain so-called "cleaning stations" where other fish congregate and perform specific movements to attract the attention of the cleaners. Cleaning behaviors have been observed in a number of fish groups, including an interesting case between two cichlids of the same genus, *Etroplus maculatus*, the cleaner, and the much larger *Etroplus suratensis*.

Evolution



Outdated evolutionary view of continual gradation

Dunkleosteus was a gigantic, 10 meter (33 ft) long prehistoric fish

Fish do not represent a monophyletic group, and therefore the "evolution of fish" is not studied as a single event.

Proliferation of fish was apparently due to the hinged jaw, because jawless fish left very few descendants. Lampreys may approximate pre-jawed fish. The first jaws are found in Placodermi fossils. It is unclear if the advantage of a hinged jaw is greater biting force, improved respiration, or a combination of factors.

Fish may have evolved from a creature similar to a coral-like Sea squirt, whose larvae resemble primitive fish in important ways. The first ancestors of fish may have kept the larval form into adulthood (as some sea squirts do today), although perhaps the reverse is the case.

Conservation

A Whale shark, the world's largest fish, is classified as Vulnerable

The 2006 IUCN Red List names 1,173 fish species that are threatened with extinction. Included are species such as Atlantic cod, Devil's Hole pupfish, coelacanths, and great white sharks. Because fish live underwater they are more difficult to study than terrestrial animals and plants, and information about fish populations is often lacking. However, freshwater fish seem particularly threatened because they often live in relatively small water bodies. For example, the Devil's Hole pupfish occupies only a single 3 by 6 metres (10 by 20 ft) pool.

Overfishing

Overfishing is a major threat to edible fishes such as cod and tuna. Overfishing eventually causes population (known as stock) collapse because the survivors cannot produce enough young to replace those removed. Such **commercial extinction** does not mean that the species is extinct, merely that it can no longer sustain a fishery.

One well-studied example of fishery collapse is the Pacific sardine *Sadinops sagax caerulues* fishery off the California coast. From a 1937 peak of 790,000 long tons (800,000 t) the catch steadily declined to only 24,000 long tons (24,000 t) in 1968, after which the fishery was no longer economically viable.

The main tension between fisheries science and the fishing industry is that the two groups have different views on the resiliency of fisheries to intensive fishing. In places such as Scotland, Newfoundland, and Alaska the fishing industry is a major employer, so governments are predisposed to support it. On the other hand, scientists and conservationists push for stringent protection, warning that many stocks could be wiped out within fifty years.

Habitat destruction

A key stress on both freshwater and marine ecosystems is habitat degradation including water pollution, the building of dams, removal of water for use by humans, and the introduction of exotic species. An example of a fish that has become endangered because of habitat change is the pallid sturgeon, a North American freshwater fish that lives in rivers damaged by human activity.

Exotic species

Introduction of non-native species has occurred in many habitats. One of the best studied examples is the introduction of Nile perch into Lake Victoria in the 1960s. Nile perch gradually exterminated the lake's 500 endemic cichlid species. Some of them survive now in captive breeding programmes, but others are probably extinct. Carp, snakeheads, tilapia, European perch, brown trout, rainbow trout, and sea lampreys are other examples of fish that have caused problems by being introduced into a lien environments.

Terminology

Fish or fishes

Though often used interchangeably, these words have different meanings. ***Fish*** is used either as singular noun or to describe a group of specimens from a single species. ***Fishes*** describes a group of different species.

Shoal or school

These goldband fusiliers are schooling because their swimming is synchronised

A random assemblage of fishes merely using some localised resource such as food or nesting sites is known simply as an ***aggregation***. When fish come together in an interactive, social grouping, then they may be forming either a *shoal* or a *school* depending on the degree of organisation. A ***shoal*** is a loosely organised group where each fish swims and forages independently but is attracted to other members of the group and adjusts its behaviour, such as swimming speed, so that it remains close to the other members of the group. ***Schools*** of fish are much more tightly organised, synchronising their swimming so that all fish move at the same speed and in the same direction. Shoaling and schooling behaviour is believed to provide a variety of advantages.

Examples:

- Cichlids congregating at lekking sites form an *aggregation*.
- Many minnows and characins form *shoals*.
- Anchovies, herrings, and silversides are classic examples of *schooling* fishes.

While school and shoal have different meanings within biology, they are often treated as synonyms by non-specialists, with speakers of British English using "shoal" to describe any grouping of fish, while speakers of American English often using "school" just as loosely.