CMAS BOOK UNDERWATER MARINE BIOLOGY

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C.M.A.S.
SCIENTIFIC
UNDERWATER MARINE BIOLOGY

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1 General information on the sea and its organisms

1.1 Introduction

Have you ever seen the ocean? Have you ever been in the ocean? Have you ever gone snorkelling or scuba diving and gotten a really good look at what exists beneath the ocean's surface? It's just amazing! The ocean is teeming with life.

When most people think about ocean life, they tend to think about fishes but there is a lot more to marine life than that. In this course, you are going to study the amazing organisms that exist in the ocean. You have probably already learned about some of these creatures (like dolphins and sharks), but there are many organisms (like zooxanthellae and deep-ocean anglerfish) that will probably be new to you.

Not only will you learn about the amazing organisms that make their homes in the ocean, but you will also learn about the complex interactions that these creatures have with one another. You will even learn about the complex interactions that these organisms have with land-dwelling creatures. As you study all of these things, you will see that the oceans play a vital role for all life on earth, and you will be amazed at God's handiwork!

The ocean is a vast realm that contains many strange and wonderful creatures. The beauty, mystery, and power of the sea fascinate people all over the world. Even professional marine biologists feel the sense of adventure and wonder in their studies.

"One is completely stunned by the incredible resourcefulness of the Creator,"

Carolus Linneaus[1]

[1] Carolus Linneaus (1707-1778): also known as Carl von Linné. He is often called the Father of Taxonomy. His system for naming, ranking, and classifying organisms is still in wide use today (with many changes). His ideas on classification have influenced generations of biologists during and after his own lifetime, even those opposed to the philosophical and theological roots of his work.

1.2 Marine Biology – an introduction

1.2.1 What is marine biology?

The ocean's beauty, mystery, and variety of life, are the main attractions for people to study marine biology. Marine biology is the more general science of biology applied to the sea. Most of the disciplined in biology are represented in marine biology. Marine biology has many branches, viewpoints, and approaches. It is also closely related to oceanography, the scientific study of the oceans. Geological oceanographers study the sea floor, chemical oceanographers study ocean chemistry, and physical oceanographers study waves, tides, currents, and other physical aspects of the sea.

1.2.2 Why study marine biology?

Life on earth is believed to be originated in the sea, therefore the study of marine life teaches us much about all life on earth, not just in the sea. Marine life helps determine the very nature of our planet. Marine organisms produce much of the oxygen we breathe and help regulate the earth's climate. Thus, to make full and wise use of the sea's living resources, to solve any kind of problems marine organisms may create, and to predict the effects of human activities on the life of the sea, we must learn all we can about marine life. In addition, marine organisms provide clues to the earth's past, the history of life, and even our own bodies that we must learn to understand. This is the challenge, the adventure, of marine biology.

1.2.3 The history of marine biology

From the first time people saw the ocean, they started to learn about marine life. Archaeologists have found ancient harpoons and simple fishbooks of bone or shell. While they gathered food, people learned through experience which things were good to eat and which were bat-tasting or harmful. Knowledge of the ocean and its organisms expanded as people gained skills in seamanship and navigation.

The Phoenicians were the first accomplished Western navigators and by 2000 B.C. they were sailing around the Mediterranean Sea, Red Sea, Black Sea, eastern Atlantic Ocean, and Indian Ocean. Ancient Greeks had considerable knowledge of nearshore organisms in the Mediterranean region. They even used an electric ray (*Torpedo*) to deliver the first electrical simulation therapy. During the 4th century B.C., the Greek philosopher Aristotle described many forms of marine life. He even recognized, among other things, that gills are the breathing apparatus of fish. Therefore, Aristotle is considered by many the first marine biologist. During the 9th and 10th centuries the Vikings continued the exploration of the northern Atlantic Ocean and they discovered Vinland, what we now call North America. Furthermore, Arab traders and people in the Far East also continued to explore and learn about the sea.

During the Renaissance, a lot of voyages of exploration began by the Europeans. Christopher Columbus rediscovered the "New World" in 1492. In 1519 Ferdinand Magellan embarked on the first expedition to sail around the globe. Fairly accurate maps, especially of places outside Europe, began to appear for the first time. The explorers were soon interested and curious about the ocean they sailed and the things that lived in it. James Cook, an English sea captain, was one of the first to make scientific observations along the way and to include a full-time naturalist among his crew. Furthermore, Cook was the first to make use of a chronometer[2] that enable him to prepare reliable charts.

By the nineteenth century it was common vessels to take a naturalist along to collect and study the life forms that were encountered. Perhaps the most famous of these shipboard naturalists was the Englishman, Charles Darwin. He sailed around the world on HMS *Beagle* for five years, horribly seasick most of the time. The *Beagle's* primary mission was to map coastlines, but Darwin used the opportunity to make detailed observations of all aspects of the natural world. This set off a train of though that led him, years later, to propose the theory of evolution by natural selection[3]. Darwin made many other contributions to marine biology. He explained, for example, the formation of the distinctive rings of coral reef called atolls. He used nets to

[2] Chronometer: Mechanical timekeeping device of great accuracy, particularly one used for determining longitude at sea.
[3] Natural Selection: A mechanism of evolutionary change that results when individuals that are better adapted than others in meeting the challenges of the environment produce more offspring.

capture the tiny, drifting organisms, known as plankton, which marine biologists continue to do today. Darwin's many interests also included barnacles. Specialists still refer to his treatise on them.

1.2.4 Mapping the Oceans

By 1701 the shape of the Atlantic Ocean basin had been determined and Edmund Halley produced a remarkable map, considering the difficulties of the time, using data collected during two voyages on the *Paramore* (1698-1700). Halley's map shows coastlines quite accurately with respect to longitude[4] and also contours (isogons) of the amount of angular divergence between magnetic and geographic north. Halley proposed that this angular divergence should be measured by mariners as a contribution to determining their position.

Very few investigations of the deep oceans were done. The earliest but unsuccessful attempt was the one by Magellan in the early 16th century. He tried to sound the ocean floor of the central Pacific, but it was too deep for his sounding lines. During the 19th century studies for the deep oceans were increased. The *Challenger* expedition of 1872-76, was mounted by the British Government to collect oceanographic information. *Challenger* underwent extensive renovations in preparation for the voyage. Laboratories and quarters for the scientific crew were added, and gear for dredging and taking water samples in deep water was installed. Though primitive by modern standards, the scientific equipment on board was the best of its day. Finally, in December 1872, *Challenger* set off. Over the next three and a half years, *Challenger* and her crew sailed around the world gathering information and collecting samples. A huge quantity of data was collected during the *Challenger's* voyage and it was published in 50 volumes. For the first time scientists began to get a coherent picture of what the ocean was like. They also learned more about the enormous variety of marine life, for *Challenger* brought back samples of thousands of previously unknown species. It can be considered to mark the birth of scientific study of the oceans.

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[4] Longitude was determined by painstaking observations of the passage of the Moon in front of stars, and eclipses of Jupiter's satellites.

In the years that followed, a series of other expeditions continued the work begun by *Challenger.* Major oceanographic cruises continue to this day. In many ways, thought, the voyage of the *Challenger* remains one of the most important in the history of oceanography.

1.2.5 Navigation

Accurate navigation at sea became possible only with the development of accurate and reliable chronometers in the 18th century that enabled longitude to be determined. The classical method of navigation used in the open sea is celestial navigation, also known as astro-navigation. The angles of the Sun, Moon, planets and stars above the horizon are measured, using a sextant[5], at a precisely recorded time. The positions of these bodies in the sky can be looked up in tables and an observation of any of them gives a position line on which the ship is situated.

Celestial navigation was greatly used by mariners for centuries. Now, navigational satellites can provide positions to within ± 100m virtually anywhere in the open oceans. US Navy was the first to develop satellite navigation and it first came into civil use in 1967. Nowadays, there are many radionavigational aids, both surface and satellite-mounted. GPS, Global Positioning System, uses an impressive array of satellites. The satellites are in circular orbits at a height of 20200 km, with 12-hour orbital periods. At least four satellites are always “in view” from a receiver anywhere on Earth. Each GPS satellite transmits accurately radio signals including precise information on its own position in space. This radio signal can be picked up by a receiver small enough to be hand-portable. The position of a ship can be fixed to within ±100m. “Differential GPS” uses a ship-board receiver in conjunction with a fixed receiver on land, giving a ship’s position to ± 10m. US military receivers have decryption codes that can extract fixes accurate t the nearest meter. Precise navigation is vital to many sorts of oceanographic study.

[5] Sextant: A navigational instrument containing a graduated 60-degree arc, used for measuring the altitudes of celestial bodies to determine latitude and longitude.

1.2.6 Depth Measurement

In the contrary with the contoured topographic maps of land areas that are based on the measurement of height *above* sea level, contoured bathymetric maps are based on measurements of depth *below* sea-level. Accurate depth determinations became possible only with the development of echo-sounding. Before the development of echo-sounders, knowledge of ocean depths was limited to relatively few isolated soundings that were made by lowering a weighted rope or steel plump-line until the weight reached the sea-floor. The depth was assumed to be the length of cable let out. In shallow waters this was done relatively easy and in short time, but in the deep oceans it could take hours and it was often of doubtful accuracy.

Echo-sounders were first used on oceanographic expeditions in the 1920s. The time needed to carry out hundreds of depth measurements decreased in a matter of days. Accurate bathymetric maps of major features such as the Mid-Atlantic Ridge and the Marianas Trench were possible to be produced. For detailed survey work, swath bathymetry is now favored, using multiple narrow beams directed to either side of the ship's track.

1.2.7 Recent Methods for Mapping the Ocean Floors

Direct imaging of the sea-floor, as district from bathymetric mapping, is achieved by side-beam sonar instruments.

Satellite altimetry uses radar to measure with great accuracy the average height of the sea-surface, which follows a surface of equal gravitational potential, the geoid[6]. Transient effects such as tides, currents, and atmospheric pressure changes, are averaged out so that the mean height of the sea-surface can be determined. Geoid anomalies (short-wavelength irregularities) correspond to topographic features on the ocean floor, and the height of the sea-surface can therefore provide a measure of bathymetry. Imaging radar (SAR) can show up bathymetric features in shallow waters.

[6] Geoid: The equipotential surface of the Earth's gravity field which best fits, in a least squares sense, global mean sea level

Detailed exploration of oceanic crustal structure and composition began in the 1960s, with the DSDP, succeeded in 1985 by the ODP. Much has been learned with the help of new technologies for imaging and through submersible operations.

1.2.8 The growth of marine labs

Biologists were excited about the organisms brought back by ocean expeditions. Unfortunately, the vessels had quarters for only a few scientists. Most biologists just got to see the dead, preserved specimens that the ships brought back to port. Such specimens revealed much about marine life around the world, but made biologists curious about how the organisms actually lived: how they functioned and what they did. Living specimens were essential for the study of these aspects of biology, but ships usually stayed in one place only for a short time, making long-term observations and experiments impossible.

Rather than study the ocean from ships, biologists began to work at the seashore. Among the first were two Frenchmen, Henri Milne Edwards and Victor Andouin, who around 1826 began making regular visits to the shore to study marine life. Other biologists soon followed suit. These excursions enabled the study of live organisms, but there were no permanent facilities and only a limited amount of equipment could be taken along.

Eventually, permanent laboratories were established. These labs allowed marine biologists to keep organisms alive and to work over long periods. The first such laboratory was the Stazione Zoologica, founded in Naples, Italy, by German biologists in 1872. Other marine laboratories were established as well. Among the earliest in the United States were the Hopkins Marine Station in Pacific Grove, California and Scripps Institution of Oceanography in La Yolla, California. In the ensuing years, more laboratories appeared all over the world, and new ones are being established even today.

The onset of World War II had a major effect on the development of marine biology. A new technology, *sonar*, or *so*und *na*vigation *r*anging, was developed in response to the growing importance of submarine warfare. Sonar is based on the detection of underwater echoes – a way of listening to the sea. The ocean, long thought of as a silent realm, was suddenly found to be full of sound, much of it made by animals. During wartime, learning about these animals was no longer the casual pursuit of a few interested marine biologists but a matter of national security.

The years immediately after World War II saw the refinement of the first really practical scuba (*s*elf-*c*ontained *u*nderwater *b*reathing *a*pparatus). The basic technology used in scuba was developed in occupied France by the engineer Emile Gagnan to allow automobiles to run on compressed natural gas. After the war, Gagnan and fellow Frenchman Jacques Cousteau modified the apparatus, using it to breathe compressed air under water. Cousteau went on to devote his life to scuba diving and the oceans. His films, books, and television programs inspired a fascination with the oceans in people around the world and alerted them to growing threats to the health of the marine environment. Using scuba, marine biologists could, for the firs time, descent below the surface to observe marine organisms in their natural environment. They could now work comfortably in the ocean, collecting specimens and performing experiments though they were still limited to relatively shallow water, generally less that 50 m.

1.2.9 Marine Biology today

Oceanographic ships and shore-based laboratories are as important to marine biology now as they were in the past. Today many universities and other institutions operate research vessels. Modern ships are equipped with the latest equipment for navigation, sampling, and studying the creatures that are collected during expeditions. Many, like *Challenger*, were originally built for other uses, but a growing number of vessels are being custom-built for scientific research at sea.

Moreover, high-tech submarines can descend to the deepest parts of the ocean, revealing a world that was once inaccessible. A variety of odd-looking vessels ply the oceans, providing specialized facilities for marine scientists. Marine biologists use underwater robots to take photos, make measurements, and collect samples in the ocean depths. Remotely operated vehicles (ROVs) are controlled from the surface, while autonomous underwater vehicles (AUVs) are preprogrammed to do their jobs independently of direct human control.

Scientists have also developed a variety of automated instrument buoys that drift with the currents or are moored in place and collect oceanographic data over long periods, even permanently. Even marine animals can be used as “autonomous samplers”. Penguins and elephant seals, for example, have been fitted with electronic sensors that record oceanographic data in the course of the animals’ normal movements.

Marine laboratories too have come a long way since the early days. Today such labs dot coastlines around the world and are used by an international community of scientists. Some are equipped with the most up-to-date facilities available. Others are simple field stations, providing a base for scientists to work in remote areas. There are even undersea habitats where scientists can live for weeks at a time, literally immersed in their work.

New technology offers exciting opportunities for the study of the oceans. Computers have had a tremendous impact because they allow scientists to rapidly analyze huge amounts of information. Space technology has also aided the study of the sea. Satellites peer down at the ocean and because they are so far away can capture the big picture, viewing broad areas of the ocean all at once.

Marine biologists today use every available tool in their study of the sea, even some decidedly low-tech ones. Information about the ocean pours in at an ever-increasing pace. Much remains to be learned, however, and the oceans remain a realm of great mystery and excitement.

1.3 The Oceans of our planet

1.3.1 Introduction

The oceans in creation are much more plentiful than you may think. In fact, the combined surfaces of earth's oceans cover 72% of the earth! With nearly three-fourths of our world covered with seawater, it is easy to see the great impact marine biology has on all of us and the importance of studying it.

The ocean water is not distributed equally over the globe, however. There is more ocean area in the Southern Hemisphere than in the Northern Hemisphere. In fact, almost two-thirds of our planet's land area is located in the Northern Hemisphere, while 80% of the Southern Hemisphere is covered by water! There are four large ocean basins on the earth, as shown in the figure below:

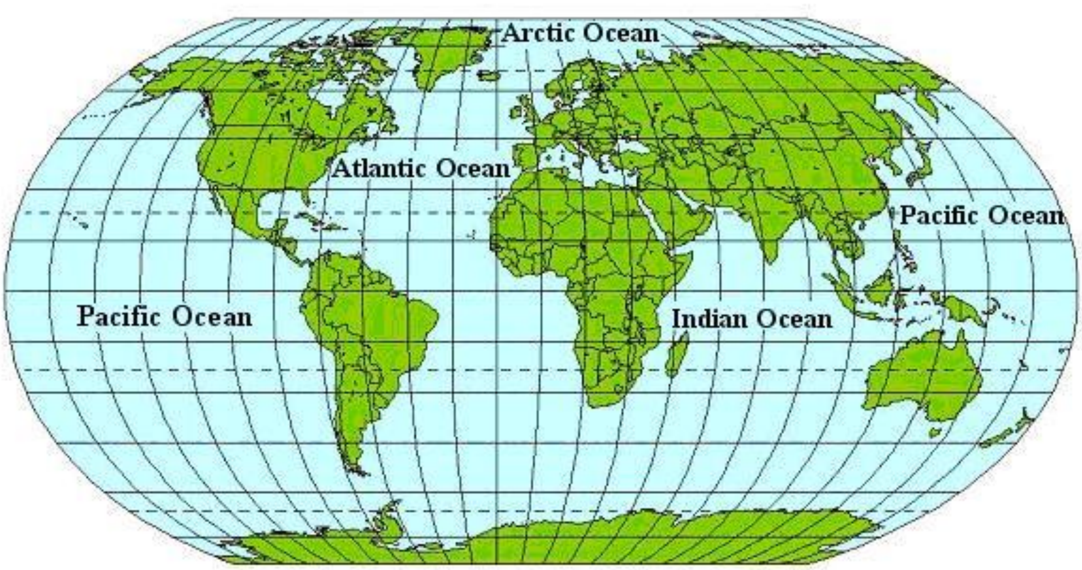


Illustration by Megan Whitaker

Figure 1: The four major ocean basins on the earth

An ocean basin is basically a very large depression, or bowl, on the surface of the earth. The largest and deepest of these is the **Pacific Ocean basin**. It is almost as large as the other three basins put together. The **Atlantic Ocean basin** is the next largest in size. The **Indian Ocean basin** is a little smaller than the Atlantic, but it is similar in depth. Finally, the **Arctic Ocean basin** is the smallest and shallowest. These four deep basins are connected to various shallower seas. The Caribbean, Arabian, and Mediterranean Seas, as well as the Gulf of Mexico, are a few examples of these shallower seas (*Table 1).*

If you look at *Figure 1,* you can see how the Pacific, Atlantic, and Indian oceans are connected by a large pathway of water that surrounds the continent of Antarctica. Scientists sometimes call this the "Southern Ocean." There also are waterways that connect these oceans to the Arctic Ocean in the north. This makes it possible for seawater and organisms to move from one ocean to another.

Table 1: The characteristics of the Earth's Oceans and Seas

	Average Depth		Area		Volume	
Ocean or Sea	**m**	**ft**	**million sq km**	**million sq mi**	**million cu km**	**million cu mi**
Pacific Ocean	4,300	14,000	165.7	64.0	707.6	169.9
Atlantic Ocean	3,900	12,900	82.4	31.8	324.6	77.9
Indian Ocean	3,900	12,800	73.4	28.3	291	69.9
Arctic Ocean	1,300	4,300	14.1	5.4	17	4.1
Australasian Central Sea	1,200	3,900	8.1	3.1	9.9	2.4
Gulf of Mexico and Caribbean Sea	2,200	7,300	4.3	1.7	9.6	2.3
Mediterranean and Black Seas	1,430	4,690	3.0	1.1	4.2	1
Bering Sea	1,440	4,720	2.3	0.9	3.33	0.8
Sea of Okhotsk	838	2,750	1.6	0.6	1.3	0.3
Hudson Bay	101	331	1.2	0.5	0.16	0.04
North Sea	94	310	0.6	0.2	0.05	0.01
Baltic Sea	55	180	0.4	0.2	0.02	0.005
Irish Sea	60	200	0.10	0.04	0.006	0.001
English Channel	54	180	0.08	0.03	0.004	0.001
The World Ocean	3,790	12,430	361.1	139.4	1,370	329

1.3.2 *The Earth's Structure*

The earth is made up of various layers, as shown in *Figure 2.* Scientists have performed many tests to determine the composition of these layers. Although no one has ever been able to travel through the earth's crust, much less to its centre, these tests help reveal the makeup of these layers. At the centre of the earth is an inner core that scientists believe is made up of solid iron under intense pressure. The next layer is the outer core, which experiences slightly less pressure, resulting in liquid iron. It is believed that the motions within this outer core produce the earth's magnetic field. The next layer is the mantle, made up of rock that is near its melting point. This slow-flowing material, called plastic rock, sometimes behaves like a liquid and sometimes like a solid. The outermost layer of the earth is the crust and is much thinner than the other layers. The crust "floats" on top of the plastic rock of the mantle.

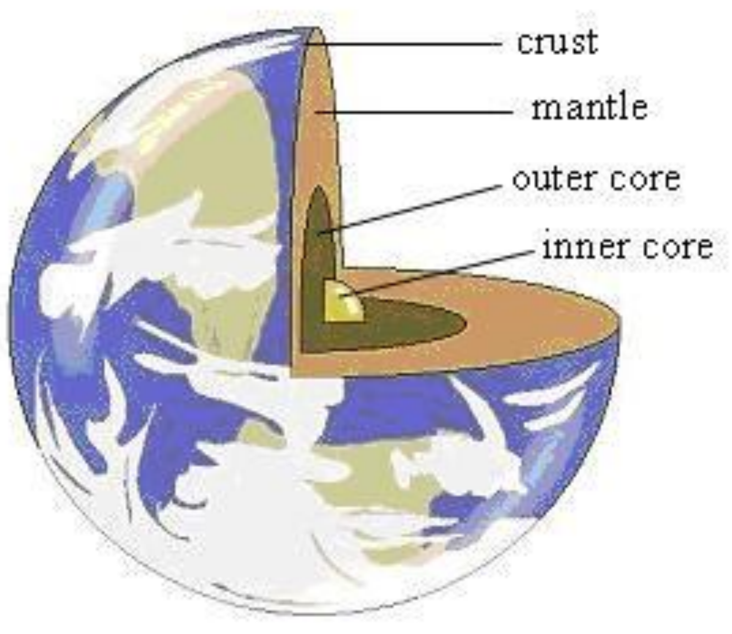


Illustration by Megan Whitaker

Figure 2: Section through the earth showing its layers.

Geologists explain that the difference between “ocean” and “continents” is caused by the chemical and physical differences in the rocks, not whether they are covered by water. The part of the earth that is covered with ocean is made up of **oceanic crust**, composed mainly of basalt. Basalt is solidified lava that is usually dark in colour. The second type of crust is **continental crust**, and it is primarily composed of granite, a substance that is chemically different from basalt and has a lighter colour. Oceanic crust is denser than continental crust and therefore “floats” a little lower on the mantle than continental crust. It is also much thinner than continental crust. Oceanic crust is about 5 kilometres thick, while continental crust is on average 20 to 50 kilometres thick (Table 2).

<u>Continental crust</u> – The portion of the earth's crust that primarily contains granite, is less dense than oceanic crust, and is 20 to 50 kilometres thick.

<u>Oceanic crust</u> – The portion of the earth's crust that primarily contains basalt, is relatively dense, and is about 5 kilometres thick.

Table 2: Characteristics of the two major crusts

Type of Crust	Average Thickness	Average Age	Major Component
Continental Crust	20-50 kilometres	3 billion years	Granite
Oceanic Crust	5 kilometres	Hundreds of millions of years	Basalt

1.3.3 Continental Drift and Plate Tectonics

As early as the 1600s, scientists began looking at the shape of the continents and noticed that they seem to "match up" like puzzle pieces. This led many to suggest that the continents may have been joined at one time in the earth's history. Later, other similarities between continents were discovered. Coal deposits and fossils (*Figure 3*) on opposite coasts of the Atlantic Ocean are so similar that they seem to be parts of a greater whole.

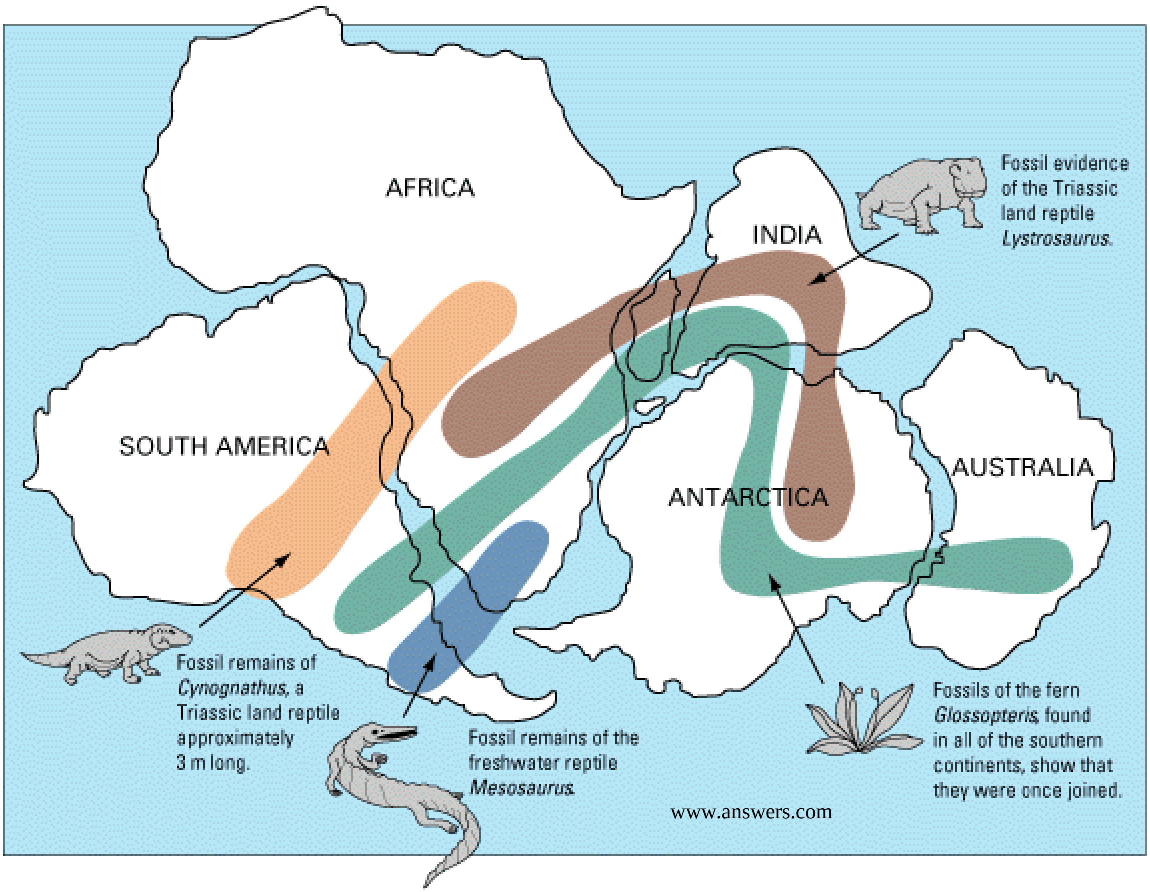


Figure 3: Fossil patterns across continents

In 1912, a German geophysicist named Alfred Wegner came up with a detailed hypothesis of continental drift[7] as an explanation of this kind of data. He suggested that all the continents at one time were part of a large supercontinent called Pangaea**.** He believed this large land mass began breaking up, and the continents slowly moved away from each other to their present positions today. Pangaea started to break up into two smaller supercontinents, called Laurasia and Gondwanaland, during the Jurassic

[7] Continental drift: Large-scale movements of continents over the course of geologic time.

period. By the end of the Cretaceous period, the continents were separating into land masses that look like our modern-day continents.

This idea was not well received in the scientific community of that time because Wegner did not have a believable explanation for the force required to move the land masses. Later, as more evidence was discovered supporting this theory, scientists began to agree that the continents do indeed drift. They named the process that moves them plate tectonics[8]. The theory of plate tectonics (meaning "plate structure") was developed in the 1960's. This theory explains the movement of the Earth's plates (which has since been documented scientifically) and also explains the cause of earthquakes, volcanoes, oceanic trenches, mountain range formation, and other geologic phenomenon.

Plate tectonics is based on the earth's crust being divided into giant, irregular plates that float on the dense mantle of the earth. Scientists now believe that radioactive decay of elements in the earth's mantle and the resulting heat cause plate movement. They think that as the heat rises through the plastic rock of the mantle, it generates currents that move the plates floating on the plastic rock (*Figure 4*). The plates are made of rock and are from 50 to 250 km thick. They move both horizontally and vertically (*Table 3*). Over long periods of time, the plates also change in size as their margins are added to, crushed together, or pushed back into the Earth's mantle.

To visualize this, imagine a large Styrofoam rectangle floating in a swimming pool. The Styrofoam would represent Pangaea, and the water would represent the plastic rock of the earth's mantle. Now imagine that you add pressure to the foam until cracks form, yet you hold the many pieces together in their original shape. Once you let go, the pieces, representing plates, will float away from each other due to the movement of the water molecules beneath them. If you heated the water below the Styrofoam, water molecules would move faster, making the pieces float away from each other more quickly. Heat-induced motion of the various compounds in the plastic rock of the mantle could cause the continents to float away from each other in a similar way.

[8] Plate tectonics: A process involving the movement of large plates on the earth's mantle.

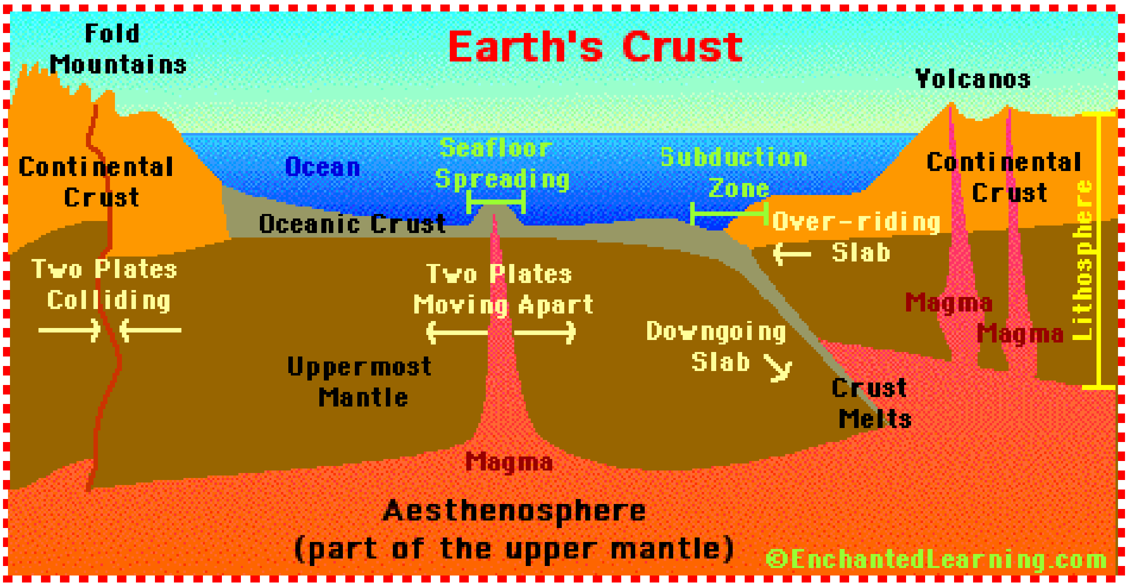


Figure 4: Movement of the Earth's plates

According to the theory of plate tectonics, the continents are resting on various plates of the earth's crust, (*Figure 5*). At the locations where the plates meet (the dark lines in the figure), there are two types of geographic structures: a mid-ocean ridge system or a trench system. The mid-ocean ridge system is a continuous chain of volcanic underwater mountains. These ridges extend all around the earth and are the largest geological features on the planet.

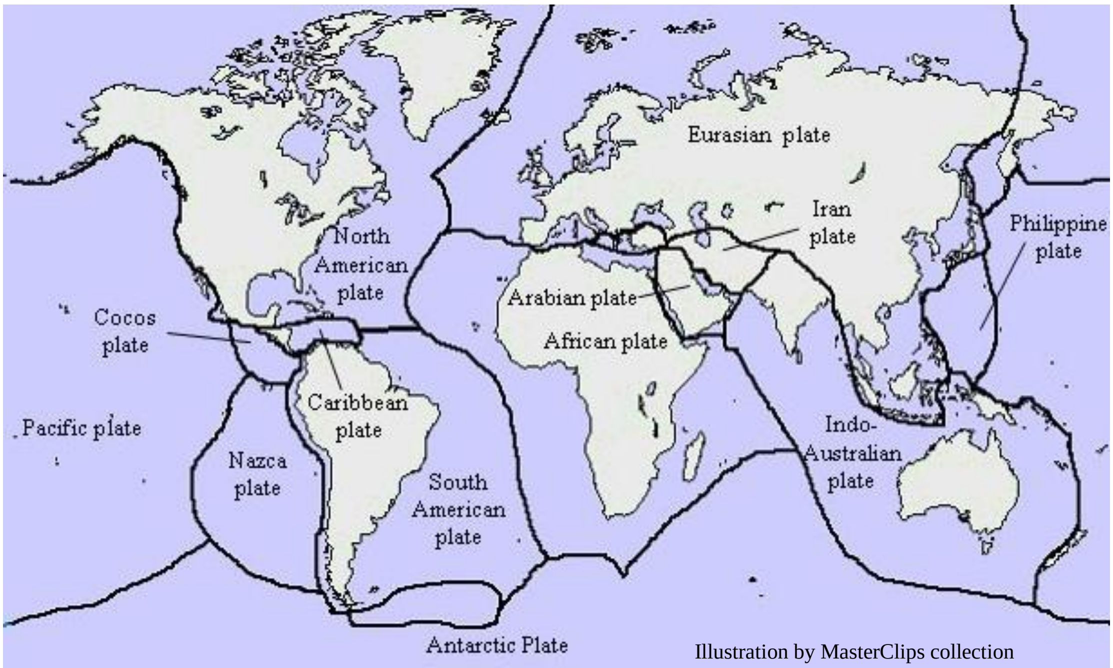


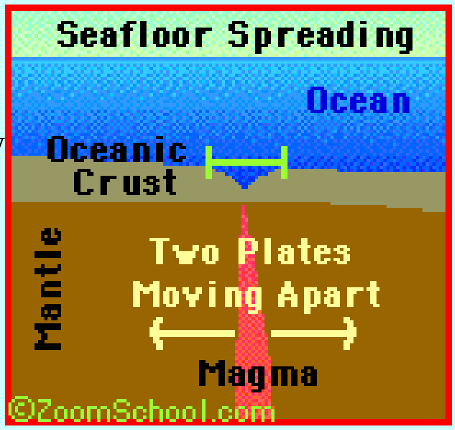
Figure 5: Major plates of the Earth's crust

Some mountains of the various mid-ocean ridges rise so high that they actually extend above the ocean's surface and form islands, such as the Azores in the Atlantic Ocean. The ridges seem to snake along the ocean floor, mirroring the positions of the edges of the continents. At other sites where plates meet, there is a system of deep depressions, or trenches. These trenches also seem to follow the shape of the nearby land masses.

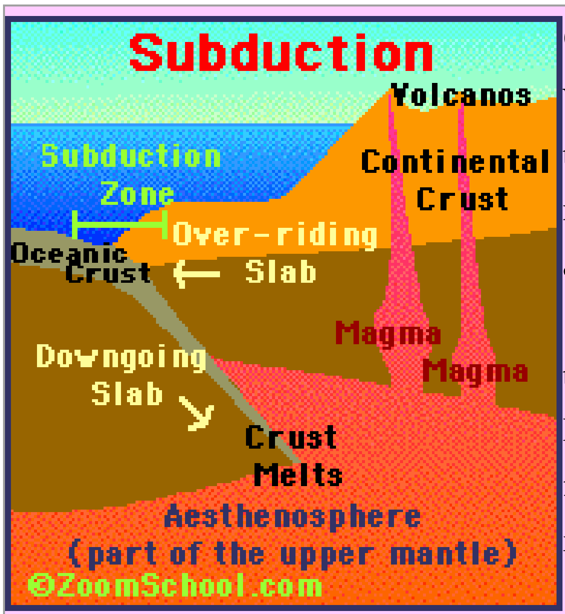
Scientists discovered that there is a large amount of geologic activity around both ridges and trenches. Earthquakes are common around ridges, and volcanoes are found near trenches. Also, the layer of sediment, loose mud or sand that settles to the bottom of the ocean floor gets thicker as you move away from the ridges.

Table 3: Types of plate movement: Divergence, Convergence, Lateral Slipping

Divergent Plate Movement: Seafloor Spreading



Seafloor spreading is the movement of two oceanic plates away from each other, which results in the formation of new oceanic crust (from magma that comes from within the Earth's mantle) along a mid-ocean ridge. Where the oceanic plates are moving away from each other is called a zone of divergence. (Ocean floor spreading was first suggested by Harry Hess and Robert Dietz in the 1960's).



Convergent Plate Movement:

When two plates collide, some crust is destroyed in the impact and the plates become smaller. The results differ, depending upon what types of plates are involved.

Oceanic Plate and Continental Plate - When a thin, dense oceanic plate collides with a relatively light, thick continental plate, the oceanic plate is forced under the continental plate; this phenomenon is called subduction.

Two Oceanic Plates - When two oceanic plates collide, one may be pushed under the other and magma from the mantle rises, forming volcanoes in the vicinity.

Two Continental Plates - When two continental plates collide, mountain ranges are created as the colliding crust is compressed and pushed upwards.

Lateral Slipping Plate Movement:

When two plates move sideways against each other, there is a tremendous amount of friction which makes the movement jerky. The plates slip, then stick as the friction and pressure build up to incredible levels. When the pressure is released suddenly, and the plates suddenly jerk apart, this is an earthquake.

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Additionally, a very interesting phenomenon was discovered around the mid-ocean ridges. Geologists had already discovered that there were times in our earth's history when the magnetism of the earth had reversed. This means that during these reversal periods, a magnetic compass would point to the earth's South Pole, instead of the North Pole (which, of course, is where it points today)! How do scientists know this? Well, in molten rock, there are tiny magnetic particles that move to align themselves toward the earth's magnetic north. As these rocks cool and harden, those magnetic particles are frozen so that they always point to what was magnetic north when the rock cooled. Geologists have discovered many layers of igneous rock (rock that forms when molten rock cools) in which the magnetic particles point south, not north. This means those rock layers must have cooled when the earth's magnetic field was the opposite of what it is today.

As scientists sampled the rocks on the sea floor near the mid-ocean ridges, they began to see a pattern of bands running parallel to the mid-ocean ridge and representing groups of rock that have alternating magnetic orientations (*Figure 6*). In other words, the magnetic particles in those bands sometimes point north and sometimes point south. These magnetic particles that are pointing in the "wrong direction" are called magnetic anomalies, and they suggest that the bands of igneous rock on the ocean floor were formed from molten rock at different times in the earth's history.

If the bands of igneous rock near the mid-ocean ridge were formed during different times in the earth's history, the sections of the earth's crust near the mid-ocean ridge seem to be *moving away from each other*. A crack in the crust results from this separation; we call it a rift between the plates.

As the plates move away from each other, there is less pressure on the mantle below the rift. The release of pressure allows the mantle material to melt enough to become liquid and rise up through the rift. Once it reaches the surface, however, it cools and becomes new oceanic crust. As it moves upward, it also lifts up the crust around the rift, forming the mid-ocean ridge. This process is called seafloor spreading[9] and explains many of the discoveries found around the ocean ridges.

[9] Seafloor spreading: The process that creates new sea floor as plates move away from each other at the mid-ocean ridges.

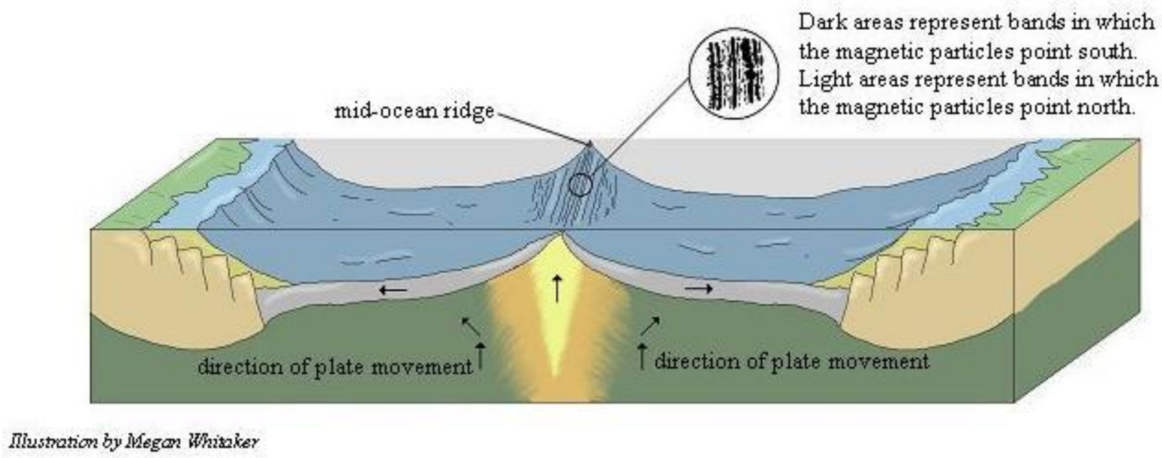


Figure 6: Alternating magnetic orientations of rocks at the mid-ocean ridge of the Atlantic Ocean.

The crust at the ridges is newer than the crust farther away from the ridges. As a result, the crust near the ridges has had less time to accumulate sedimentary material. That explains why the sediments of the ocean floor are thicker as you travel farther away from the ocean ridges.

Now let's put all of this information together to understand what scientists believe about the ocean floor. Seafloor spreading and plate tectonics are closely related to one another and indicate that the earth's crust is divided into giant irregular plates that float on the denser mantle material below. Each plate is bounded by oceanic trench and ridge systems. Some plates are made of both oceanic and continental crusts. New oceanic crust material is formed at the mid-ocean ridges, and as it moves away from the ridges, it carries the bottom sediments and continental land masses with it. Now this rate of movement is extremely slow; today the plates move at a rate of between 2 and 18 centimetres per year.

1.3.4 The features of the Ocean bottom

The ocean floor can be divided into four main regions (*Figure 7*). Beginning at the shoreline of the continents and extending seaward is the continental shelf[10]. It is actually a structural part of the continental landmass and would not be under the ocean if sea levels were to drop by as little as 5%.

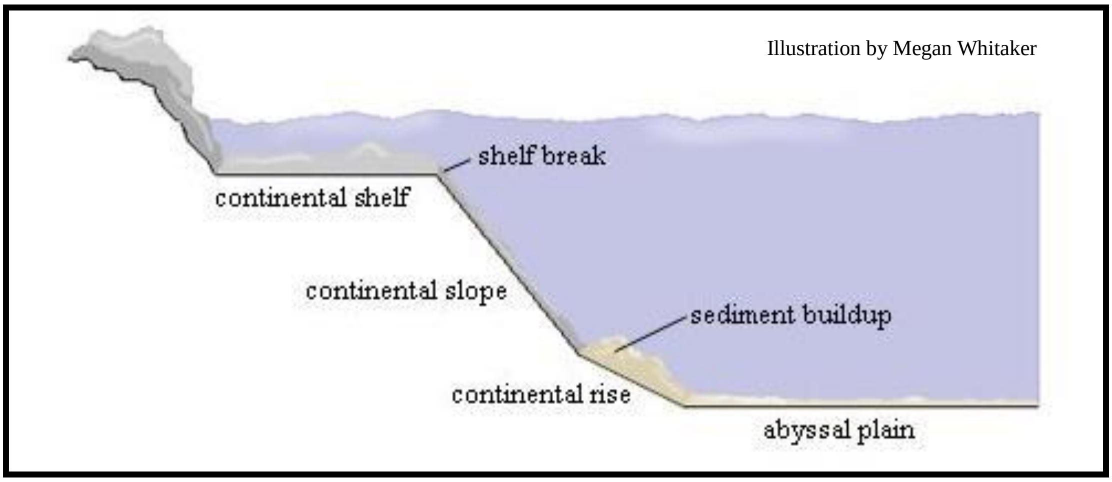


Figure 7: Diagram of the Ocean bottom

Continental shelves make up about 8% of the ocean's surface area but contain the richest part of the ocean where most of its life is found. This is due to the fact that more light reaches the sea floor at the continental shelf, resulting in more producers, such as plants and algae. More producers mean a greater opportunity for animal life, as animals are consumers and therefore need to eat producers. The shelves are relatively smooth, sloping gently outward toward the sea. The outer edge of the shelf, where the bottom begins to become steeper, is called the shelf break. This occurs at depths of 120 to 200 meters and marks the beginning of the second region, the continental slope[11]. This slope is the boundary between the continental masses and the true ocean basins, and it extends downward to the deep sea floor.

[10] Continental shelf : The gently sloped, shallow section of the edge of a continent, extending from the shore to the point where the slope gets steeper.
[11] Continental slope: The steeper section of a continental edge, extending seaward from the continental shelf.

Deep at the base of the continental slope is a build-up of sediments resulting in the third region, the continental rise[12], which continues down to the sea floor. Because of its location at the foot of the more steeply graded continental slope, the continental rise collects debris and sediment.

The last region of the sea floor lies at a depth of 3,000 to 5,000 meters (10,000 to 16,500 feet) and is almost flat. This flat seafloor area is called the abyssal plain, and it gently slopes toward the mid-ocean ridges. Someone may think that the abyssal plain is the deepest part of the ocean. This is not true and we have to remember the trench systems. In the trench areas, the ocean is actually at its deepest, reaching depths of up to 11,020 meters (6.8 miles) in the Mariana Trench of the Pacific, the deepest known place in all the oceans.

[12] Continental rise: The gently sloping area at the base of the continental slope.

1.4 The physical and chemical properties of the oceans

1.4.1 Properties of water

Water makes up 80% to 90% of the volume of most marine organisms and provides buoyancy and body support for many of them. It also is the medium for most chemical reactions needed to sustain life.

All matter is made up of tiny particles called atoms. When two or more atoms are chemically combined into a larger particle, the result is a molecule. A water molecule is made up of one relatively large oxygen atom and two smaller hydrogen atoms. The three atoms of a water molecule form an angle, with the oxygen atom at its vertex.

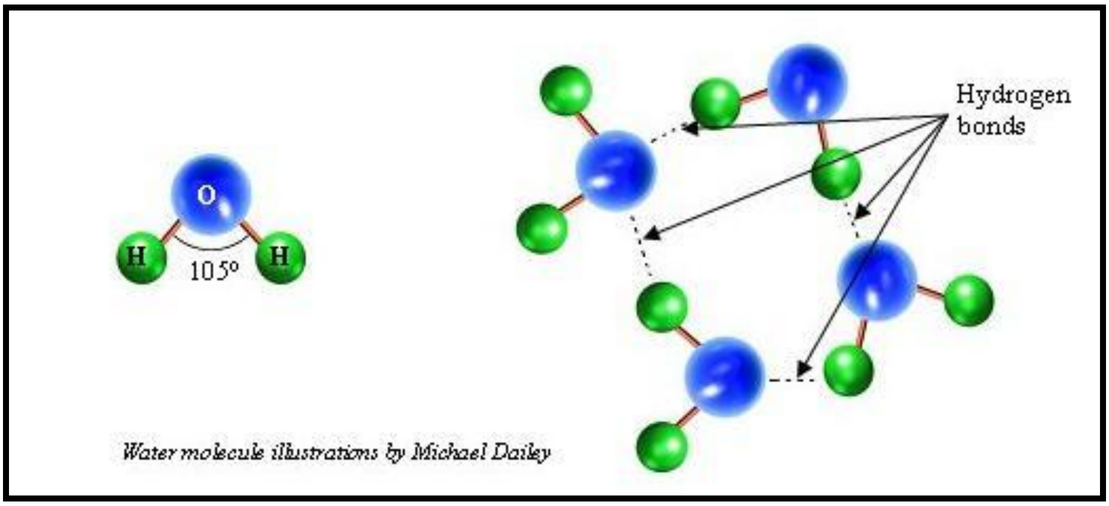


Figure 8: The water molecule and Hydrogen Bonding

The bonds between the hydrogen atoms and the oxygen atom of a water molecule are formed by the sharing of two negatively charged electrons. The oxygen atom has a stronger "pull" on these electrons, causing the oxygen end of the molecule to have a slight negative charge. This leaves the hydrogen ends of the molecule with a slight positive charge. Each end on one water molecule attracts the oppositely charged end of other water molecules. The resulting attraction between water molecules forms a weak bond, called a hydrogen bond (*Figure 8)*. These bonds are not as strong as bonds within a molecule, but they make water different from most substances on earth.

Hydrogen bonding creates a flexible "skin" at the surface of water. This is called surface tension, and it helps hold water molecules close to one another at the surface of a body of water. It is so strong that items such as needles and razor blades can float on the surface of water if they are placed there in a careful manner. Even insects like the water strider can walk on water because of its surface tension. Without hydrogen bonding between molecules, water would be in a gaseous state at normal temperature and pressure, boiling at –80° C and freezing at –100° C. This would make the existence of life on earth impossible.

Water exists on earth in all three of the possible phases of matter: solid (ice or snow), liquid (what you normally call water), and gas (water vapour) (*Figure 9*). The molecules in liquid water are moving constantly, and some are being held in small groups due to hydrogen bonding. These groups continually form and break apart. The molecules will move faster if the temperature of the water is higher. If a water molecule moves quickly enough, it may break free of all the hydrogen bonds and go from liquid phase to gaseous phase. This process is called evaporation, and you have experienced it whenever you take a hot shower and see the resulting "fogginess" in the air from the water vapour. As the temperature rises, so does the rate of evaporation, resulting in more and more molecules escaping the hydrogen bonds. In water vapour, the molecules are not held together by hydrogen bonds and are much farther apart than in the liquid phase.

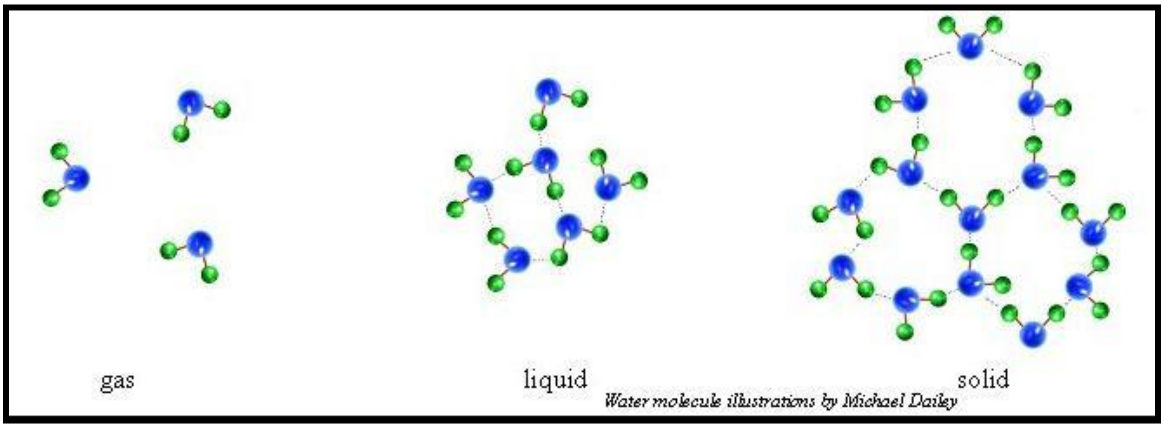


Figure 9: Structure of water molecules in Solid, Liquid, and Gas phases

As liquid water cools, the molecules move more slowly and pack closer together, taking up less space. This decrease in volume results in the water becoming denser. As a result, cold seawater will sink below warmer seawater. Fresh water also gets denser as it gets colder, but only down to a temperature of about 4°C (39°F). Below 4°C, fresh water actually gets *less* dense as it cools (which is why solid ice cubes will float in liquid water). This happens because of the hydrogen bonding. In the liquid phase, water molecules are free to get very close to one another to take full advantage of the hydrogen bonds. As the water begins to freeze, the molecules actually move apart from one another in order to fit into the arrangement they must have in the solid phase. Since the molecules are farther apart from one another in the solid phase, solid water is less dense than liquid water.

Water has another amazing property that results from its hydrogen bonds: It has a large specific heat[13]. It takes a lot more energy to increase the temperature of water by 1° C than most other substances. Because of this, a large amount of heat must be removed from a sample of water in order to cool it down. In the same way, a large amount of heat must be added to water in order to warm it up. Fortunately for aquatic organisms, this means the temperature of water does not change very quickly, resulting in a more constant environment.

In addition, water can dissolve more substances than most other liquids. A substance that can dissolve other substances is called a solvent, and water is sometimes called the "universal solvent." It is able to dissolve a lot of substances because of its small size and because of the slight electrical charges on the atoms of its molecules. Water is especially good at dissolving a class of molecules called salts, which are made of particles that have opposite electrical charges (*Figure 10*). These electrically charged particles are called ions, and they are either negatively or positively charged. Table salt (sodium chloride) is an example of an ionic molecule, consisting of a positively charged sodium ion (Na^+) and a negatively charged chloride ion (Cl^-). Remember, water molecules have a slight positive side (the hydrogen atoms) and a slight negative side (the oxygen atom). Ions have a stronger charge than the slight charges of water molecules, so when a salt crystal is placed in water, the strong electric charges on the

[13] Specific heat: The amount of energy required to raise the temperature of one gram of a substance by 1.00 ° C.

ions attract the water molecules, causing a layer of water molecules to surround each ion. This weakens the attractions that hold the salt crystal together, and it causes the salt crystal to dissolve.

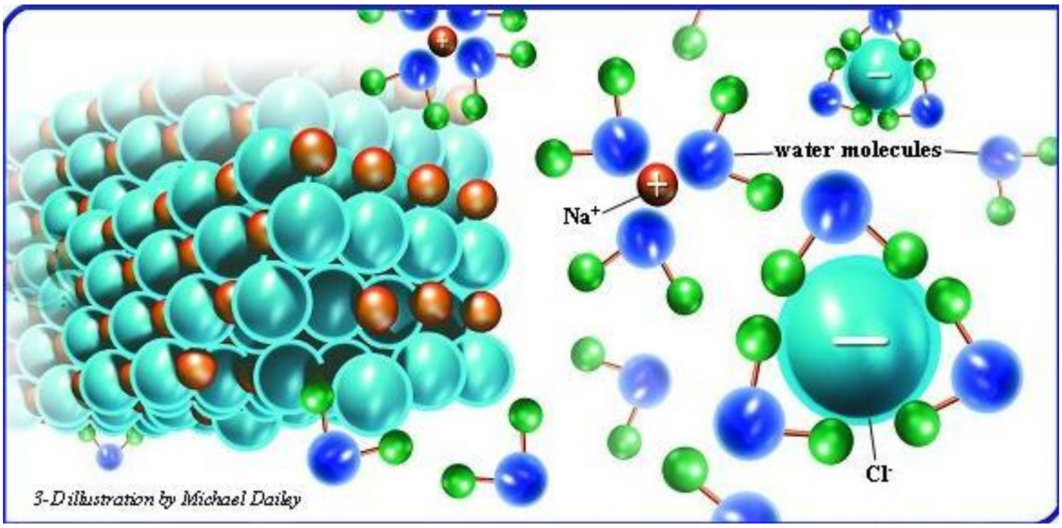


Figure 10: The dissolving of a salt crystal by water

1.4.2 Seawater – Why is the sea salty?

Seawater consists of pure water with materials dissolved in it. The solids dissolved in seawater come from two main sources. Some solids come from the weathering of rocks on land and are carried to the ocean by rivers. Others come from the mantle areas of the earth and are released into the ocean through deep openings called hydrothermal vents. Materials from the mantle can also reach the ocean by volcanic eruptions. This puts materials into the atmosphere that then enter the ocean by way of rain or snow.

In general, positive ions such as magnesium, potassium, and sodium, enter the ocean by way of rivers. Negative ions, such as chloride and sulphide, enter through volcanic eruptions and hydrothermal vents (*Figure 11*).

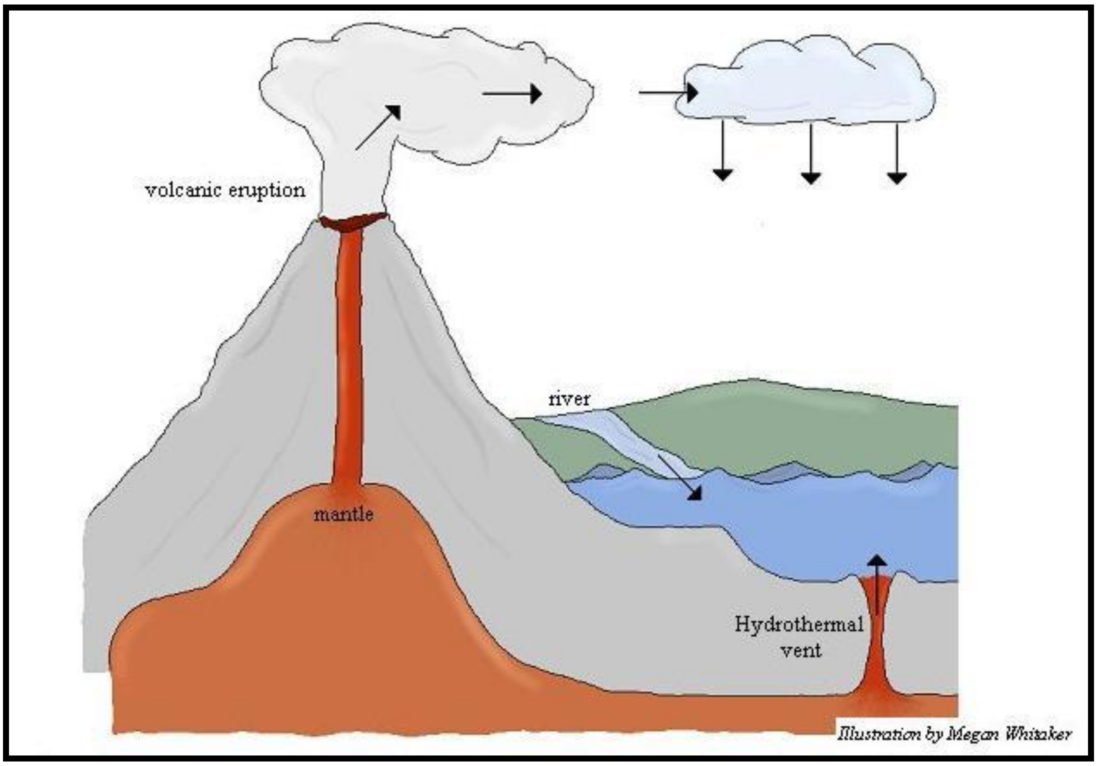


Figure 11: How dissolved solids get into seawater

Sodium and chloride account for about 85% of the solids in the ocean. If we took a sample of seawater and allowed all of the water to evaporate, the material left behind would be the salts that had been dissolved in it. Water can only evaporate in its pure form. It does not bring dissolved solids into the air with it.

Salinity[14] is typically expressed as the number of grams of salt left behind when 1,000 grams of seawater is evaporated. The units of salinity are parts per thousand, or ‰. For example, if we evaporated 1,000 grams of seawater and were left with 32 grams of salt, we would say that the salinity of the seawater was 32 parts per thousand, or 32 ‰.

Salinity is an important measurement in biology because salt is dissolved in the bodily fluids of all living things. The level of dissolved salts in a fluid controls the biochemical process of osmosis and many metabolic processes. The organisms that live in the ocean are strongly affected by salinity. Even the smallest change in salinity can affect or even kill some of them. However, with the exception of areas that

[14] Salinity: The total amount of salt dissolved in a solvent.

experience regular changes, such as at the mouths of rivers, the salinity of the oceans in creation stays relatively constant. As you study more about life on our earth, you will be amazed to see that in practically every habitat, no matter how harsh, some types of organisms are able to survive and even thrive there. This is the case at river mouths. These areas, where fresh water is constantly flowing into salt water, contain many creatures that have specially designed mechanisms to cope with drastic salinity changes.

Organisms are affected not only by the total amount of salt in seawater but also the kind of salt. The more common ions found in seawater are shown in Table 4 and are grouped according to their abundance. The first seven ions make up over 98% of the total salt concentration in seawater. And, no matter what the salinity is in the ocean, the relative concentrations of these ions remain remarkably constant. In other words, no matter where you take a sample of seawater in the world, chloride ions will make up the same percentage of whatever salt is present. This very interesting fact means that although marine organisms are exposed to possible salinity change due to evaporation, rain, or other mechanisms, they don't have to deal with changes in the *ratios* of various ions. It is therefore easier for them to control their internal salt and water balance.

Table 4: Ions found in seawater with 35‰ salinity

	Ion	Concentration ‰
Major Ions	Chloride	19.3
	Sodium	10.6
	Sulfate	2.6
	Magnesium	1.3
	Calcium	0.4
	Potassium	0.3
	Bicarbonate	0.1
Minor Ions*	Bromide	0.067
	Borate	0.027
	Strontium	0.013
	Fluoride	0.001

*Other elements are found in trace amounts

There is a remarkable and vital similarity between the chemical composition of seawater and the composition of the body fluids of marine organisms. Well, according to the hypothesis of evolution, the seawater in the oceans of the world has changed substantially over time. As a result, an evolutionist would have to assume that animals adjusted their body fluids to match their environment as the oceans of the world evolved. This is a very difficult "model" to explain, since it requires random mutations in a very complex DNA structure to produce *any* desired result in an organism's bodily makeup. A much more reasonable explanation is that organisms were designed to fit their environments by an intelligent Designer.

1.4.3 Salinity, Temperature, and Density

We have already discussed how temperature affects the density of seawater. Cold seawater is denser than warm seawater and will sink below it to a lower depth. It turns out that salinity influences the density of seawater, too. As water gets saltier its density increases. Therefore, the saltier and/or colder the water, the denser it is. Salinity and temperature, therefore, affect the density of water. In the ocean, we find that temperature has a greater influence on seawater density than does salinity because it has a greater range. Ocean temperatures can range from -2° C to 30° C, but open-ocean salinities vary by only a few parts per thousand.

However, the rate at which salts enter the ocean is much higher than the rate at which salts are leaving the ocean. This means that the ocean is constantly increasing in salinity. In fact, scientists have been studying this for several hundred years, and they know how quickly the salinity of the ocean has been increasing. With this information, they can calculate how long it took for the sea to become salty. Well, it turns out that it probably did not take very long. Calculations indicate that at *most*, it has taken 62 million years for the oceans to reach their current salinity, and that is using very generous assumptions including that the oceans started out as fresh water seas. If we take into account that the oceans were most likely created with some saltiness in order for the organisms that inhabit them to survive, the time required for the oceans to reach their present salinity is probably much shorter. The oceans themselves, then, are strong evidence that the earth is quite young, despite what some scientists would have you believe.

Seawater also contains dissolved gases in addition to its dissolved solids. However, unlike solids, gases dissolve better in cold water than they do in warm water. Nitrogen, carbon dioxide, and oxygen are the most abundant of these gases. They are found in the earth's atmosphere and dissolve into seawater at its surface. Nitrogen gas is not involved in the basic life processes of most organisms, but carbon dioxide and oxygen play an active role. Carbon dioxide (CO_2) is used by producers such as plants and marine microorganisms for photosynthesis, making oxygen as a by-product. Many organisms utilize oxygen for respiration and produce carbon dioxide as a by-product. Marine life, therefore, depends upon dissolved gases in the ocean.

How do these parameters change in regard to ocean depths? There are some general statements that can be made about the vertical distribution of ocean temperature, salinity, and density. The densest seawater is found on the bottom of the ocean, but the physical processes that cause water to become denser (such as evaporation and cooling) occur on the ocean surface. So, dense water on the ocean bottom must have once been at the surface and then sunk to its present location. This is the process that drives the circulation of water into the deep ocean basins.

Most of the oceans in creation are made up of two major layers. On top, there is a thinner, well-mixed layer. This layer extends down to a point at which a rapid decrease in temperature occurs. Scientists call this feature a **thermocline** (*Figure 12*). Below this point is a layer of heavier, cold and dense water that remains very stable. The thermocline inhibits the mixing and exchange of nutrients and gases, such as the oxygen (*Figure 13*), between the two layers. In some cases it even prevents organisms from moving from one layer to the other.

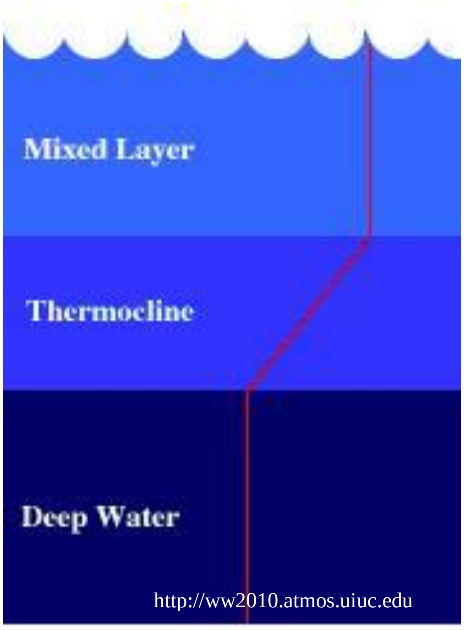


Figure 12: Thermocline is the layer that divides the mixed layer with the deep water layer

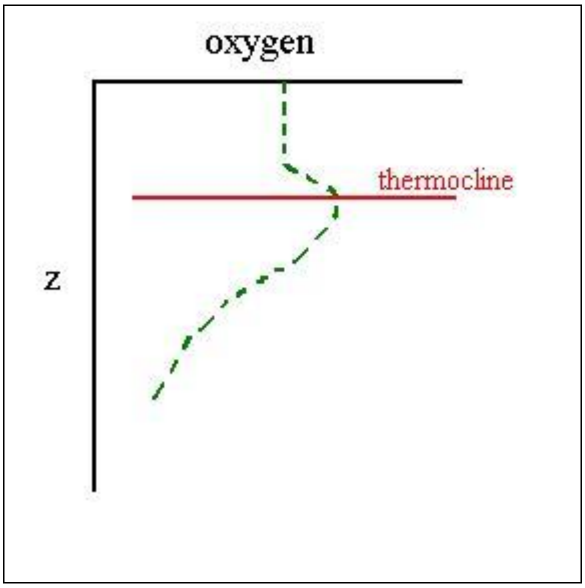


Figure 13: Thermocline inhibits the mixing of gases, such as the oxygen.

1.4.4 Light in the sea

Why is the ocean blue? There is actually a very simple answer to this question. Visible sunlight is made up of different wavelengths of light that are perceived by our eyes as various colours. Different wavelengths (colours) of light penetrate transparent seawater to different depths (*Figure 14*).

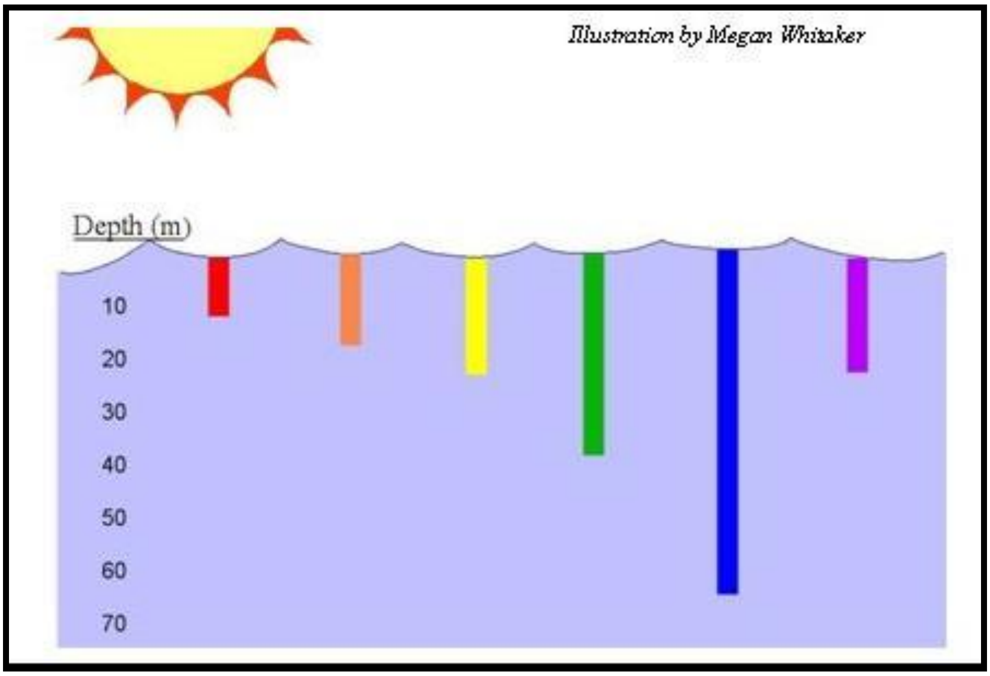


Figure 14: Light penetration in transparent seawater

The ocean is most transparent to blue light, so the greater the depth, the fewer the colours that can penetrate, and the bluer the ocean appears. Also, the blue sky reflects off the surface of the ocean, enhancing its blue appearance.

All producers need light in order to make food for themselves, and the penetration of light into the ocean is vital for marine life. The amount of light that can enter the water depends upon the water's transparency. The more material suspended in the water, the more difficult it is for light to penetrate, and the fewer producers that can survive there.

1.4.5 Pressure

Organisms living in the ocean constantly experience pressure from the weight of the water above them. On land, pressure from the earth's atmosphere is 14.7 pounds per square inch, or 1 atmosphere. Pressure in the ocean increases dramatically with depth, because water is much heavier than air. For every 10 meters of depth, another atmosphere of pressure is added. And, as the pressure increases, gases are compressed, affecting marine life. Because of this drastic pressure change, most marine organisms can tolerate only small changes in depth, limiting the range in which they are able to live. Most of the marine organisms can survive at only 1 to 3 atmospheres of pressure, which means they can live in only the first 100 feet of water. At the same time, however, there are some organisms which have been designed to withstand the constant high pressure of the deep sea. The life cycles and habits of these creatures are relatively unknown because, in order to study them, we must bring them to the surface, or at least to depths in which we can function. At the surface, their bodies cannot withstand the relatively small pressure, and they cannot survive.

An example of a marine organism living in greater depths is the Megamouth Shark (*Figure 15*). It lives in the deep waters of the ocean. Because they rarely come to the surface waters, little is known about them. We think that they live at depths between 150 and 1,000 meters. The inside of the shark's mouth is slivery, and its teeth are small and hook-like. Like the whale shark and the basking shark, the megamouth shark is a filter-feeder, eating small shrimp and a variety of plankton. Adult megamouth sharks reach a length of about 5 meters.

Figure 15: Megamouth Shark

1.4.6 The motion of the Ocean

The ocean is always in motion. This constant moving and churning helps keep the temperature and salinity of the world's oceans at a constant level. Heat from the sun drives these circulation processes, benefiting all marine life forms. These processes include currents, waves, and vertical water movements. The tides are also a part of the motion of the ocean, but they are not caused by heat from the sun.

The strongest motion in the ocean is at its surface and is made up of surface currents and waves. Ocean surface currents are in regions where winds regularly blow over the ocean in a reasonably constant direction and velocity, pushing the water along. Surface currents, then, are large, horizontal movements of water molecules being pushed by the winds above them.

The winds in our atmosphere result from temperature differences caused by heat from the sun. The heat is its strongest at the equator and, of course, much weaker at the North and South poles. To understand wind patterns, consider cold air near the surface of the earth at the North Pole. The air will move from the North Pole toward the equator, to even out the temperature differences. As it makes its way there, however, it encounters warmer climate. This warms up the air, causing it to rise. When the air makes it to the 60° N latitude, it becomes so warm that it rises into the upper atmosphere and begins *moving back toward the Pole.* In the end, this sets up a loop of winds that travel continuously from the Pole to a latitude of about 60° N and back again. This loop of winds is shown as the blue loop in Figure below. A similar loop of winds extends from the South Pole.

The exact opposite effect is going on at the equator. As the warm air rises, it starts traveling toward the poles. At latitude of about 30° N, however, it cools down enough to sink and begin traveling back toward the equator. Thus, from the equator, there is also a loop of winds that travel to a latitude of about 30° N and then turn around and come back again. That is represented by the red loops of wind in the figure. In the middle of these two loops of wind there is a third loop (the brown loop) that occurs as a reaction to these two loops. The result of all this mess is shown in *Figure 16*.

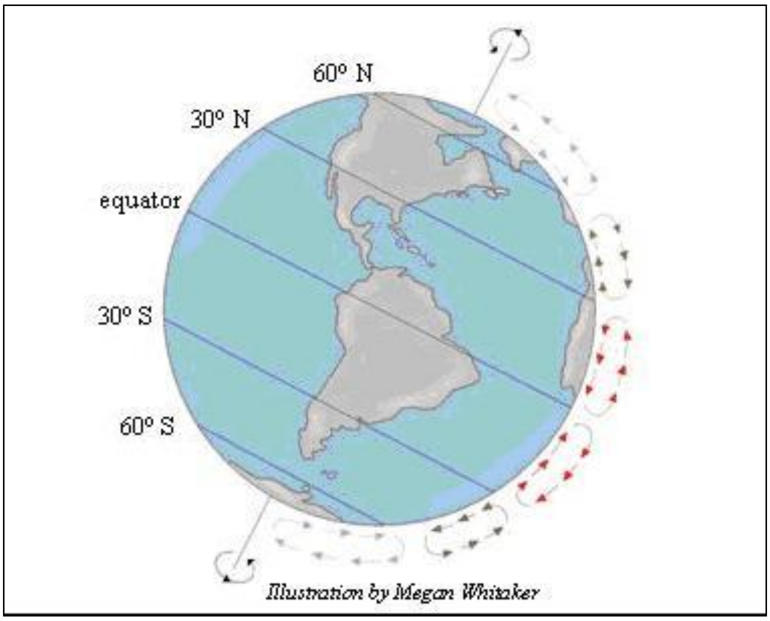


Figure 16: Global Wind Patterns – A First Approximation

However, the winds don't move straight as shown in *Figure 16*. They actually *curve*. The winds moving toward the equator curve in a direction opposite of the rotation of the earth. Scientists call this phenomenon the *Coriolis effect*[15], named after the French physicist Gaspard de Coriolis.

In the red loops of *Figure 16*, the winds blowing near the surface of the earth are moving toward the equator. Because of the Coriolis effect, these winds bend west (opposite the rotation of the earth) and approach the equator at an angle of about 45°. These winds are called the *trade winds* (*Figure 17*) and are the most consistent winds on earth. Farther away from the equator, we find the brown loops of winds shown in Figure 3.6.1. The winds near the surface of the earth on these loops are bent opposite the trade winds, because they are travelling away from the equator instead of toward it. Thus, the Coriolis effect causes them to bend in the opposite way. These winds are called the *westerlies* (*Figure 17*). They are more variable than the trade winds due to many land interruptions. Scientists call these winds "westerlies" because they move in the opposite direction of the trade winds and come from the west. The northernmost and southernmost winds are called the *polar easterlies* and are the most variable winds of all. They curve in the same direction as the trade winds, since they once again move toward the equator near the surface of the earth.

[15] Coriolis effect: The way in which the rotation of the earth bends the path of winds and resulting sea currents.

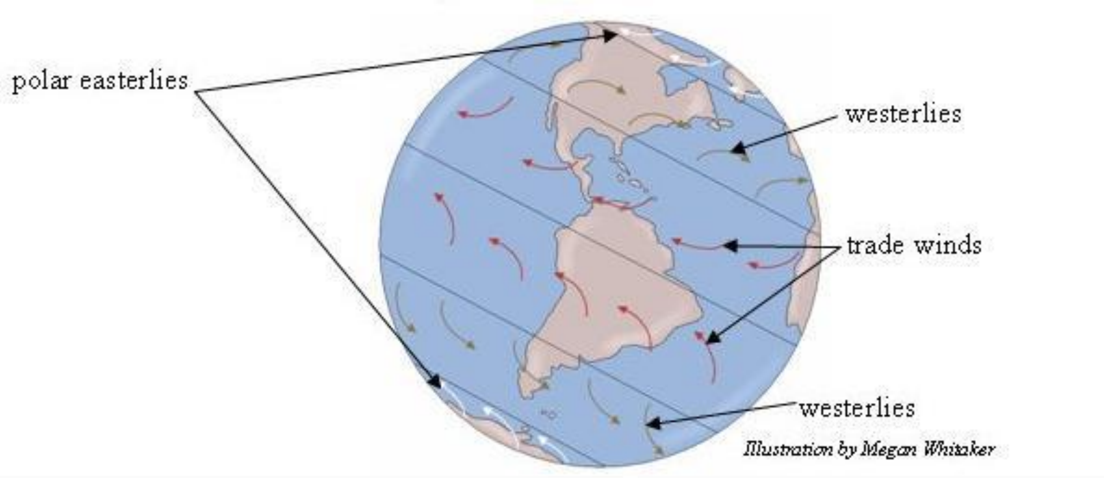


Figure 17: Major Atmospheric Wind Fields

Now all these major wind fields in the atmosphere push against the ocean surface and create currents. As the wind pushes against the ocean surface, it causes the water to move. When the wind moves the water, it actually forces the surface currents to move at a 45° angle from the wind direction. The equatorial trade winds being bent from the Coriolis effect, for example, cause the currents below them to move parallel to the equator. As water gets "pushed around" all over the world, large surface currents result in a circular pattern. Scientists call these currents *gyres*[16] (*Figure 18*).

The warm-water currents on the western side of the gyres of the world carry a lot of solar heat from the equator to higher latitudes. And the opposite is true, too; cold currents flow along the eastern sides of the oceans, bringing colder water to the equatorial areas. This movement helps to regulate the temperatures of our planet, keeping the cold and hot temperatures from becoming extreme.

The temperature of the sea surfaces of the world is also a result of this circulation. Along the Pacific coast of the United States and the western coast of South America, the colder water temperatures are a result of a gyre. On the west coast of North America, the current loop carries water from near the Arctic (cooler water) southward. On the west coast of South America, the loop of current carries water from near the

[16] Gyres: Large, mostly circular systems of surface currents driven by the wind.

Antarctic (cooler water) northward. As a result, the ocean water is cooler on the west coasts of North and South America. Because of this, cold-water organisms can survive closer to the equator on these coasts than in other parts of the world. Conversely, warm-water organisms can survive farther from the equator on the eastern coast of Asia, because the gyres bring warm water from near the equator to parts of the ocean far from the equator.

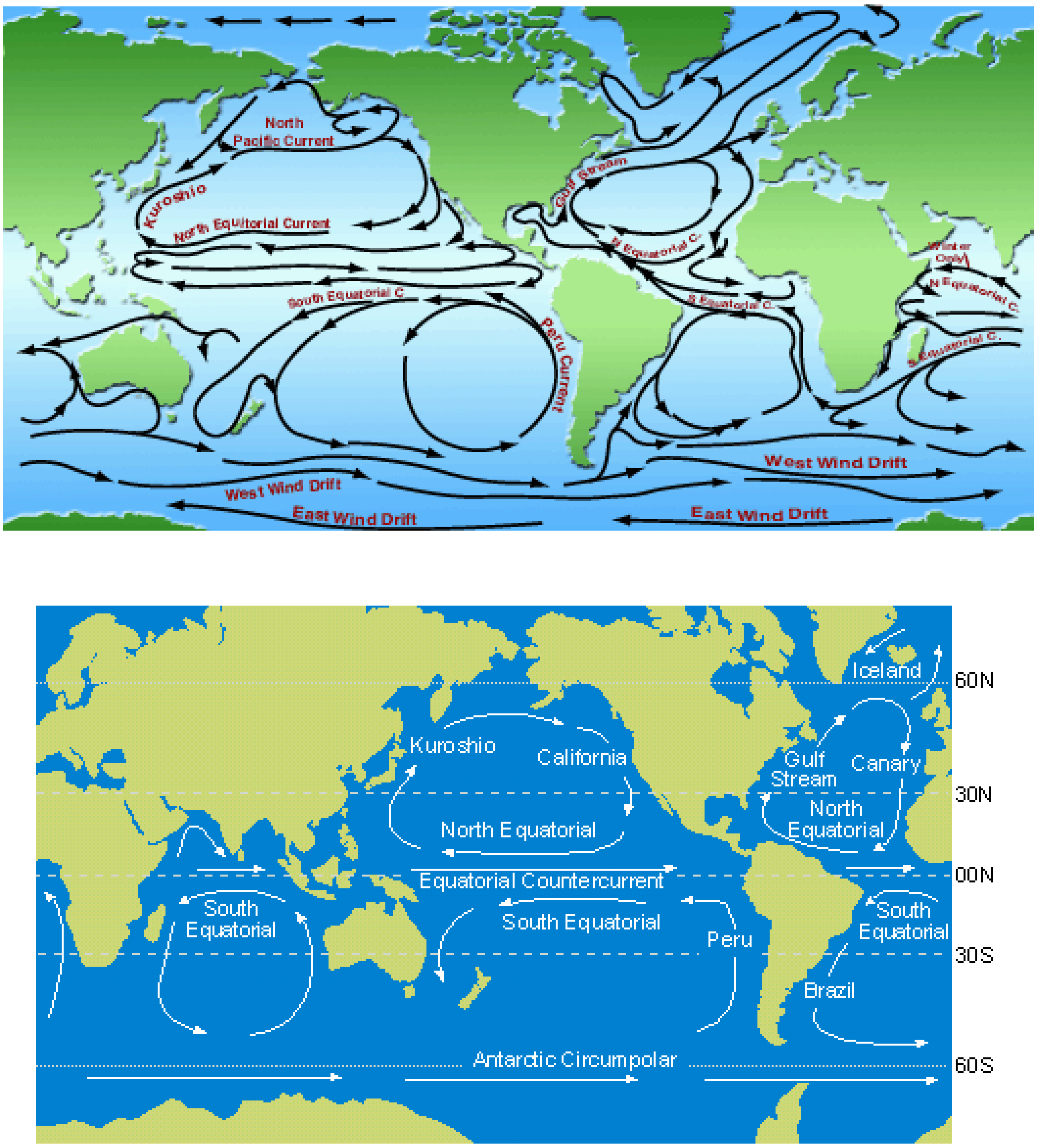
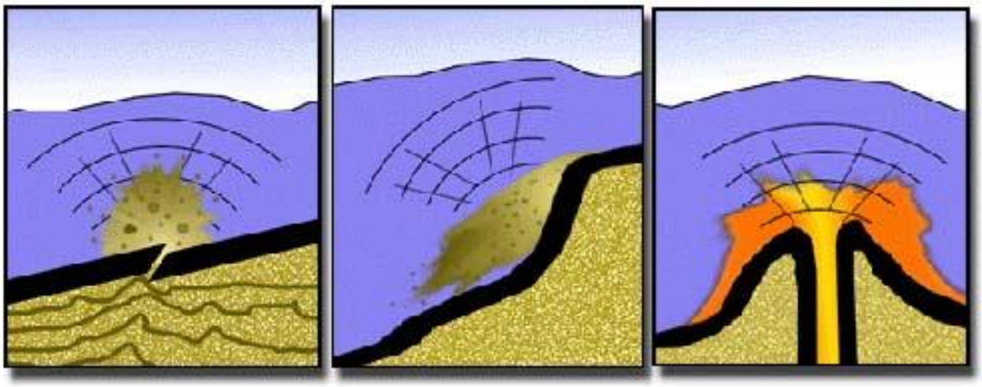


Figure 18: Map of the Earth showing major surface currents and gyres of the Ocean Basins

Two of the largest currents are the Antarctic Circumpolar Current and the Kuroshio Current. The Antarctic Circumpolar Current, sometimes called the West Wind Drift, circles eastward around Antarctica. The Kuroshio Current, which is located just off Japan's coast, travels up to 75 miles a day at a speed of up to 3 miles per hour.

The Gulf Stream is a current with a strong influence on the East Coast of the United States. Actually, the Gulf Stream is part of a larger current system, which includes the North Atlantic Current, the Canary Current and the North Equatorial Current. From the Yucatan Peninsula in Mexico, the Gulf Stream flows north through the Straits of Florida and along Florida's East Coast. When it reaches North Carolina, around Cape Hatteras, it begins to drift off into the North Atlantic towards the Grand Banks near Newfoundland. The Gulf Stream usually travels at a speed of 3 or 4 knots.

Sometimes reaching heights of 40 meters or more, *tsunamis* are the most dramatic and destructive of waves. Underwater disturbances, such as volcanoes, earthquakes and landslides, are the cause of these monster waves:



EARTHQUAKES ----------LANDSLIDES------------VOLCANOES

The larger the disturbance, the larger the tsunami will be. In the open ocean, tsunamis may be hard to spot. Long wavelengths can hide the size of the wave, but just like other kinds of waves, changes occur when the wave enters shallow water. The wavelength shortens, and the height increases. The strength of the disturbance, the distance the wave travels and the shape of the coastline combined determine the tsunami's height, and ultimately, its destructiveness.

A simple explanation of *Tsunami*:

- WHAT IS TSUNAMI

Tsunami is a Japanese word with the English translation, "harbor wave." The phenomenon we call tsunami is a series of large waves of extremely long wavelength and period usually generated by a violent, impulsive undersea disturbance or activity near the coast or in the ocean. When a sudden displacement of a large volume of water occurs, or if the sea floor is suddenly raised or dropped by an earthquake, big tsunami waves can be formed by forces of gravity. Earthquakes, landslides, volcanic eruptions, explosions, and even the impact of cosmic bodies, such as meteorites, can generate tsunamis. Tsunamis can savagely attack coastlines, causing devastating property damage and loss of life.

- EARTHQUAKES AND TSUNAMI

Tsunamis can be generated when the sea floor abruptly deforms and vertically displaces the overlying water. Tectonic earthquakes are a particular kind of earthquakes that are associated with the earth's crustal deformation; when these earthquakes occur beneath the sea, the water above the deformed area is displaced from its equilibrium position. Waves are formed as the displaced water mass, which acts under the influence of gravity, attempts to regain its equilibrium. When large areas of the sea floor elevate or subside, a tsunami can be created.

- WHEN TSUNAMI ENTER IN LAND

Just like other water waves, tsunamis begin to lose energy as they rush onshore - part of the wave energy is reflected offshore, while the shoreward-propagating wave energy is dissipated through bottom friction and turbulence. Despite these losses, tsunamis still reach the coast with tremendous amounts of energy. Tsunamis have great erosional potential, stripping beaches of sand that may have taken years to accumulate and undermining trees and other coastal vegetation. Capable of inundating, or flooding, hundreds of meters inland past the typical high-water level, the fast-moving water associated with the inundating tsunami can crush homes and other coastal structures. Tsunamis may reach a maximum vertical height onshore above sea level, often called a run up height, of 10, 20, and even 30 meters.

- WHAT IS THE SPEED OF TSUNAMI

Tsunami wave can travel at the speed of a commercial jet plane, over 800 km/h. They can move from one side of the Pacific Ocean in less than a day. The waves can be extremely dangerous and damaging when they reach the shore.

- TSUNAMI AND HUMAN REACTION

1. If you are at home and hear there is a tsunami warning, you should make sure your entire family is aware of the tsunami. Your family should evacuate your house if you live in a tsunami evacuation zone.

2. If you are at the beach or near the ocean and you feel the earth shake, move immediately to higher ground. Do not wait for a tsunami warning to be announced.

3. If you are on a ship or boat, do not return to port if you are at sea and a tsunami warning has been issued for your area. Tsunami can cause rapid changes in water level and unpredictable dangerous current in harbors and ports.

1.4.7 Ocean Circulation

The predominant circulation patterns in the open ocean are horizontal ocean currents that affect the upper surface waters, but the vertical circulation of open ocean water masses may be more important for marine life. There are two types of vertical circulation of ocean water masses: upwelling and thermohaline. In upwelling, deep ocean water rich in dissolved nutrients moves up the continental slope into coastal surface waters, aided by offshore wind patterns. The nutrient-rich waters encourage the growth of plankton, which serves as the base for the food chain throughout the oceans. In thermohaline circulation, differences in the temperature, density, and salinity of ocean water masses cause the nutrient-rich deep ocean waters to rise and mix with surface waters. Thermohaline circulation is restricted to Polar Regions of the northern and southern hemispheres. This illustration depicts both types of circulation as they occur in the southern hemisphere.

Life in the oceans is not uniformly abundant. Because of the low ratio of surface water to deep water and the lack of seasonal nutrient enrichment, much of the open ocean is a watery desert, especially the tropical seas. The most productive areas are the coastal regions, areas of upwellings (*Figure 19*), and the Arctic and Antarctic oceans.

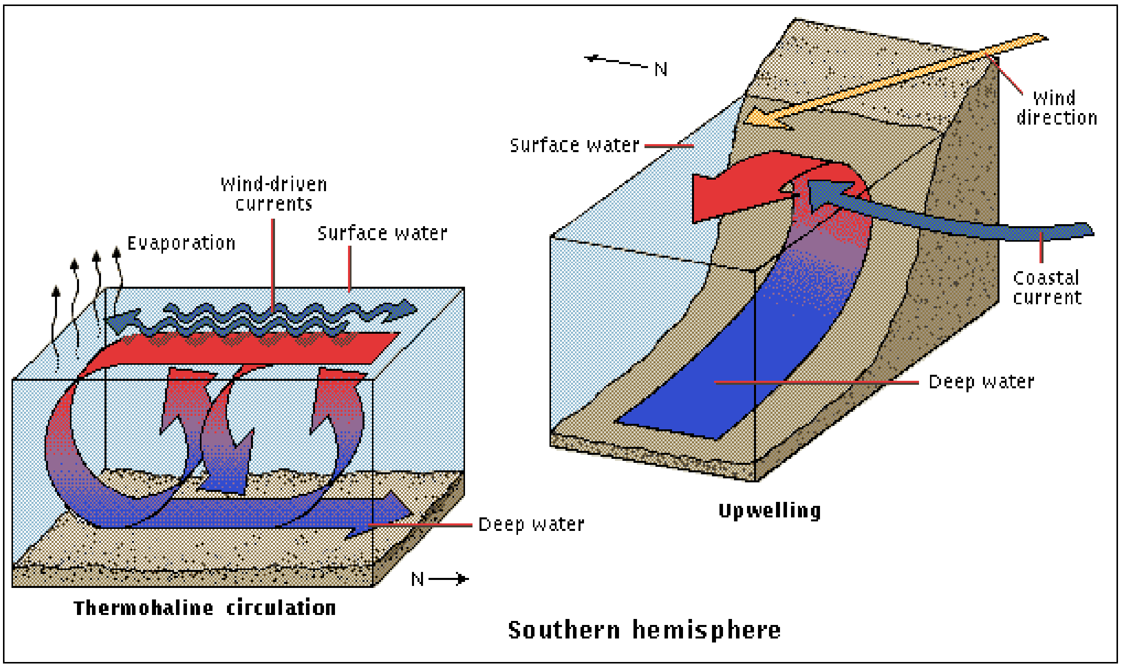


Figure 19: The process of upwelling

The intense cold that makes the Antarctic landmass so forbidding also influences the great productivity of the Antarctic waters. Cold water, made denser by the freezing of ice (which removes fresh water from salt), sinks to the bottom and moves northward from the continental shelf, as does the surface water. The northward-moving water is replaced by a deep mass of water flowing southward between the surface and bottom layers. That water, rich in nutrients, rises to the surface in an upwelling that stimulates a heavy growth of phytoplankton in the form of diatoms and dinoflagellates. The phytoplankton is consumed by zooplankton and other grazers, including the enormous populations of shrimplike krill, which in turn serve as food for many fish species and whales.

The rich Antarctic waters are pulled away from the shore and become part of the Antarctic Circumpolar Current, also known as West Wind Drift. This current, the strongest ocean current on earth, is partially diverted by the southern tip of South America, forming the Humboldt Current off the coast of Peru. As the surface water is pulled out by winds, the nutrient-rich deep water replaces it, aided by the absence of a continental shelf. This is an important upwelling region, and it supports an enormous amount of life. Copepods and opossum shrimp replace the krill of the Antarctic. Feeding on these crustaceans are immense schools of small fish that, in turn, are consumed by seabirds, replacing whales at the top of the food web.

El Niño phenomenon

In the 1500s, fishermen who lived in South America began to wonder about a current of unusually warm water that came to their shore every few years near Christmastime. Since the fishermen believed in the birth of the Christ child at Christmas, and since they spoke Spanish, they named the hot water El Niño, which means "the infant" in Spanish.

TEST this: take two cups that are the same. They can be ceramic, plastic, Styrofoam, whatever, as long as they're the same. Fill one with cool water. Fill the other with hot water. (Not boiling, just good and hot.) Place them on a table. Hold each of your hands over one cup and feel the difference in the air above the water. (Don't actually

touch the water. Just feel the air.) The hot water warms the air above it. The cool water doesn't.
Now, imagine you fill your bathtub with hot water. Think about how warm and steamy the air in the bathroom gets. Now, imagine millions and millions of bathtubs-full of hot water. All of that moist, hot air has to go somewhere. Scientists know that hot air rises and carries the moisture with it. Once the moisture gets into the air and starts to cool, rain clouds start to form.

TEST this: hold a small mirror over the cup of hot water for a few minutes. The moisture in the air should collect on the mirror, and, as it cools, form tiny droplets. Imagine the bathroom mirror after you fill the bathtub with hot water. The "water" on the mirror is caused by the water vapor in the air gathering and cooling. Now imagine the air over the hot water of the tropical Pacific Ocean. Huge rain clouds start to form and flooding results in South American countries along the coast.

What is La Niña?

La Nina is essentially the opposite of El Nino. La Nina exists when cooler than usual ocean temperatures occur on the equator between South America and the Date Line. The name La Nina ("the girl child") was coined to deliberately represent the opposite of El Nino ("the boy child"). The terms El Viejo and anti-El Nino are also sometimes used. La Nina occurs almost as often as El Nino, but has been lesser known. La Nina and El Nino are but two faces of the same larger phenomenon.

Stronger than usual trade winds accompany La Nina. These winds, from the east, push the ocean water away from the equator in each hemisphere. (This is caused by the rotation of the earth.) Cold water from below rises to replace the warm surface water which has moved away from the equator.

The cool water acts as an impediment to the formation of clouds and tropical thunderstorms in the overlying air. This suppression of rain-producing clouds leads to dry conditions on the equator in the Pacific Ocean from the Date Line east to South America.

1.5 Marine Ecology

1.5.1 The ecosystem

Ecology is a science that looks at organisms and how they interact with their environment. The word comes from the Greek root *oikos*, meaning “house,” and the English suffix *-ology*, meaning “the study of.” So, ecology is the science of the relationship between an organism and its environment, including all the physical and chemical conditions of that environment.

When we study a specific area in creation, we can begin to understand how organisms interact with their environment, and we can observe how living and nonliving things affect each other.

“Non living” is the part of the environment that includes its physical and chemical features. This is sometimes referred to as the *abiotic* part of an environment. The abiotic components of an environment, such as temperature, pressure, and salinity, provide the conditions under which an organism must survive in order to live there.

<u>Biotope:</u> the term is constructed with two Greek words, *Biòs* that means Life, and *topos* that means place, site, field, etc. The concept refers to the physical conditions of any Ecosystem, which includes the kind of environment (soil, aquatic freshwaters, oceanic, atmospheric, etc.), the amount of solar energy that falls on that defined environment, the amount of energy available for biosystems and the organic and inorganic nutrients there in that Ecosystem.

In addition to the abiotic components of an environment, organisms must interact with other organisms. They compete for living space and food, attract mates, and interrelate in many other ways. This is called the *biotic* component of an environment.

<u>Biocenosis</u>: Term composed by two Greek words, *biòs* that means Life, and *koinòs* that means *collective*. It refers to the living portion of an Ecosystem that is structured by all the living beings that form *a self-regulating unit existing in a specific biotope*.

The character of any environment, then, is determined by both biotic and abiotic factors.

A *habitat* is a specific place where an organism lives. It includes the biotic and abiotic factors in a location. A *population* is a group of individuals of the same species that live together. A *community* represents all the populations of organisms living in the same area. An *ecosystem* is composed of one or more communities, including the physical environment of a specific area. This really means *everything*, living and nonliving, included in a given location. Also, *within* an ecosystem, there can be smaller defined ecosystems. Each ecosystem makes different demands on its inhabitants, and the nature of life in a specific habitat is to a great extent determined by its abiotic features.

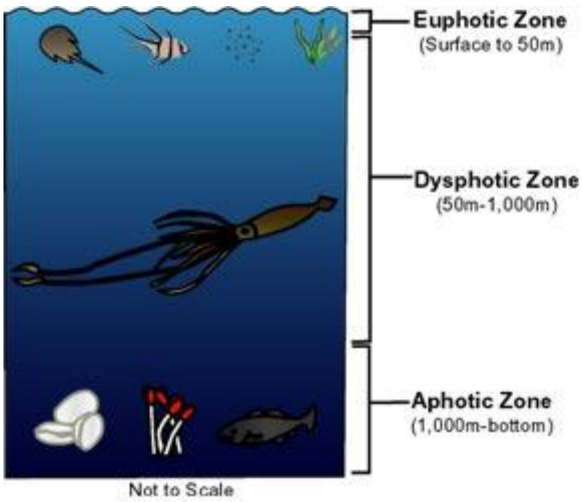
1.5.2 Marine Life – Environmental zones

As observing the surface, standing on the sandy shore, it's very difficult to perceive the amazing diversity of activity that exists in the ocean. The world of people, trees and birds is relatively flat, never extending too far above or below the ground. Oceans are different; they have an average depth of more than 2 miles and contain life nearly everywhere, even on the deepest bottoms!

Communities vary in their physical and chemical conditions, and the organisms that live in each have specific strategies that allow them to survive. The boundaries of the various zones of the ocean are defined by their physical characteristics, such as temperature, depth, and light penetration.

At the boundary between land and sea is the shallow *intertidal zone* (*Figure 20*). This zone is defined by the tidal changes of sea level along the shoreline. The intertidal zone is a thin strip of area that is exposed to air when the tide is low and is under water when the tide is high. Above this zone is the *splash zone*. This area is never under water but is exposed to the salt spray of the waves. Below the intertidal zone is the *inner shelf*. It is always under water and is the area where light can penetrate into the water.

The combination of the splash, intertidal, and inner shelf zones make up the *photic zone*. This area is where light intensity is great enough for photosynthesis to occur. The depth of a photic zone varies depending upon the clarity of the water, but usually is about 50 to 100 meters. Below the photic zone is the *dysphotic zone*, where light can be measured, sometimes as deeply as a kilometer down, but is too faint to support photosynthesis. From the lower boundary of this zone and extending all the way to the bottom is the *aphotic zone*, where no light ever passes and animals have evolved to take advantage of other sources of food. One such environment is hydrothermal vent communities.



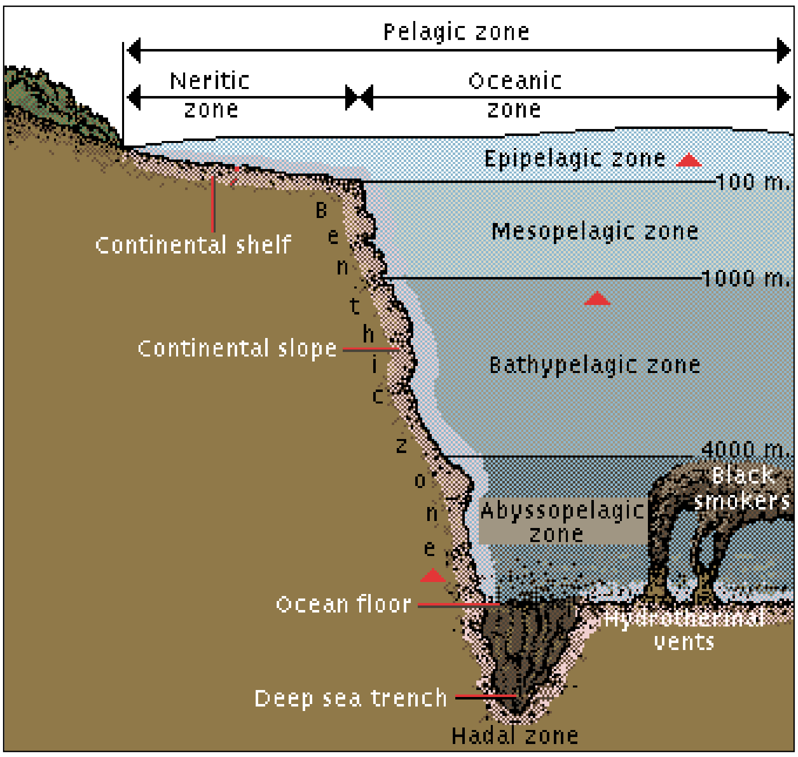


Figure 20: Zones of the Marine Environment

From the top of the aphotic zone to the edge of the continental shelf is the *outer shelf*. As you move farther away from the shelf, there are three more zones identified by their depth. The *bathyal zone* is where the continental shelf drops down to the deep ocean. The *abyssal zone* refers to the abyssal plains of the deep ocean floor. The *hadal zone* is in the deep ocean trenches.

We don't know a lot about some of the unusual creatures that live in the deep. One such creature is the giant squid, which can grow to be over 60 feet (18 meters) long! Even more unusual is the oarfish, a long thin fish, which has only been seen by humans a few times. Anglerfish dwells far down in the darkness and have adapted to their environment by forming a glowing lure to attract a smaller fishes within reach of their huge toothy mouths. A Lantern fish, gulpers (so named because of their gaping mouths), skates and shrimp are also found at great depths. The rare coelacanth, nearly unchanged from the fossil remains millions of years old, was discovered by scientists off the southern coast of Africa in the late 1930s and has since been found in other corners of the Indian Ocean.

Marine organisms can be divided into two major groups depending upon where they live. *Benthic* organisms are those that live on the ocean floor. Some are permanently attached, such as corals, while others move along the bottom, such as rays. Benthic plants and animals inhabit distinct seafloor habitats. The shallow-bottom habitat that extends from the shore to the edge of the continental shelf supports mollusks, polychaete worms, and attached algae and sponges. The continental slope and beyond make up the benthic zone, which includes the deepest part of the ocean floor. It is sparsely populated with deposit feeders and filter feeders such as the pycnogonid sea spiders and stalked crinoids

Organisms that live up in the water column are called *pelagic*. Among the pelagic organisms, there are *plankton* (which move along with the ocean currents), including phytoplankton and zooplankton. There are also organisms called *nekton* that are able to swim against the flow of currents. Most fish, for example, are nektonic organisms.

Plankton is the dominant life and food source of the ocean. Phytoplankton, which carries on photosynthesis near the water surface, provides food for grazing zooplankton and the fish life it supports. The deepwater and bottom life forms depend on a rain of organic matter from above.

Finally, areas of the pelagic water column are also divided into sections. The neritic zone is the near shore ocean environment, which occurs over the continental shelf. Most photosynthetic life (life that uses light energy to convert carbon dioxide and water into food), such as phytoplankton and floating sargassum, is located in this region. Zooplankton, which is the floating creatures ranging from microscopic diatoms to a small fishes and shrimp, also live here. Many species of whales, like the gigantic blue and humpback whales, feed almost entirely on the tiny zooplankton. These whales force seawater through baleen plates (combs of bony material that form in the place of teeth) to filter out the tiny sea creatures. The largest of all fish, the whale shark, lives off plankton alone!

Although fish are found everywhere in the ocean, the abundance of small organisms in the neritic zone generously brings a plentiful source of nutrition for larger animals. Great schools of tunas and mackerel feed on squids, krill and small fish that gather where warm waters meet nutrient-rich cooler waters. The largest example the Northern Blue fin Tuna, can increase to be more than 10 feet long and weigh over 1500lbs! Most sharks are common near the surface as well, some feeding on schools of fish, while others, including the basking and whale sharks, eat plankton.

The oceanic zone is comprised of all the other pelagic areas in the ocean. It extends from 200 meters deep all the way down to the bottom of the ocean, which can be thousands of meters. All these divisions and subdivisions help scientists study the organisms that inhabit the oceans of the world.

1.5.3 *Nutrient Cycles*

Many of the materials in life are recycled again and again. This is also the case with the basic elements of life. Inorganic molecules are incorporated into the components of living autotrophic organisms. These molecules are then transferred to heterotrophic organisms when feeding on the autotrophic organisms. Finally, the molecules are released back into the ecosystem when an individual dies, and its body is broken down by decomposers.

The *carbon cycle* is a relatively simple cycle in an ecosystem. Carbon dioxide (CO_2) is an atmospheric gas and is also found dissolved in water. This is the main source of carbon in living systems. During photosynthesis, primary producers fix carbon dioxide and produce simple sugars. These sugars are the main source of carbon for all other organisms in the ecosystem. Respiration of that sugar by consumers and decomposers converts the organic carbon compound back into inorganic carbon dioxide, which is then available for the producers again.

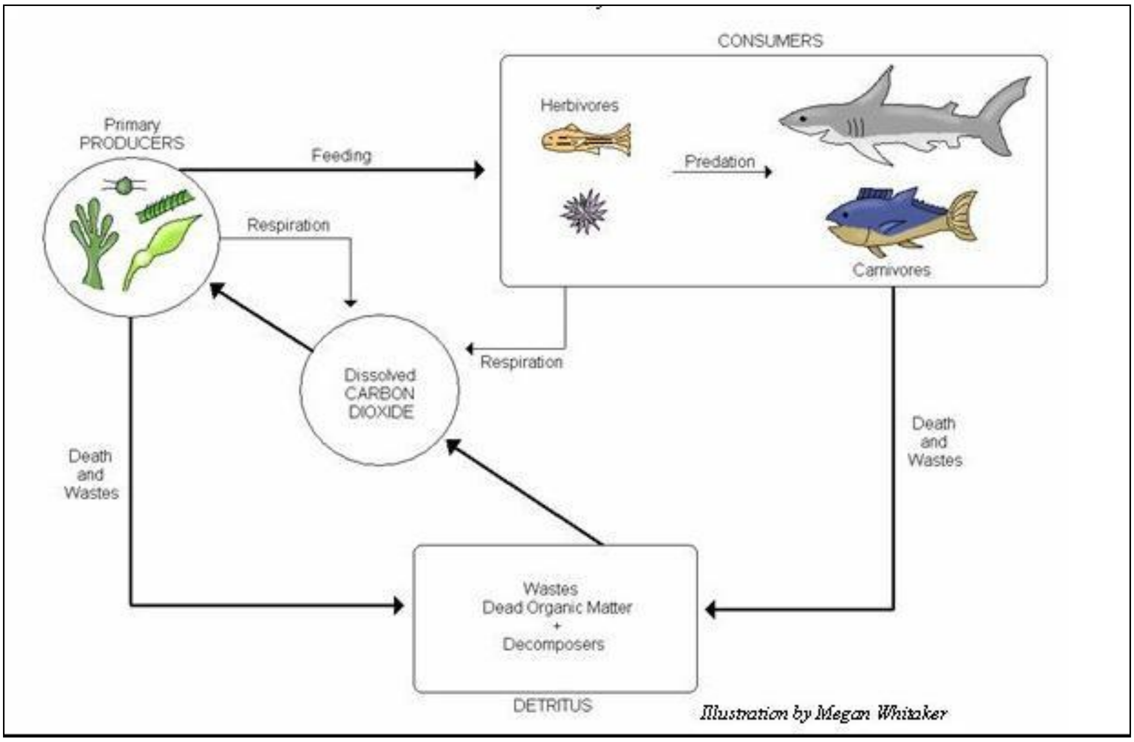


Figure 21: The Carbon Cycle

Primary producers (*Figure 21*) take dissolved carbon dioxide (inorganic) from the water and use sunlight to convert it and water into sugar (an organic molecule that contains the previously inorganic carbon) and oxygen. This, then, is the carbon fixation process. Now that the carbon is in an organic molecule, it is eaten by the herbivores, which in turn are eaten by the carnivores. In the end, then, the carbon that was inorganic (in the form of CO_2) gets distributed to all the living creatures. At the same time, the primary producers, herbivores, and carnivores are all burning their food for energy, so they are all putting carbon dioxide back into the environment. When organisms die, their bodies become detritus, and the decomposers convert the carbon in the detritus back into carbon dioxide so that the primary producers have enough carbon dioxide to continue the cycle.

In living organisms nitrogen is not present in as large a quantity as carbon, but nitrogen compounds such as DNA and amino acids are essential for life. The *nitrogen cycle* is essential for making sure that there is enough nitrogen in an ecosystem so that these compounds can be made.

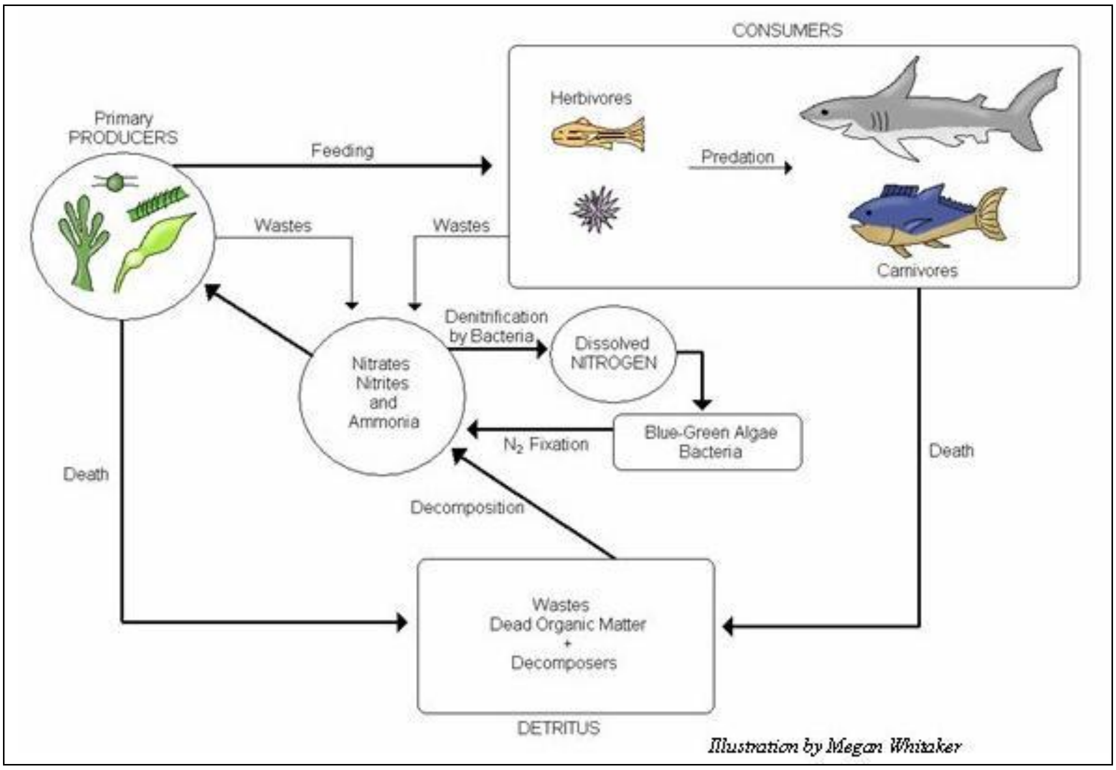


Figure 22: The Nitrogen Cycle

The nitrogen cycle begins the same way as the carbon cycle, with gaseous nitrogen (N_2) from the atmosphere dissolving into the water (*Figure 22*). At this point, however, two cycles differ dramatically. In its gaseous natural form, most organisms are unable to utilize nitrogen. If that were the end of the story, there would be plenty of nitrogen around, but few organisms could use it. Amazingly enough however, some types of bacteria (like blue-green algae) can convert the nitrogen into other forms (like nitrates), that most marine organisms can use. The process by which N_2 is converted to these useful forms of nitrogen is called *nitrogen fixation*[17], and without it, organisms could not survive.

Once nitrogen has been converted into a useable form, it enters the next part of the nitrogen cycle. The most important form of fixed nitrogen is nitrate. Primary producers use nitrate and other nitrogen compounds in their synthesis of biologically important molecules. As the primary producers are eaten by the herbivores, and as the herbivores are eaten by the carnivores, nitrogen passes to all organisms in the ecosystem.

Nitrogen gets back into the ecosystem in two ways. First, some of it is expelled as waste. For example, urine contains ammonia, which is a biologically useful form of nitrogen. Ammonia is mostly used by certain bacteria that convert it back into gaseous nitrogen. This process is called *denitrification*.

The second way that nitrogen gets back into the ecosystem is through the work of the decomposers. When organisms die, the decomposers convert the nitrogen in their bodies back into the more useful forms of nitrogen. Those useful forms of nitrogen can then be used by the primary producers or the denitrifying bacteria to keep the nitrogen cycle going.

The recycling of nitrogen and carbon, as well as other elements, is evidence of the cyclic nature of matter. Matter is repeatedly used and re-used. Although some matter might leave the cycle (such as when an organism becomes fossilized), most of the elements necessary for life have been travelling throughout these cycles since the beginning of creation.

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[17] Nitrogen fixation: The converting of gaseous nitrogen into useful organic nitrogen substances.

1.5.4 Trophic Relationships

Organisms can be divided into two groups based upon how they obtain their energy. *Autotrophs* get energy from their environment and use it to make their own food using water and simple molecules. The source of most autotrophs' energy is sunlight.

Heterotrophs obtain their energy from feeding on the autotrophs or on other heterotrophs. As a result, the energy travels from the source (sunlight), to an autotroph, and then to a heterotroph. Scientists can follow this energy pathway as they study the organisms in an ecosystem. This is done by observing the food the organisms in the ecosystem consume.

When looking at food relationships, or trophic relationships, organisms can be divided into two groups. The first group, the *primary producers*, is composed of the organisms that make their own food. Those, of course, are the autotrophs. The second group, the *consumers*, is made up of those organisms that eat the primary producers. They are the heterotrophs. Some consumers feed on other consumers instead of feeding directly on producers. As a result, there is an "energy trail" that can be followed as one group is eaten by another group.

This can be shown in its simplest form in a *food chain*. An example of a food chain typical to the coast of California would begin with kelp (*Figure 23*). Kelp is a primary producer, capturing sunlight to make its food. This energy is transferred to sea urchins, which are consumers that feed on the kelp. The energy in the sea urchins is then transferred to sea otters when they eat the sea urchins. Finally, the energy travels to a shark, another consumer, which preys on the sea otters. Scientists call each step in a food chain a *trophic level.*

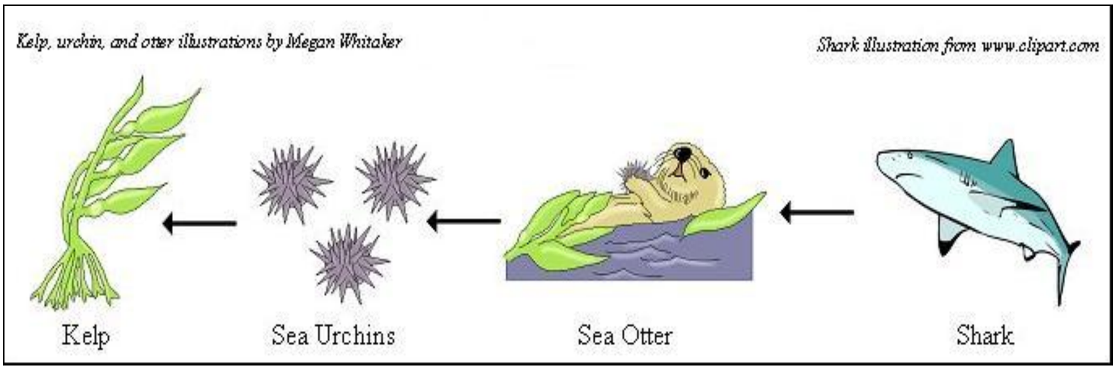


Figure 23: A Kelp forest food chain

In an ecosystem, there is usually more than one type of primary producer, and there are many consumers that feed on more than one of them. Also, organisms often change their feeding habits as they grow. Therefore, a food chain is not a completely accurate depiction of what is occurring in an ecosystem. A more correct representation would be a *food web*, which is made of many different food chains. Food webs can be simple or extremely complex, depending upon the number of species in an ecosystem and the different types of food they consume. Many organisms may feed on the same primary producer and be eaten by different consumers, which in turn are eaten by various other consumers. If there is more than one primary producer within the ecosystem (which is usually the case), there would be many interwoven food chains that create the food web (*Figure 24*).

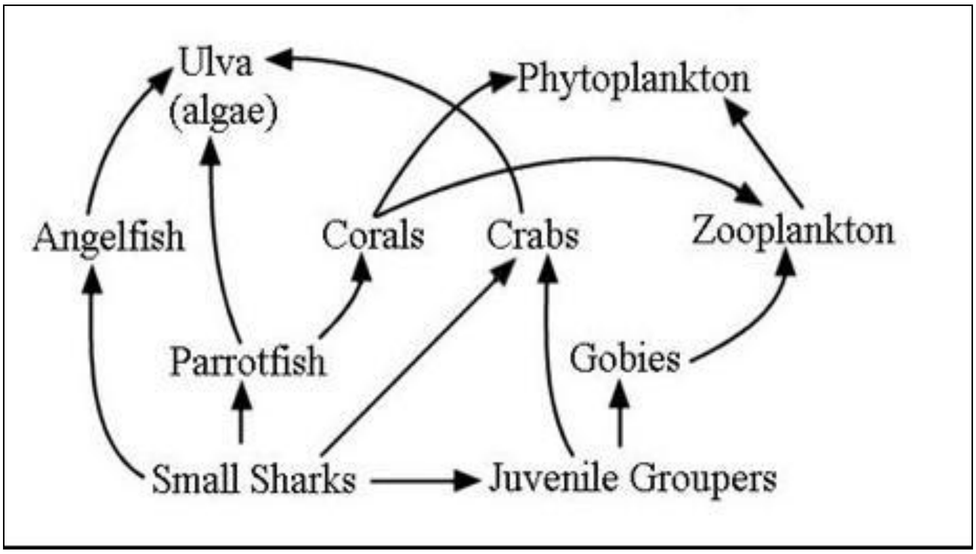


Figure 24: A portion of a food web in a coral reef ecosystem

The best way to better understand the trophic relationships in an ecosystem is to focus on an individual food chain within a food web. It helps to label the steps in a food chain by calling each step a trophic level. The first level is represented by the primary producers. In the kelp-forest example, the kelp would be in the trophic level called the *producer level*. The sea urchins that feed on the kelp would be in the next level, called the *primary consumers*. The sea otters that eat the sea urchins would be in the next level, called the *secondary consumers*. And if a sea otter was preyed upon by a shark, the shark would be in the *tertiary consumer* level. These levels help to simplify a rather complex association in an ecosystem. There are also other organisms that feed on the sea urchins. And in many cases, a consumer feeds on organisms from many levels.

The flow of energy moves through the food chain (and web), but at each step, there is an 80 to 90 percent loss of energy. What this means is that for each step up the food chain, a great deal of energy is lost. Take the example of the sea otter and the sea urchins. When a sea otter feeds on the sea urchin, it does not eat the hard outer layer or the spines. The energy bound up in that material is unusable to the next food-chain level; it is lost from this specific food chain. Each consumer also gives off energy contained in their secretions and excrements. Those are also lost to the next level consumer. We can use an *ecological pyramid* to illustrate this. Usually there is less and less original energy contained in each level as you move up the pyramid. That means there are usually fewer organisms as you move up the pyramid, too. For example, in the kelp-forest food chain, there are fewer sea urchins than kelp, fewer sea otters than sea urchins, and fewer sharks than sea otters (*Figure 25* and *Figure 26*).

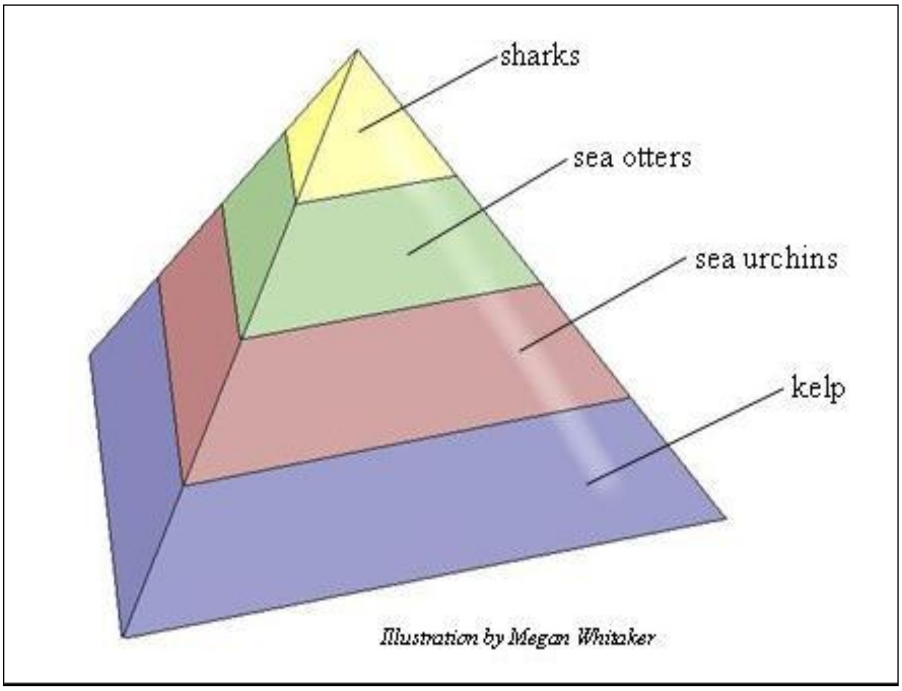


Figure 25: An ecological pyramid based on energy

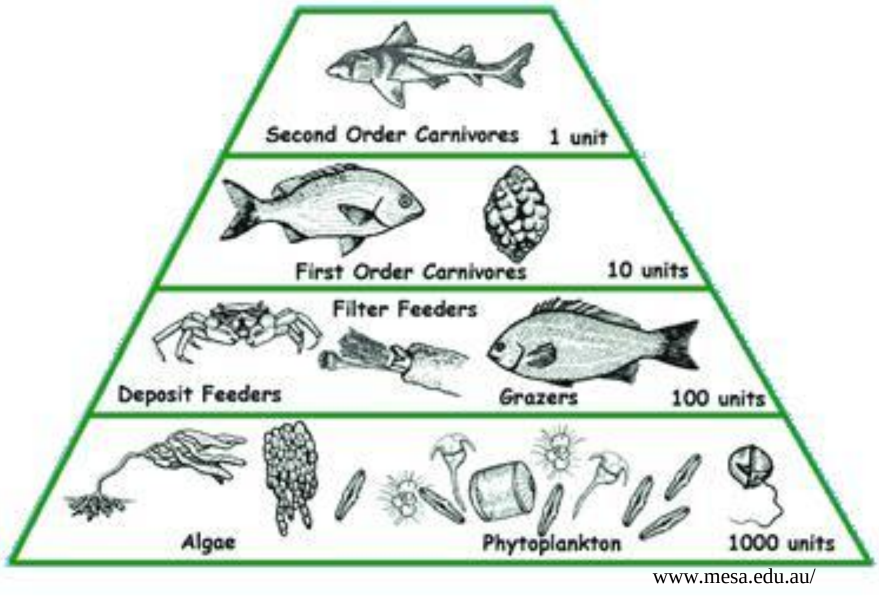


Figure 26: Generalised energy pyramid

Some organic material, and the energy within it, is lost to the consumers at a higher level. However, it is not lost to the *ecosystem*. Remember that there are decomposers placed in creation that break down living matter into its primary components. On the ocean floor, there can be dead bodies of animals, decaying bits of seaweeds, molted exoskeletons, and many other bits of unused organic material. The decomposers and this material make up what scientists call *detritus*[18].

Detritus represents the recycling bin of the ocean ecosystem. Many organisms feed directly on detritus and, therefore, bring the energy bound up in it back to the food web. The decomposers living among the dead organic matter break the materials down into their components, enabling primary producing organisms to reuse the components. It represents a completely cyclic nutrient pathway.

1.5.5 Predator and Prey relationships

A *predator* is the organism that eats another organism, and the prey is the organism that is eaten by the predator. These are the terms usually reserved for carnivorous situations, but in ecology these terms are also used for herbivorous situations. For example, in a marine environment, animals can eat algae. In that situation, the animal would be the predator and the algae would be the prey.

Whether it is one animal eating another animal, or an animal eating a plant or alga, it is still predation, because it involves something getting eaten. This situation can have an effect on a population. When a predator feeds on an organism, it decreases the prey organism's population. If the predator does not feed on too many individuals, the prey population can most likely grow and reproduce to repopulate the area. If too many individuals are preyed upon, however, the population could be so reduced that it cannot replace the lost individuals, and the population begins to decline. Conversely, if there are not enough prey organisms upon which to feed, the predator population does not have enough of a food supply to sustain it, and its population begins to decline. So you can see how predation can affect the numbers of both prey and predators in an ecosystem.

[18] Detritus: Dead organic matter and the decomposing organisms living among it.

Predators have been given many strategies with which to feed upon their prey. Some, like the shark, are efficient hunters. Others, like the tasseled anglerfish, attract their prey with the use of a lure. Still others, like the octopus, are artistically camouflaged, waiting for unsuspecting prey to swim by. There are just as many strategies employed by prey to avoid being eaten. Some organisms use speed and maneuverability to escape capture. Several hide or mimic their surroundings to avoid being seen. Others utilize defense mechanisms, such as stinging cells or offensive chemicals (*Figure 27*).

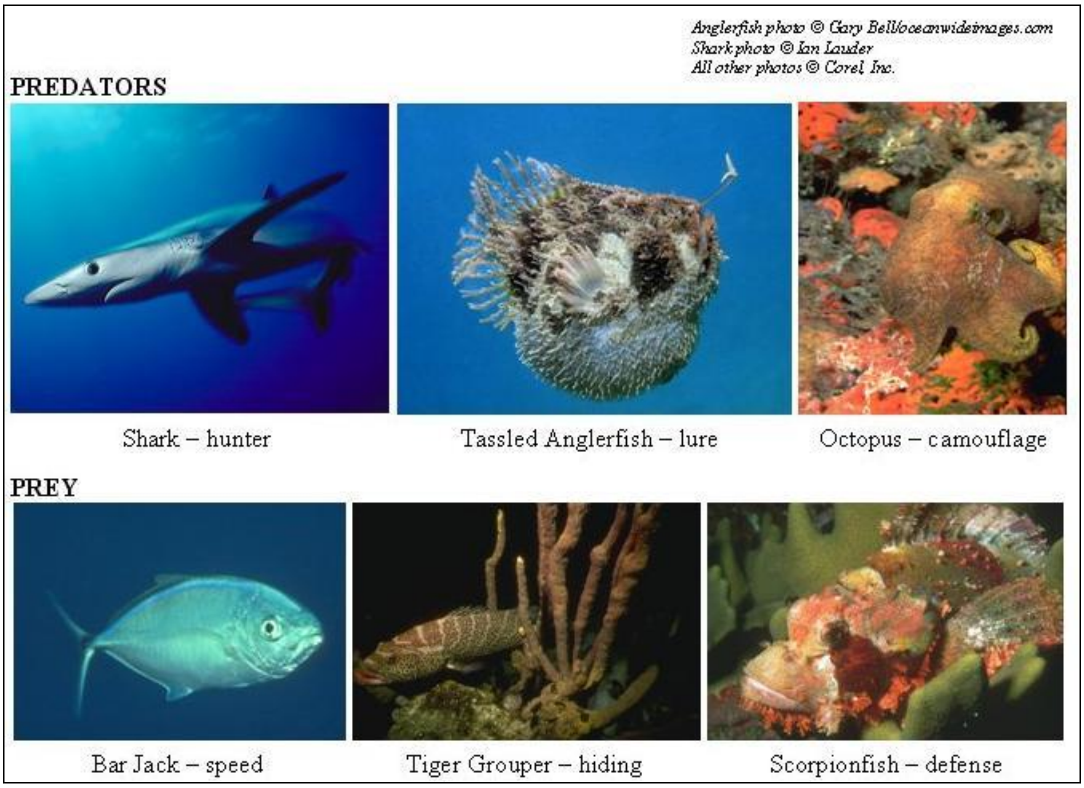


Figure 27: Predator and Prey Strategies

1.5.6 Symbiosis, Parasitism, Commensalism

There are some organisms that have such a close association with others that they could not survive without those relationships. Not only is symbiosis an important part of creation as a whole, but some of the most interesting forms of it also occur in marine environments.

The term “symbiosis” refers to a close living association between two species. The first individual, usually the larger one, is called the *host*, while the second, usually the smaller one, is called the *symbiont*.

One type of symbiosis is *commensalism*, where one species benefits from the relationship while the other is not affected. As an example of commensalism, the long-spined black sea urchin provides protection for the urchin crab, but the urchin crab does not provide anything for the sea urchin.

Parasitism is similar to predation in that one of the interacting species feeds on the other. Parasites are generally much smaller than their hosts and usually live in a long or continuous association with them rather than instantly devouring them. Nearly every animal in creation (as well as humans) has one or more parasites living on or in its body. Among fishes, probably the most notable parasites are the isopods. Isopods are crustaceans that are several centimeters long and attach to their host on the skin, fins, or gills. They feed on the tissue to which they are attached (*Figure 28*).

Figure 28: Marine Isopod Feeding on a Creolefish

Another type of symbiosis is *mutualism*, which is a relationship in which both organisms benefit. Marine environments are full of examples of mutualism. In some of these cases, both partners require each other in order to live. For example, consider the relationship between coral and tiny dinoflagellates called *zooxanthellae* that live in the coral's tissue. The coral provides the zooxanthellae both nutrients and a place in which to live, and in return, the zooxanthellae provide the coral with necessary food and minerals so it can survive.

The mutualism between the zooxanthellae and coral is sometimes referred to as a result of “co-evolution,” where two organisms evolved at the same time and became ideally suited to the complex mutualism we see today. The coral could *not* have developed without the zooxanthellae providing its necessary food, and the zooxanthellae could *not* have survived without the protection the coral provides.

There are many examples of mutualism exist in the marine environment; consider the very common relationship of the “cleaner” and the “cleaned.” There are many small cleaner fish and cleaner shrimp that feed on the external parasites or damaged tissue of the mouth and skin of host fishes. The cleaner receives food, while the host gets rid of irritating tissue and parasites. Not only are there many species of cleaners, but there are also even *more* species that receive the cleaners' services. In many cases, the cleaner sets up a “cleaning station” where fish actually line up and wait their turn to be cleaned. They voluntarily open their mouths or lift their fins to accommodate the cleaner (*Figure 29*). In many examples of cleaner/cleaned mutualism, the organisms involved do not necessarily *need* each other to survive – it just makes life better for them.

Figure 29: The Oriental Sweetlips and the Blue-Streak Wrasse

Another example is the brightly colored clownfish and its mutualistic relationship with the sea anemone (*Figure 30)*. Sea anemones have stinging nematocysts that paralyze fish that swim into their tentacles. The clownfish, however, have a slimy covering that makes them immune to the anemone. Thus, they swim inside the tentacles, protected by the anemone. Because of their bright colors and their tendency to wriggle in the sea anemone's tentacles, they attract fish to the anemone, increasing its food supply. Clownfish also lay their eggs on rocks under the protection of sea anemone tentacles, which adds a measure of protection to the eggs before they hatch.

Figure 30: Clownfish and sea anemone

There are marine ecosystems in which many organisms are involved in a mutualistic relationship as a group. For example, a particular species of coral, *Pocillopora damicornis*, has been found to harbor as many as 16 individual species of crabs, shrimps, and fishes. These creatures find refuge from predators by hiding in the coral colony, but they also protect the coral colony from predators. For example, when the crown-of-thorns starfish (*Acanthaster planci*) attacks the coral, one of the species of shrimp attacks the starfish with its claws. In addition, one of the species of crab grabs onto the starfish's tube feet and jerks up and down in order to force the starfish to move on. This relationship between many species in a marine ecosystem gives you an idea of just how complex these marine ecosystems can be.

1.6 Coral Reefs

1.6.1 Introduction

Coral reef communities are generally found on the continental shelf, but they are not located in all parts of the world. Coral reefs are home to an amazing assortment of organisms and are truly the underwater equivalent of a diverse rain forest. So where are coral reefs found? Coral reef communities are found in the tropical climates of the world (Figure 31). This is because reef-building corals need warm temperatures in order to survive. They are found between the Tropic of Cancer and Tropic of Capricorn latitudes (Figure 32). This "band" around the earth receives a much larger portion of sunlight throughout the year than the rest of the world and has overall warmer climates. The west coasts of Central America, South America, and Africa have few reefs and yet are still within the tropical zones of the earth. This is because these coastlines experience a strong upwelling of cold water and cold currents coming from the poles. The Coriolis effect causes ocean currents to spiral clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere. This effect results in the presence of cooler water off these western coasts, and as a result, water in those areas cannot support the growth of corals.

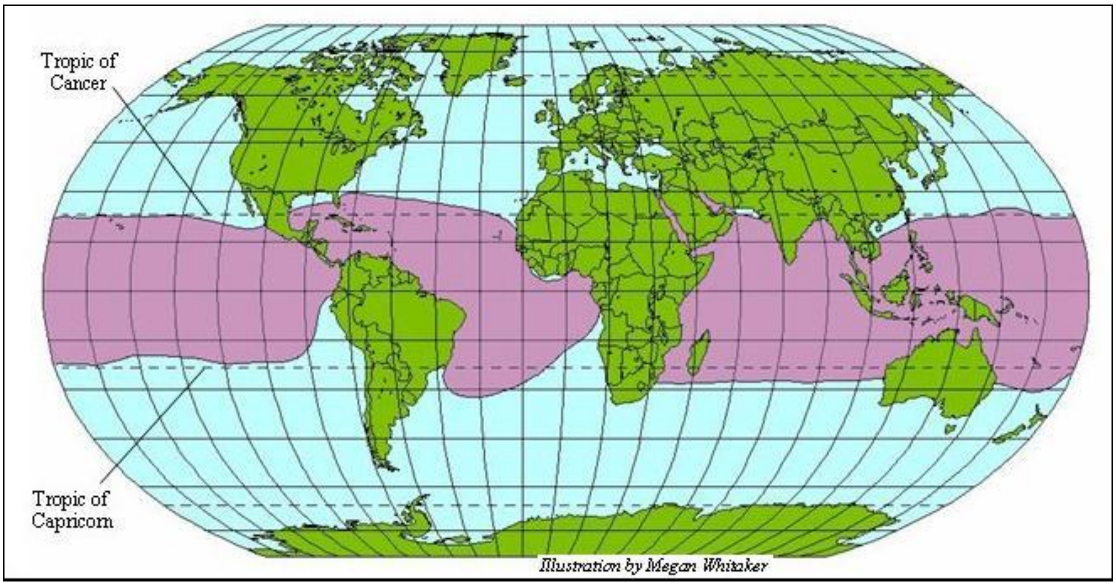


Figure 31: Areas of the world where coral reefs can grow

Figure 32: Coral reefs are found almost exclusively in the seas and oceans between the Tropic of Capricorn and the Tropic of Cancer.

Besides warm temperatures, reef-building corals have other specific requirements in order to grow. There must be a hard surface on which coral larvae can settle. Also, corals need shallow water in which light can penetrate. Also, these types of corals cannot grow well without the presence of tiny algae called zooxanthellae. The zooxanthellae living in symbiosis with corals require light in order to photosynthesize and thrive in warmer water. Therefore, you find coral reefs located on continental shelves or around islands where the water is shallow enough to allow for light penetration. Corals grow better in clear water because there is superior light penetration in such waters. Water that is clouded with silt has poor light penetration and slows coral growth. Even though most corals require an ample amount of light in order to survive, there are some coral species that can grow in deeper water where light does not penetrate as well. These corals, however, do not produce reefs and do not live in symbiosis with zooxanthellae.

1.6.2 What is a Coral

Coral is made by millions of tiny carnivorous (meat eating) animals called polyps**.**
Polyps live in groups called colonies.

Polyps: The polyp is related to the anemone, and http://www.kidcyber.com.au/IMAGES/coralpolyps2jpgconsists of a stomach with a mouth at one end (Figure 33). The mouth is surrounded by a number of tentacles. These tentacles resemble feet, which is how they get their name: 'polyp' is a Greek word meaning '*many feet*.'

Figure 33: Polyps are carnivorous animals that made up the Corals

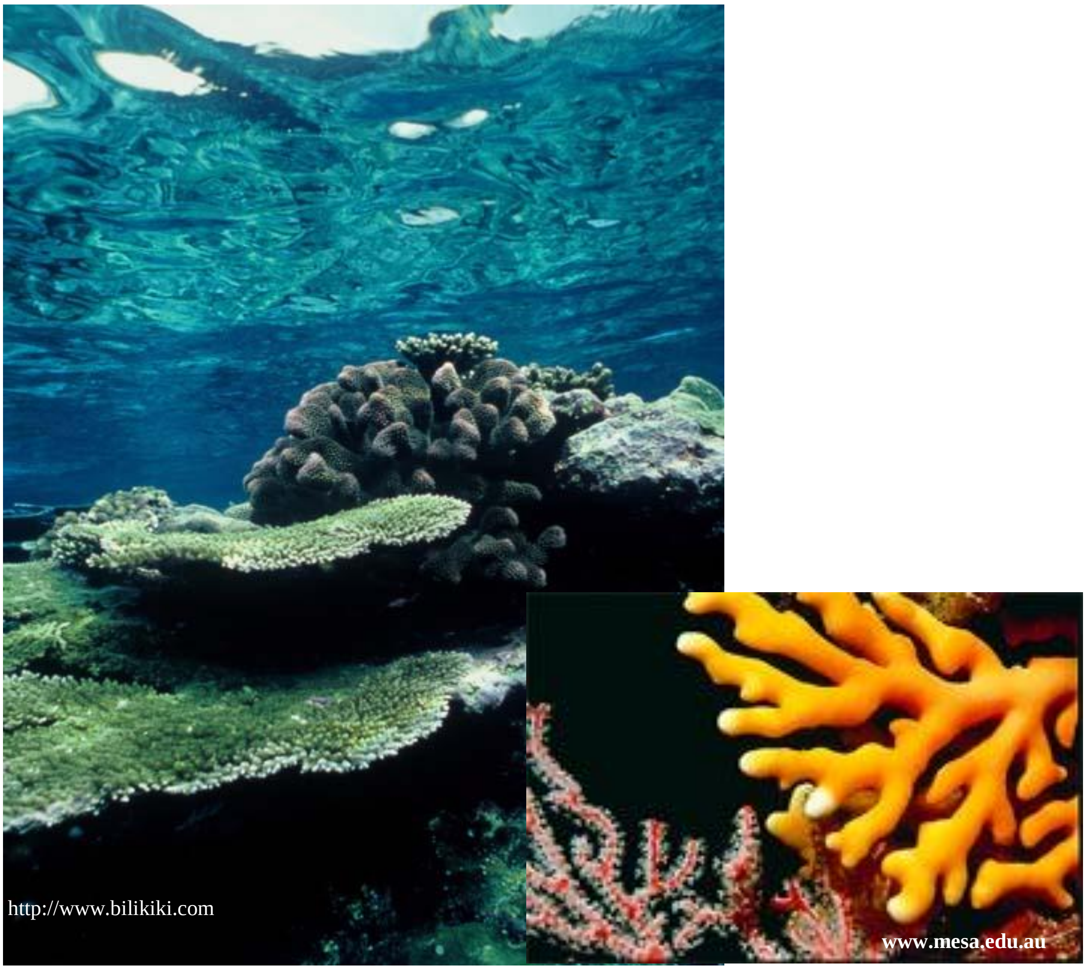
The tentacles are covered with tiny stinging cells, and when a small creature brushes against the tentacles, it is killed. The prey is then brought into the stomach to be digested. Polyps cannot move from their limestone homes. They mostly feed at night.

A polyp reproduces in either of two ways: by dividing its own body to form two polyps, *or* by producing sperm and eggs just after the full moon in November, eggs and sperm are released from coral polyps and float about for a few days. A small number of eggs will fertilize, hatch into larvae, and settle on the reef to begin new colonieshttp://www.kidcyber.com.au/IMAGES/coralpolyps2jpg which grow rapidly. One polyp can become a colony of 25,000 polyps in 3 years.

Building up a Coral reef each polyp builds a case of limestone around itself, using calcium from the water. It is like a house, with a floor and walls. This remains after it has died and forms a foundation for another polyp to build a house on, putting a floor on the roof of the old one. When these limestone formations increase, they are called a coral reef.

There are three categories of corals:

- **Hard Corals:**



- **Soft Corals:**

- **Sea Fans:**

1.6.3 Types of Reefs

There are basically three types of coral reefs found in creation, growing off both continents and islands. *Fringing reefs*[19] form borders along shorelines that have a hard surface on which the coral larvae can settle (Figure 34).

Figure 34: A fringing reef in Papua New Guinea

Even if there is a minimal amount of hard substrate, it is a sufficient starting point for corals to develop. Once a coral larva settles and begins to grow into a colony, bits of broken coral and remains of organisms that live and feed near the coral begin to accumulate among the sediments. Then coralline algae can grow atop this material, packing down the rubble and sediments, providing more substrate on which even more corals can settle.

Fringing reefs get their name because they "fringe" the shoreline. Since they are so near the shoreline, these kinds of reefs are most likely to be affected by sediments and runoff. The longest known fringing reef is in the Red Sea, spanning over 400 km. This area of the world has no fresh water streams to carry sediments into the ocean, so there are not very many things to hinder the growth of a reef.

[19] Fringing reef: A type of coral reef that forms as a border along the coast

A second type of coral reef is a *barrier reef*[20] (Figure 35).

Figure 35: A portion of the Great Barrier Reef in Australia

Barrier reefs are located farther offshore than fringing reefs and are separated from the shoreline by a *lagoon*. Lagoons are calm areas because the barrier reef acts as a shield against currents and waves. The lagoon of a barrier reef therefore often has a soft bottom filled with sediment. This is an ideal environment for seagrasses.

The most famous barrier reef in the world is the Great Barrier Reef of Australia. It is considered to be the largest biological feature on earth and extends some 2,000 km in length. It is composed of a series of thousands of smaller reefs, varying in shape, size, and depth. At some points, the width of the reef is over 300 km and includes islands and sand cays too. Well-developed barrier reefs are also found throughout the Indian and Pacific oceans, and there are two found in the Caribbean.

[20] Barrier reef: A type of coral reef that occurs at a distance from the coast.

Perhaps the most curious of the three types of coral reefs is the *atoll*[21] (Figure 36). Atolls are ring-shaped reefs, enclosing one or more shallow lagoons.

Figure 36: Aerial photo on numerous atolls in the Indian Ocean

Most atolls are found in the Pacific Ocean and some parts of the Indian Ocean. They are found in areas far away from land, sometimes surrounded by ocean depths of hundreds or even thousands of meters. Since there is no shallow water around the atolls, how did these coral reefs grow? They certainly could not have built up from the sunless, deep-ocean bottom. Also, why are they always in rings?

After years of hypotheses as to how atolls form, some data were found that helped to explain these strange coral formations. In the 1950s, a scientist by the name of Henry Ladd drilled two test holes down into the Enewetak Atoll, located in the Marshall Islands of the South Pacific Ocean. He found over 1,400 meters (4,600 feet) of calcium carbonate reef material lying above basalt volcanic rock. *It appeared that the coral reefs of atolls were growing on top of extinct volcanoes*. This hypothesis was first proposed by Charles Darwin in the mid-1800s and was largely ignored until test drills such as the one made by Ladd.

[21] Atoll: A ring of coral reef with steep outer slopes, enclosing a shallow lagoon.

Darwin suggested that all oceanic coral reefs were supported by volcanic mountains below. He further proposed that fringing reefs, barrier reefs, and atolls were stages in the life of a single coral reef (Figure 37). He suggested that as a new volcano rose up to the surface of the ocean from years of eruptions, planktonic coral larvae would eventually begin to settle on the new hard substrate. The larvae would then grow near the surface, close to the shore of the protruding volcano, forming a fringing reef.

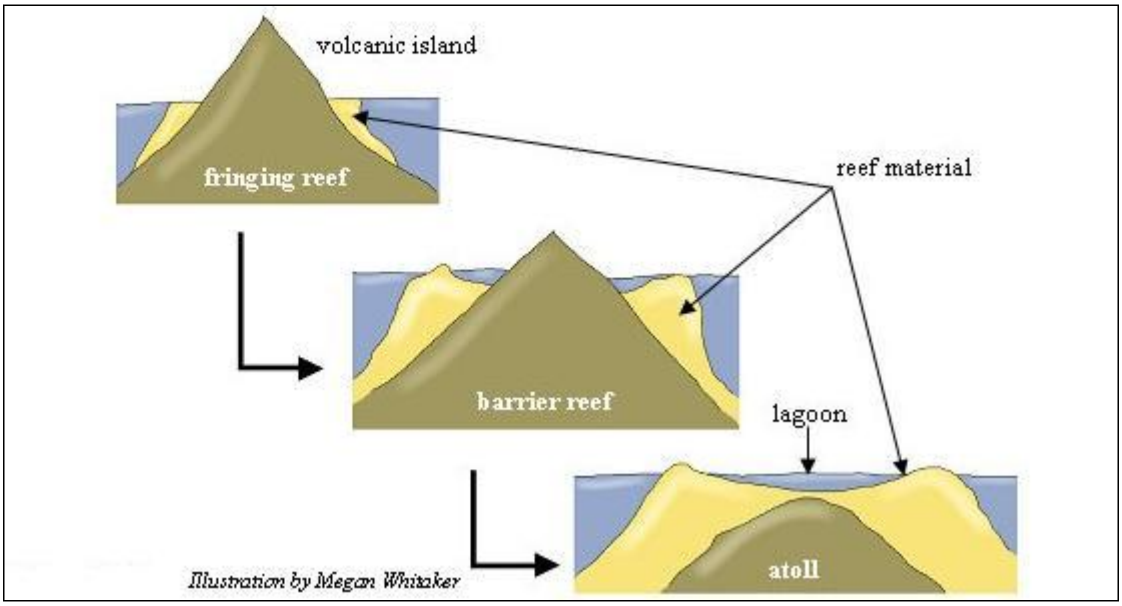


Figure 37: Development of coral atolls due to a sinking island or rising sea level

The reef would grow most rapidly on its outermost side where water movement is stronger, and bits of coral would be broken off to produce additional shallow substrate on which new corals could develop. Darwin then proposed that the weight of the building reef combined with the cooling of the volcano could begin to cause the island to sink. As the volcanic island subsided, the coral would continue to build upward. This would cause the fringing reef to eventually become a barrier reef. Eventually, as the volcanic island continued to sink, it would be completely submerged in the water, and coral would grow on top of it. Because the coral had grown for a longer time around the edges of the island, however, there would be a lagoon in the middle, forming an atoll.

Although no one has actually observed an atoll being formed this way, the available data seem to support the theory. After all, the theory does explain the observation that an atoll always forms in a ring with a lagoon in the centre. It also explains how coral could have grown in the middle of the ocean away from land. Finally, the fact that the Enewetak Atoll has been demonstrated to be sitting on top of volcanic rock fits perfectly into the theory.

Over the years, we have found that coral reef growth rates vary drastically, depending on conditions. Coral growth rates near the surface of the ocean are lower because of exposure to ultraviolet light and air during low tides. However, coral growth rates in deeper waters are faster. But as previously mentioned, reef-building corals need light to grow in a healthy manner, so they cannot survive in *really* deep waters. However, they do grow quickly in waters deep enough to shield the coral from ultraviolet light and keep the coral fully submerged at all times. In fact, direct measurements of coral growth under deep-water conditions demonstrate that reefs are built nearly five times faster in deeper waters than the growth rates seen in shallower coral reefs. If the coral that built the Enewetak Atoll grew under such conditions, the entire atoll could have been built in under 3,500 years.

Does it make sense to think that the formation of an atoll would allow for deep-water coral growth conditions? Actually, such an idea fits perfectly into the theory of atoll formation. After all, the volcanic island has to sink as the coral grows. When this happens, of course, the corals are lowered into deeper waters, producing faster growth rates.

There are other factors that can contribute to the growth of a coral reef as well. Marine biologists sometimes “help out” a coral reef by sinking debris such as ships and cars. This gives the coral a hard substrate upon which to grow, rapidly increasing the size of the coral reef. Nature can also do that. Trapped sediments and debris brought in by storms can significantly add to the thickness of a reef. An example of this is when, in 1972, Cyclone Bebé created a new land formation on the Funafuti Atoll in a matter of hours. The resulting embankment was 3.5 meters high, 37 meters wide, and extended 18 kilometres in length.

There is yet another factor that needs to be considered. Studies have shown that coral can double its growth rate if the water temperature is increased by only 5º C. Thus, if the water were warmer at sometime in the past, it would reduce the time needed to form an atoll. The water could be warmer in the past since the atoll is built on a volcano. Volcanoes are known to increase the surrounding water temperature when they are active.

When you take all these factors into account, it becomes very clear that while the previously discussed theory is a viable description of how atolls form, there is no reason to think it takes an enormously long time. Indeed, the Enewetak Atoll is the thickest known coral reef on the planet. If the available data indicate that it can be formed in less than 3,500 years, the other coral reefs in the oceans could have been formed in even shorter amounts of time.

1.6.4 Coral Reef Ecology

Scientists are only beginning to *identify* all the types of organisms that live on a reef. Learning how they *interact* with one another is a tremendous undertaking and will continue to take many years of study for scientists to even begin to have an understanding.

One thing that is already known is that corals grow well in very clear water and this is because there is better light penetration. But it also means that the water is not nutrient-filled and has very little plankton. Since plankton is essential for the food chain, how do these rich ecosystems survive? Zooxanthellae that live inside the corals' bodies provide food and they have produced via photosynthesis for their coral host. The minerals they provide, along with reduced carbon dioxide levels from photosynthesis, also aid in the formation of the corals' calcium carbonate skeleton. Besides a safe home, the zooxanthellae get many nutrients (such as nitrogen and phosphorus) back from the coral in the form of its wastes. Zooxanthellae take the waste products from the coral and convert them into usable, organic matter that is passed back to the coral. This nutrient recycling alleviates the need for a large, external supply of food and is one reason why coral reefs can successfully survive in waters containing few nutrients. Coral can eat plankton floating in the water, but without the zooxanthellae, they would not be able to make their skeletons as easily, their waste products would not be recycled as efficiently, and they would need a richer external supply of nutrients.

Furthermore, the reef makes much of its own usable nitrogen thanks to cyanobacteria living in many reef species and on the reef surfaces. The bacteria benefit from organic carbon excreted by the corals, and the corals benefit from the usable nitrogen produced by the bacteria. Nitrogen fixation is tremendously high in a coral reef, and scientists are still discovering the processes and complex associations between nitrogen fixers and their coral reef hosts.

This recycling food pathway is exhibited by other reef organisms as well. Many invertebrates on a coral reef, such as sponges, have symbiotic algae living within their bodies just like coral have in theirs. Also, many reef fishes feed on corals and produce wastes utilized by corals for food. In this way, nutrients move through the ecosystem as food, then as waste products, and then as food again. The coral reef is extremely proficient at utilizing its nutrients and therefore needs very little supplementation. Nevertheless, there is some loss of nutrients in the food web. Some food gets carried away by currents, and there is a little loss of net nutrients as the food cycle progresses. So the reef does need a supply of added nutrients in order to thrive. Much of this supply comes in via currents, which bring in nitrogen and phosphorus. They also bring in plankton, which the coral eat.

The reef communities have a high primary productivity due in great part to the zooxanthellae. The corals utilize much of the nutrition produced by the zooxanthellae, but there are a number of organisms that feed upon the coral or its mucus, thus moving the nutrients up the trophic ladder to other organisms that will feed upon the coral eaters. Seaweeds are also notable primary producers on the coral reef, providing material for fishes and other organisms upon which to graze.

1.6.5 The Importance of Coral Reefs

Coral reefs are a precious resource in the ocean because of their beauty and biodiversity. Coral reefs provide shelter for a wide variety of marine life, they provide humans with recreation, they are a valuable source of bio-organisms for potential medicines, they create sand for beaches, and they serve as a buffer for shorelines. Coral reefs are built by millions of coral polyps, small colonial animals resembling overturned jellyfish that fix excess carbon dioxide in the water from the atmosphere into limestone.

1.7 Use of the sea

1.7.1 Introduction

From the early years of life on earth we have evidence that man was related to the sea in one way or another. At first the sea was used by people as a food resource and as the time passed and people developed on earth, they discovered the enormous possibilities of exploitation that the sea had to offer them (fishing, travel-trade, mining, energy producing, jewelry, diving, etc). Because the living aquatic organisms can replace their populations we call them *renewable recourses*. The recourses that can not be replaced we call them *non renewable*, like minerals and oil.

1.7.2 Fishing

Because the ocean is a large, extremely productive area of the world, people look to it as a source of renewable food. Much of the developing world today depends on fishing as a means of providing an important source of protein. Originally fishing was a way to obtain food for survival with no other factors determines the amount of fish that had to be captured. With the development of the life on Earth, human population started to grow exponentially and so did the need for food. Today in the world of free competition and globalization the fishing industry is a big operation and in some cases it supports a country’s economy and other related industries, like the processing industry.

Many cultures use traditional fishing methods that have been used for generations; however, in industrialized areas of the world, human populations are quite large, and technology has aided in more efficient fishing techniques. Commercial fisheries employ satellites to identify the location of large schools of fish. Over time, technology has produced larger ships that are able to remain out in the ocean for longer periods of time, taking full advantage of prime fishing seasons. Some ships can actually process the fish while out at sea, reducing the need to return to port. With the advent of this technology, fish populations seem to be dwindling. At the same time, however, many fisheries employ marine biologists and other scientists to help manage ocean-creature populations to aid in preserving the species.

Some countries, such as Japan, utilize a large percentage of seafood as a traditional part of their diets; while other countries, such as the United States, are increasing their demand because of the health benefits of seafood. Globally, the rising demand for fish has led to a general increase in worldwide fisheries' catches.

Along the Pacific Coast of South America, the native sardine populations have been wiped out, most likely because of aggressive fishing and El Nino's warming effect on those coastal waters. Salmon catches along the North American coast are now closely monitored by both the Canadian and United States governments to make sure that enough of these fish can return to their river of birth to spawn and populate the next generation.

In general most of the organisms of the sea are eaten by people at least in one part of the word due to traditional reasons or other. Most fishes harvested for food are referred to as *finfish.* The next largest group of harvested ocean creatures is *shellfish*, comprised of crustaceans (such as shrimps and crabs) and molluscs (such as clams and oysters). Seafood is especially important to coastal communities, which often depend on it as a major food supply as well as a means of business, but it is also important to the entire world's population in that it is a good source of protein. The Figure 31 shows you the amount of finfish, molluscs, and crustaceans caught by fisheries worldwide from 1998-2002.

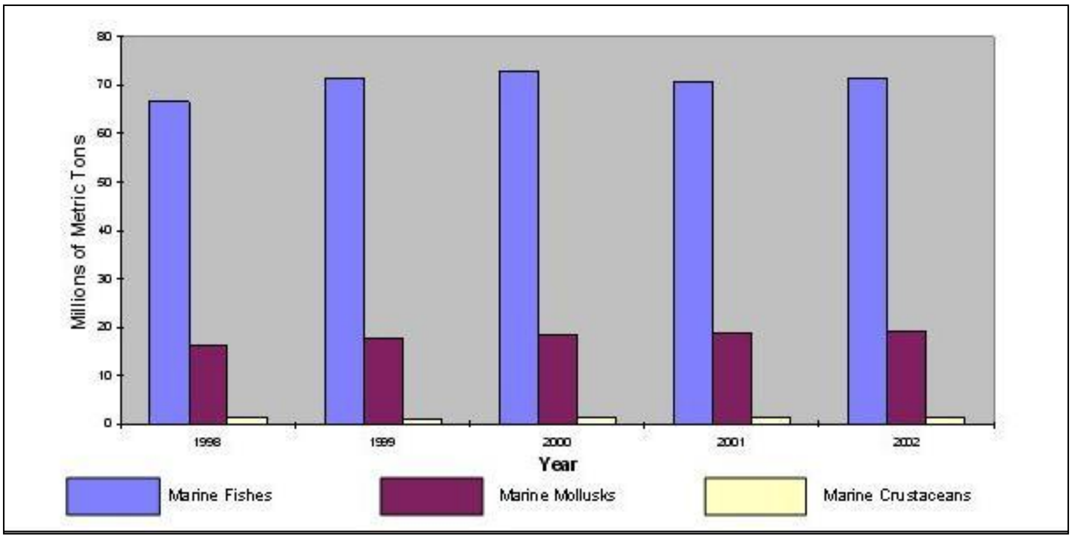


Figure 38: Worldwide fisheries' catches of important fishes, molluscs, and crustaceans for five years

Nowadays the need for a bigger fishing effort is driven by the desire for bigger profit; therefore the current fishing pressure on the aquatic organisms is more intense than ever. As an outcome of this, many aquatic populations are facing the problem of extinction. For example, whales' fat was intensively used during the industrial revolution for oiling mechanical parts of the engines and the machines used in the factories, and before that it was even used as a fuel for lighting. Therefore, an intense whaling that was driven by all those needs was a big threat to the whale population at that time (*Figure 32*).

Figure 39: Whaling during the 19th century

There are many fishing methods; for example fishing by hands, the use of explosives, chemicals, poisons, electricity, spire, nets, hooks, traps, intense light etc.

A continual over-fishing of a specific fish population, will eventually lead to the collapse of the population. Over-fishing occurs when the amounts of the harvested fish is bigger than the amount that the population can "produce" in a unit of time. In general a fish population of a medium to a large size has higher productivity. As an impact to the marine ecosystems when a population collapses other populations are affected and the balance in the food chain is changed. This change may not alwayshave instantly visible results. In the case of the free trade the pressure to the fish population is always to the category of over fishing unless restriction is placed by law.

In Cyprus the major commercial species are over exploited, therefore measures where taken in some cases in order to allow the fish stokes to recover. In the wild only 0.01 % of the laid eggs are reaching the maturity age. As a solution to the problem of over-fishing wild fish populations is aquaculture. With the development of technology it is possible to breed and grow in intensive conditions a variety of sea food. Efforts are focusing on the development of new techniques for farming more marine species but one of the main problems is that the feed that it is used in aquaculture is originated from the sea in the first place (fish meal). Current research is being made for finding a different source of protein that will be able to be used in aquaculture like vegetable protein.

1.7.3 Mining

Some of the most valuable recourses are in the bottom of the sea or under it.

1. Oil and natural gas

In order to use the oil resources found in the sea, the difficulty of an unpredictable and unstable environment -like the ocean- needs to be overcome. This involves a more complex, difficult, high cost, operations than the ones used for mining on land. Due to this, most of the underwater oil resources are not exploited in the same degree as the ones in land. Nowadays, due to the fact that the recourses on land are running out with greater rates than before, the exploitation of the marine non-renewable resources are the alternative solution.

The mining of oil from the sea is done on huge steel or concrete platforms that are anchored to the bottom floor. The drilling of a well is made by a specific kind of ship that detects and performs drilling tests.

The biggest problem is the possible pollution from leaks on the platform. These leaks can affect the fish stocks of the coastal populations, the tourist industry, but the most important is the ecological distraction.

For this reason the oil and gas mining on the continental shelf has been forbidden or is done under a very strict control.

2. <u>Oceanic mines</u>

The ocean floor is probably one of the richest sources for many minerals and metals. On the other hand is not viable to use this recourse yet, but as the recourses in land are running out, new technologies are developed in order to make this exploitation viable. Some of the most promising elements that can be used in many ways, such as the magnesium condoyle deposits, copper, nicelium, and cobaltium, are coming from the sea. Some of these deposits are placed in depths of 5000 m near Hawaii islands. The most common example of mineral that is obtained by the sea is the sea salt.

1.7.4 Energy production

The energy that is contained in the oceans is vast, not only by oil and gas but from the water it self and its motions.

Many ideas are aiming in this direction, like building dams to capture the water tide and use it when the tide is down to generate electricity with the release of water back to the sea.

Other experiments are dealing with the molecular division of the sea water to get energy and others are trying to use waves and the differences of the water temperature of various depths in order to make an electro-turbine to work.

1.7.5 Human impact on the marine environment

We can say that the sea is very beautiful .Unfortunately, often enough it’s not. The blue water becomes brown and smelly. Barrels with toxic and nuclear waste are rotting on the sea bottom. Deathly chemicals are discharge into the sea every day. The coral reefs are poisoned by fishermen; oil leaks are threatening the endangered species of marine mammals and birds. Sick and dying dolphins and whales are washed out to the shore. The list is very big, and the above examples are a small fraction of what is going on in the sea because of man.

Pollution is when an abnormal concentration of pollutants is present in the water body.

Contamination is an action that can alter the physical and chemical characteristics of the environment. The contamination can be thermal, chemical, or biological. A biological contamination is the discharge of domestic wastes into the sea with high organic and bacteriological loads. The discharge of industrial wastes is often chemical with toxic contaminants. A thermal contamination is when water of higher or lower temperature is discharge into the sea. Coral reefs were destroyed by thermal contaminations from a power station that was using the seawater to cool down the engines of the station and then was discharging the water back into the sea.

The impact that many contaminants have on the living organisms is multiple. They may cause them reproduction malfunctions postponed growth, abnormal physical characteristics etc. Some chemical pollutants like heavy metals and chloride carbohydrates have additional effects and death is observed when the critical concentration is reached. Radio-active wastes were dropped off in barrels in the deep ocean and in some cases radioactive fish were detected before they ended up in a fish market.

The main problem with the contaminants is that they enter the food chain and move upwards (i.e. phytopankton to zooplankton to planktonic fish to carnivorous fish to marine mammals and marine birds).

For example a contamination of chloride carbohydrate, originated from pesticides on land cultivation, ends up, by air or by a river into the sea. The phytoplankton is the first to be contaminated (let's assume that the contamination concentration is 0.1ppm). As the phytoplankton is being consumed by the zooplankton, the zooplankton gets also contaminated, but the concentration goes up to 0.3ppm. The fish that consumes that zooplankton gets contaminated and the concentration reaches the 0.5ppm. The carnivorous fish afterwards is contaminated with a concentration of 1ppm and the primary consumer of the pyramid, the marine mammals and sea birds, reach the striking concentration of 10-25 ppm.

The heavy metals are far more toxic and can cause even death to humans that consume contaminated seafood like bivalves that were present in polluted areas (Minamata Japan 1955-1970).

In many cases the primary pollutant may not be harmful to the organisms but with the process of some bacteria can form other chemical compounds that are very toxic. The organisms that live in polluted waters present a tolerance in low oxygen levels and to high fluctuations of pH .Very few species have these abilities and in polluted waters there are only a few species in great abundances. With this in mind, scientists can determine the degree of pollution according to the organisms that are present in an area and the limitations of the biotic factors.

Good pollution indicators are macrofauna species such as polychaetes (i.e. *Capitella capitata (Figure 33), Scolelepis tuliginosa*, *Audounia tentaculata*) that have the ability to live in polluted waters that other organisms can not survive.

Figure 40: ***Capitella capitata***

So with the presence or not of some organisms scientists can calculate more or less the degree of pollution of an area using statistical programs. In some cases like the oysters (Ostrea edulis) can revile by sight the existence of high concentrations of cooper and zinc in the water that they live because they get a green-blue colour of flesh.

Artificial Marine parks

One way of helping the environment and the fish stocks to recover, is the creation of marine parks, protected from any kind of human activity, where fish and other marine life can grow undisturbed. The only activity that is usually allowed is diving and snorkelling.

The artificial reefs can be created with a variety of materials from old car tires, cement blocks, old cars to old ships. There has been an increase of wild population of fish in places that artificial reefs were developed and that helped the local fisheries in some extend.

1.8 Sustainable Diving

1.8.1 Introduction

The following marine wildlife viewing guidelines are intended to help you enjoy watching marine wildlife without causing them harm or placing personal safety at risk. Please note that these are general guidelines and that the types of wildlife, local habitat conditions, and numbers of people present in an area may require local restrictions or closures to protect the wildlife. Always follow local and species-specific guidelines and regulations when available, and respect the rights of landowners and other wildlife viewers on your travels.

1.8.2 General Guidelines

<u>Learn before you go</u>
Read about the wildlife, viewing sites and local regulations to get the most from your wildlife viewing experience. Many species live only in specific habitats such as estuaries, coral reefs, sand dunes or the open ocean. Seasonal and daily cycles also influence when and where an animal may be located. Research on the internet, buy regional viewing guidebooks, talk with local residents and hire local guides to increase your chances of seeing marine wildlife.

<u>Keep your distance</u>
Use binoculars, spotting scopes and cameras with zoom lenses to get a closer look. Marine wildlife may be very sensitive to human disturbance, and if cornered, they can harm the viewer or leave the area. If wildlife approaches you, stay calm and slowly back away or place boat engines in neutral. When closer encounters occur, do not make sudden moves or obstruct the travel path of the animals - let them have the unhindered "right of way."

Hands off

Never touch, handle or ride marine wildlife. Touching wildlife, or attempting to do so, can injure the animal, put you at risk and may also be illegal for certain species. The slimy coating on fish and many marine invertebrates protects the animal from infection and is easily rubbed off with a hand, glove or foot. Avoid using gloves when diving or snorkeling to minimize the temptation to touch. Remember, wild animals may bite, body slam or even pull you underwater if startled or threatened.

Do not feed or attract marine wildlife

Feeding or attempting to attract wildlife with food, decoys, sound or light disrupts normal feeding cycles, may cause sickness or death from unnatural or contaminated food items, and habituates animals to people. Habituated animals are vulnerable to vessel strikes or vandalism, and can be dangerous to people.

Never chase or harass wildlife

Following a wild animal that is trying to escape is dangerous. Never completely surround the animal, trap an animal between a vessel and shore, block its escape route, or come between mother and young. When viewing from a boat, operate at slow speed, move parallel to the swimming animals, and avoid approaching head-on or from behind, and separating individuals from a group. If you are operating a non-motorized vessel, emit periodic noise to make wildlife aware of your presence and avoid surprise.

Stay away from wildlife that appears abandoned or sick

Some marine animals such as seals, leave the water or are exposed at low tide as part of their natural life cycle -- there may be nothing wrong with them. Young animals that appear to be orphaned may actually be under the watchful eye of a nearby parent. An animal that is sick or injured is already vulnerable and may be more likely to bite. If you think an animal is in trouble, contact the local authorities for advice.

Wildlife and pets don't mix

Wild animals can injure and spread diseases to pets, and in turn, pets can harm and disturb wildlife. For example, wild animals recognize dogs as predators and quickly flee when they see or smell dogs. If you are traveling with a pet, always keep them on a leash and away from areas frequented by marine wildlife.

Lend a hand with trash removal

Human garbage is one of the greatest threats to marine wildlife. Carry a trash bag with you and pick up litter found along the shore and in the water. Plastic bags, floating debris and monofilament line pose the greatest risk to wildlife.

Help others to become responsible wildlife watchers and tour operators

Speak up if you notice other viewers or tour operators behaving in a way that disturbs the wildlife or other viewers, or impacts sensitive habitats. Be friendly, respectful and discrete when approaching others. When operating a boat, lead by example and reduce your speed in areas frequented by marine wildlife, anchor properly and encourage others to do the same. Violations of the law should be reported to local authorities.

It's up to you!

Carry a few copies of these guidelines on your travels and share them with others. When choosing a commercial tour operator, ask if they follow these guiding principles and patronize those businesses that do. After all, protecting and conserving marine wildlife and habitats is everyone's responsibility.

1.8.3 While Scuba Diving

Photograph with Care

Dive carefully as many aquatic creatures are fragile regardless of size. Improper photo techniques can damage sensitive aquatic life and harm fragile organisms with the bump of a camera or tank, swipe of a fin or even the touch of a hand.

Dive Neutral

Camera systems may add weight or be buoyant. Make sure to secure photo and dive equipment and be properly weighted to avoid contact with reefs or other vital habitat. Practice buoyancy control and photography skills in a pool before swimming near sensitive and fragile environments.

Resist Temptation

Avoid touching, handling, feeding, chasing or riding aquatic life. Avoid altering an organism's location to get the perfect shot. Many aquatic creatures are shy and easily stressed. These actions may interrupt feeding, disturb mating or provoke aggression in a normally non aggressive species.

Dive with care

While diving, move slowly and deliberately through the water. Be patient and still while photographing - allow organisms to show their natural behavior for a more significant and meaningful shot.

Buoyancy control

Make sure the difficulty of the dive and the environmental conditions are appropriate for your current skills and comfort level. In this effect you will be able to stabilize yourself underwater with the parameter to avoid any destructions of the environment.

Be informed about the Cyprus laws and regulations and the European Union laws

Be aware of local regulations and protocols regarding behavior around marine mammals and other species before entering the water. These regulations protect creatures and aim to assure their preservation for future generations.

1.8.4 Respect towards the environment – Take some action

Respect the environment, you are a visitor

Consider enrolling in an AWARE - Coral Reef Conservation, Project AWARE Specialty or Underwater Naturalist course to learn sustainable dive techniques and increase knowledge about the environment you're photographing.

Take photos only

Avoid souvenir collection. Nearly everything found in the aquatic realm is alive or will be used by a living creature. Removing specimens such as corals and shells can disturb the delicate balance and quickly deplete dive sites of both their resources and their beauty.

Sharing your images for scientific purposes

Use images for conservation by reporting environmental disturbances or destruction using your photographs as evidence. Assist scientific research and improve resource management by contributing your photos to The Whale Shark Project and other monitoring programs. You may also submit your photos to Project AWARE. Your images have the power to change perspectives and influence conservation.

Conservation and aware with a meaning

Join Project AWARE Foundation, the dive industries leading nonprofit environmental organization. CMAS support helps conserve underwater environments through education, advocacy and action.

2. Organismic Biology

2.1 Classification and Taxonomy

2.1.1 Introduction - The Kingdoms of Life

Classification in biology is the identification, naming, and grouping of organisms into a formal system based on similarities such as internal and external anatomy, physiological functions, genetic makeup, or evolutionary history.

With an estimated 10 million to 13 million species on Earth, the diversity of life is immense. Determining an underlying order in the complex web of life is a difficult undertaking that encompasses advanced scientific methods as well as fundamental philosophical issues about how to view the living world. Among the scientists who work on classification problems are systematists, biologists who study the diversity of organisms and their evolutionary relationship. In a related field known as taxonomy, scientists identify new organisms and determine how to place them into an existing classification scheme.

The classification of living organisms has been controversial throughout time, and these schemes are among those in use today. *Top:* Aristotle’s system distinguished only between plants and animals on the basis of movement, feeding mechanism, and growth patterns. This system groups prokaryotes, algae, and fungi with the plants, and moving, feeding protozoa with the animals. *Center:* The increasing sophistication of laboratory methods and equipment, however, revealed the differences between prokaryotic and eukaryotic cells, prompting a classification system that reflects them. *Bottom:* Most recently, five kingdoms have emerged to take both cellular organization and mode of nutrition into account.

Greek philosopher Aristotle (384-322 BC) grouped life forms as either plant or animal. Microscopic organisms were unknown.

		Plants	Animals				
		Plants	Animals				
		Fungi					

In 1735 Swedish naturalist Carolus Linnaeus formalized the use of two Latin names to identify each organism, a system called binomial nomenclature. He grouped closely related organisms and introduced the modern classification groups: kingdom, phylum, class, order, family, genus, and species. Single-celled organisms were observed but not classified.

Kingdom:		Plantae	Animalia				
Organisms:		Plants	Animals				
		Fungi					

In 1866 German biologist Ernst Haeckel proposed a third kingdom, Protista, to include all single-celled organisms. Some taxonomists also placed simple multicellular organisms, such as seaweeds, in Kingdom Protista. Bacteria, which lack nuclei, were placed in a separate group within Protista called Monera.

Kingdom:		Protista	Plantae	Animalia			
Organisms:		All single-celled organisms, such as amoebas and diatoms, and sometimes simple multicellular organisms such as seaweeds.	Plants	Animals			

In 1938 American biologist Herbert Copeland proposed a fourth kingdom, Monera, to include only bacteria. This was the first classification proposal to separate organisms without nuclei, called prokaryotes, from organisms with nuclei, called eukaryotes, at the kingdom level.

		PROKARYOTES	EUKARYOTES				
Kingdom:		Monera (Prokaryote)	Protista	Plantae	Animalia		
Organisms:		Bacteria	Amoebas, diatoms, and other single-celled eukaryotes, and sometimes simple multicellular organisms, such as seaweeds.	Plants Fungi	Animals		

In 1957 American biologist Robert H. Whittaker proposed a fifth kingdom, Fungi, based on fungi's unique structure and method of obtaining food. Fungi do not ingest food as animals do, nor do they make their own food, as plants do; rather, they secrete digestive enzymes around their food and then absorb it into their cells.

Kingdom:		Monera (Prokaryote)	Protista	Fungi	Plantae	Animalia	
Organisms:		Bacteria	Amoebas, diatoms, and other single-celled eukaryotes, and sometimes simple multicellular organisms, such as seaweeds.	Multicellular, filamentous organisms that absorb food	Multicellular organisms that obtain food through photosynthesis	Multicellular organisms that ingest food	

In 1990 American molecular biologist Carl Woese proposed a new category, called a Domain, to reflect evidence from nucleic acid studies that more precisely reveal evolutionary, or family, relationships. He suggested three domains, Archaea, Bacteria, and Eucarya, based largely on the type of ribonucleic acid (RNA) in cells.

	PROKARYOTES			EUKARYOTES			
Domain:	Archaea		Bacteria	Eucarya			
Kingdom:	Crenarchaeota	Euryachaeota		Protista	Fungi	Plantae	Animalia
Organisms:	Ancient bacteria that produce methane	Ancient bacteria that grow in high temperatures					

A *prokaryote* is a relatively simple unicellular organism, such as a bacterium, characterized by the absence of a nucleus and other specialized cell structures. Scientists distinguish prokaryotes from eukaryotes, which are more complex organisms with cells that contain a nucleus, such as plants and animals.

A *eukaryote* is an organism whose cells contain a nucleus, a saclike structure that encloses the cell's hereditary materials. The presence of a nucleus distinguishes eukaryotes from prokaryotes, those simple, one-celled organisms in which the hereditary material floats free within the cell. Unlike prokaryotes, eukaryotes display a tremendous diversity of form, from complex, single-celled amoebas, diatoms, and dinoflagellates to multicellular plants, animals, and fungi.

The categories of taxonomic order are the following:

Kingdom

Phylum

Class

Order

Family

Genus

Species

2.2 Kingdom Plantae

2.2.1 Introduction

In this chapter we will examine the plantae kingdom and especially the algae. For the purpose of this course we will examine the two kingdoms, animalia and plantae. The Kingdom of Plantae **(Carolus Linnaeus, 1735)** is divided into six Phyla:

1 Phylum: SCHIZOPHYTA

2 Phylum: PHYCOPHYTA

3 Phylum: MYCOPHYTA

4 Phylum: BRYOPHYTA

5 Phylum: PTERIDOPHYTA

6 Phylum: SPERMATOPHYTA

The first phylum ***SCHIZOPHYTA*** is divided into two classes:

1) Bacteria or Schizomycetes
2) Cyanophyceae

The class *Bacteria or Schizomycetes* is then divided into six orders:

1) Pseudomonadales
2) Eubacteriales
3) Clamydobacteriales
4) Actinomycetales
5) Myxobacteriales
6) Spirochaetales

The class Cyanophyceae on the other hand is divided into four orders:

1) Chroococales
2) Pleurocapsales
3) Dermocapsales
4) Hormogonales

The second phylum ***PHYCOPHYTA*** is divided into seven classes:

1) Euglenophyceae
2) Pyrophyceae or Dinoflagellatae
3) Chrysophyceae
4) Xanthophyceae
5) Clorophyceae
6) Pheophyceae
7) Rodophyceae

The class *Clorophyceae* is divided into nine families :

1) Volvocales
2) Chlorococales
3) Ulotrichales
4) Cladophorales
5) Cheatophorales
6) Oedogoniales
7) Siphonales
8) Conjugales
9) Charales

Two representatives of Clorophycaea that we all might know is the *Cladophora prolifera* (*Figure 41*) (due to the problem that the bloom of this algae create during the early 90's in the costal area of Cyprus), and the *Ulva lactuca* (*Figure 42*) that is also named sea lettuce.

Figure 41: ***Cladophora prolifera***

Figure 42: ***Ulva lactuca***

The above is an example of the taxonomic classification of the organisms with the **Carolus Linnaeus, 1735** system that includes two Kingdoms; Plantae (that includes protista, fungi and monera) and Animalia.

This study will not get into detail of the classification system and the above was an example of how it works and to understand the size of the system.

2.2.2 *Algae*

Algae include simple and plant like organisms. Like plants, most algae use the energy of sunlight to make their own food, through a process called photosynthesis. However, algae lack roots, leaves, and other structures typical of a true plant. Algae are the most important photosynthesizing organisms on Earth. They capture most of the sun's energy and produce more oxygen (a by-product of photosynthesis) than all plants combined. Algae form the foundation of most aquatic food webs, which support an abundance of animals.

Algae vary greatly in size and grow in many diverse habitats. Microscopic algae, called phytoplankton, float or swim in lakes and oceans. Phytoplankton is so small that 1000 individuals could fit on the head of a pin. The largest forms of algae are seaweeds that stretch 100 m (300 ft) from the ocean bottom to the water's surface. Although most algae grow in fresh water or seawater, they also grow on soil, trees, and animals, and even under or inside porous rocks, such as sandstone and limestone. Algae tolerate a wide range of temperatures and can be found growing in hot springs, on snow banks, or deep within the polar ice.

The earliest life-forms on this planet are thought to be early ancestors of cyanobacteria, a type of algae formerly called blue-green algae. Fossilized cyanobacteria have been found in rocks more than 3 billion years old. These early algae formed when there was no oxygen in the atmosphere, and scientists theorize that as the algae photosynthesized, they released oxygen as a by-product, which eventually accumulated in the atmosphere. Algae were probably the first organisms capable of photosynthesis and, until the appearance of plants on earth, the only photosynthesizers for billions of years.

Physical Characteristics

With the exception of the cyanobacteria, algae are eukaryotes. An important organelle found in eukaryotic algae is the chloroplast, which contains the light-absorbing pigments responsible for capturing the energy in sunlight during photosynthesis. In most algae the primary pigment is chlorophyll, the same green pigment used in plants. Many algae may also contain secondary pigments, including the carotenoids, which are brown or yellow, and the phycobilins, which are red or blue. Secondary pigments give algae their colourful hues. The cyanobacteria are prokaryotes. As their modern name implies, the cyanobacteria have many characteristics that resemble bacteria.

Like plants, most algae have rigid cell walls composed largely of cellulose. An exception is the diatom, whose cell wall is composed primarily of silica, which provides rigidity and also produces elaborately sculpted patterns of grooves that serve as identifying features. Many eukaryotic algae have whip like appendages called flagella attached to their cell walls.

By beating flagella in a rotary movement, these algae are able to move through water with considerable speed. A few algae that are devoid of rigid cell walls are able to protrude one part of the body ahead of the other to crawl on solid surfaces in an amoeba-like fashion. Algae come in a variety of shapes and forms. The simplest form is the single, self-sufficient cell, such as *Euglena*, dependent only on sunlight and carbon dioxide and minerals from the water. Numerous one-celled algae may clump together to form a colony. Although these cells are attached to one another, each cell within a colony continues to function independently. Still other algae are multicellular organisms. In the simplest multicellular algae, the cells are joined end to end, forming filaments, both branched and unbranched. More complex structures may be shaped like a small disc, tube, club, or even a tree. The most complex algae have highly specialized cells. Some seaweeds, for instance, have a variety of specialized tissues, including a rootlike holdfast, a stipe, which resembles a plant stalk, and a leaflike blade.

While most algae create their own food through photosynthesis, some are unable to photosynthesize. These algae ingest food from external sources by absorbing simple nutrients through the cell membrane. To absorb more complex nutrients, algae that lack rigid walls are able to engulf food particles and digest them. Some of the algae known as dinoflagellates extend a feeding tube, called a peduncle, to suck in food. Other dinoflagellates use special harpoonlike structures to snare their food. Some algae are parasites, living in or on another organism from which they get their food. Some parasitic red algae live off other red algae, and parasitic dinoflagellates live in the intestines of some marine animals, such as copepods and annelids.

Reproduction

Algae reproduce in astoundingly diverse ways. Some reproduce asexually, others use sexual reproduction, and many use both. In asexual reproduction an individual reproduces without combining its genetic material with that from another individual. The simplest form of asexual reproduction is binary fission, in which a unicellular organism simply divides into two new individuals. Some multicellular algae, including Sargassum, reproduce asexually through fragmentation, in which fragments of the parent develop into new individuals. In a similar process called budding, special buds detach from multicellular algae and develop into new individuals, commonly found in Sphacelaria. Many algae produce special cells called spores that are capable of growing into new individuals. If these spores move about using flagella, they are known as zoospores.

In sexual reproduction, genetic material from two sexes is combined. The simplest form of sexual reproduction in algae is conjugation, in which two similar organisms fuse, exchange genetic material, and then break apart. For example, in Spirogyra, which produces both asexually and sexually, two long, unbranched filaments join via conjugation tubes, through which genetic material is exchanged between cells. Most multicellular algae undergo a more complex form of sexual reproduction involving the union of special reproductive cells, called gametes, to form a single cell, known as a zygote.

Many algae incorporate both sexual and asexual modes of reproduction. This is well demonstrated in the life cycle of the alga Chlamydomonas. The mature alga is a single haploid cell—that is, it contains only one set of chromosomes. During asexual reproduction the cell undergoes mitosis, a type of cell division that produces genetically identical offspring. Four daughter cells are created that emerge from the enclosing parent cell as spores. The spores develop into mature haploid cells that are genetically identical to the parent cell.

Certain environmental conditions, such as lack of nutrients or moisture, may trigger the haploid daughter cells to undergo sexual reproduction. Instead of forming into spores, the haploid daughter cells form gametes that have two different mating strains. These two strains are structurally similar and are called plus and minus strains.

Opposite mating strains fuse in a process known as isogamy to form a diploid zygote, which contains two sets of chromosomes. After a period of dormancy, the zygote undergoes meiosis, a type of cell division that reduces the genetic content of a cell by half. This cell division produces four genetically unique haploid cells that eventually grow into mature cells.

Some multicellular green algae, such as Ulva, follow a distinct pattern of reproduction called alternation of generations, in which it takes two generations—one that reproduces sexually and one that reproduces asexually—to complete the life cycle. The two mature forms of the algae, alternating between diploid and haploid individuals, are identical in appearance, or isomorphic. The haploid form, called a gametophyte, undergoes mitosis to produce haploid gametes. These gametes unite to form a diploid zygote, which develops into the diploid form called a sporophyte. The sporophyte undergoes meiosis to form haploid spores that, in turn, form gametophytes.

Not all algae that undergo alternation of generations have haploid and diploid forms that look alike. In the life cycle of the seaweed Laminaria, the gametophyte and the sporophyte are distinct in appearance, or heteromorphic. The Laminaria sporophyte appears as long, bladelike structures that grow on rocks just below the water in intertidal zones. The gametophyte is short, with branched filaments.

Life Cycle of an Alga

The sea lettuce Ulva grows on rocks and other surfaces in shallow seas worldwide. It follows a reproductive pattern called alternation of generations, in which it takes two generations—one that reproduces sexually and one that reproduces asexually—to complete its life cycle. Although mature members of both generations look the same to the naked eye, microscopic chromosomal differences distinguish one from the other. In this diagram, the first generation, which has two complete sets of chromosomes (2n), appears against a white background, while the second generation, which has only one set of chromosomes (n), is visible against a grey background. The first generation, called the sporophyte, undergoes asexual reproduction to form spores, tiny reproductive cells that develop into mature individuals called gametophytes. Gametophytes produce gametes, male and female reproductive cells that fuse together during fertilization to produce a zygote, an organism with two complete sets of chromosomes that matures into a sporophyte, thus completing the life cycle.

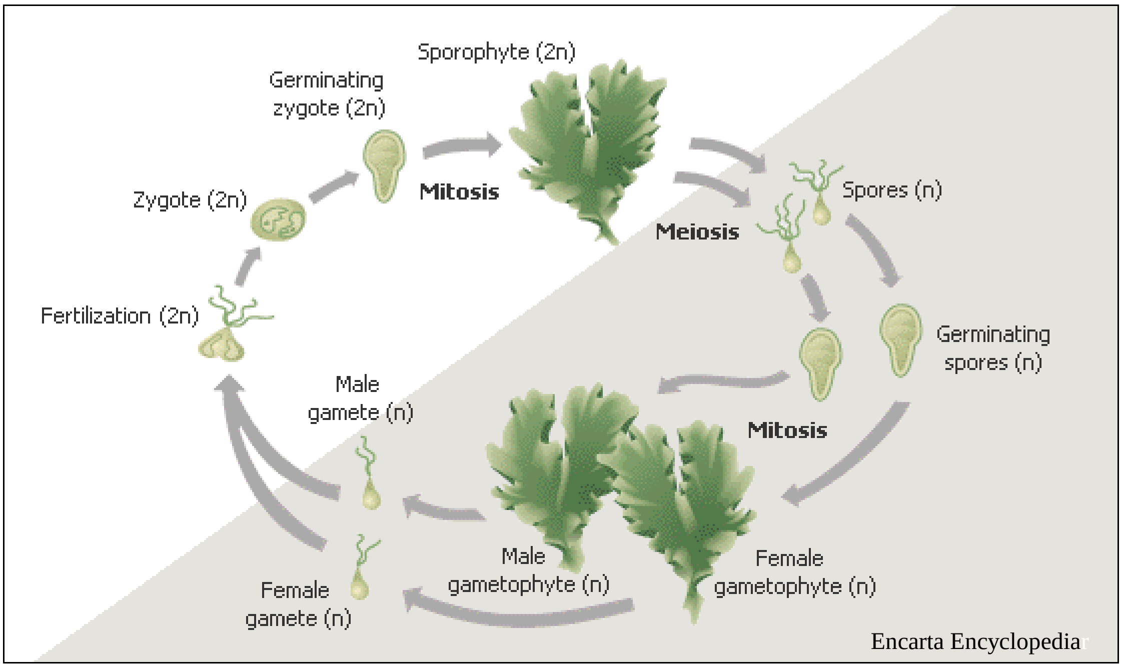


Figure 43: The Life Cycle of Sea-Lettuce *Ulva*

Types of Algae

The most common classification system distributes algae in more than one kingdom. Most algae are classified in the Kingdom Protista, along with other eukaryotic organisms that lack true specialized tissues. The cyanobacteria, however, are classified with the bacteria in the Kingdom Prokaryotae, which consists of prokaryotic organisms. This classification system continues to be intensely debated as new research increases our understanding of the way that these organisms are related. In the following scheme there is some information about the 5 largest groups of algae.

Phylum (Common Name)	Example(s)	Number of Species	Characteristics
Cyanophyceae (Cyanobacteria, formerly blue-green algae)	Chlamydomonas, Anabaena	2,000	Cells lack nucleus and other internal structures. Most common in fresh waters but also found in marine waters and in terrestrial habitats, such as soil, tree trunks, or desert rocks. Some survive in extreme environments reaching 73° C (163° F). Reproduce asexually.
Clorophyceae (Green Algae)	Spirogyra, Ulva, Volvox	8,000	Cells contain plantlike chlorophyll pigments that give algae their grass-green colour. Found in lakes and oceans and on land in soil and on tree trunks. Reproduce via sexual and asexual reproduction.
Rodophyceae Rhodophyta (Red Algae)	Palmaria, Polysiphonia Posidonia .	6,000	Deepest-dwelling algae. Many species contain the red pigment phycoerythrin, which captures light even at great ocean depths. Reproduce via asexual and sexual reproduction. Commercial source of carageenan, a thickener used in ice cream, cosmetics, and medicines; and agar, a gel used in laboratories.
Chrysophyceae Heterokontophyta (Golden-Brown Algae, Brown Algae,and Diatoms)	Vaucheria, Nereocystis, Fragilaria	10,500	Includes some of the largest algae, such as kelp and other seaweeds. Many species are golden-brown from carotenoid pigments. Commercial source of edible foods (kombus and wakame) and algin, a stabilizer used in paints, plastics, and foods. Diatoms form diatomaceous earth, used in aquarium filters, insecticides, and as a polishing agent.
Dinoflagellatae (Dinoflagellates)	Gonyaulax; Pyrodinium	2,000	Unicellular with stiff cellulose plates resembling armor. Many species have ornamentation that resembles horns, spines, or wings. Some species are photosynthesizers, others feed on other tiny organisms or are parasites. Reproduce asexually. Some species undergo a population explosion that forms a red tide that may suffocate fish or produce toxins that are lethal to humans who eat contaminated shellfish. Some species produce bioluminescence.

Red Algae

Red algae form the phylum Rodophyta with approximately 500 genera and 6000 species. Found in warm coastal waters and in water as deep as 260 m (850 ft), red algae species adapt to varied water depths by having different proportions of pigments. Their red colour (*Figure 44*) is due to a red pigment, phycoerythrin, which is well suited to absorb the blue light that penetrates deeper into water than the other colours of light. Red algae found in deep water may be almost black due to a high concentration of phycoerythrin. At moderate depths red algae appear red, while in shallow water they may appear green because a smaller proportion of phycoerythrin is unable to mask the green of chlorophyll. Most red algae are multicellular and come in a variety of shapes, including filaments, which are shaped like a blade of grass, and seaweed shapes. Unlike most other eukaryotic algae, red algae have no flagella.

Figure 44: Red Algae

Red Coralline Algae belong to the phylum Rodophyta. The red coralline algae can incorporate calcium carbonate into their cell walls, giving their body a rigid, segmented appearance and texture. Coralline algae are important members of coral reefs, producing new material and cementing together other organisms (*Figure 45*).

Figure 45: Mediterranean Algae - *Corallina elongata* Ellis et Solander

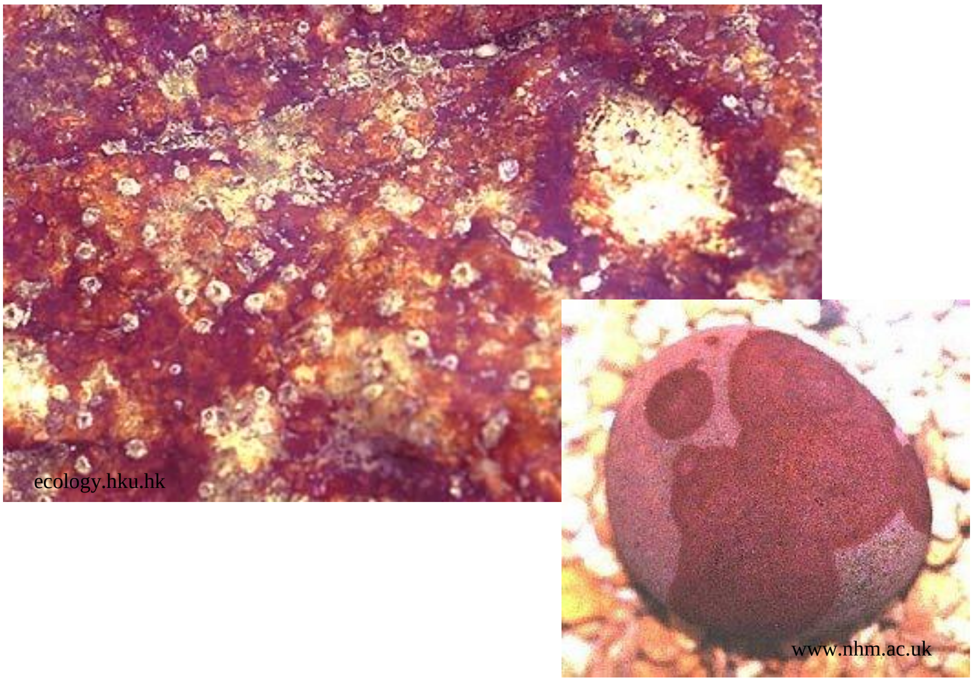


Figure 46: Calcareous Red Algae - *Hildenbrandia*

Red algae use diverse strategies to reproduce, including fragmentation and spore production. One unusual strategy, found in many species including those in the genus Polysiphonia, involves the alternation among three generations. A diploid sporophyte produces diploid spores that germinate into another diploid sporophyte that looks completely different from the first one. Meiosis occurs in the second sporophyte, producing haploid spores that germinate into gametophytes. Surprisingly, in some species, the gametophytes look nearly identical to the second sporophyte.

Almost all red algae live in marine habitats, although some species are found in fresh water or damp soil. Many types of seaweed are red algae, typically found growing along the coast and attaching firmly to the seafloor using a root like holdfast.

Green Algae

Green algae form the phylum Chlorophyta and are named for their green chloroplasts, which are similar in composition to the chloroplasts found in land plants. Green algae range in shape from unicellular plankton that grows in lakes and oceans to colonial filaments of pond scum to leaf like seaweeds that grow along rocky and sandy intertidal areas. Some green algae also live on tree trunks and soil. Several green algal species are symbiotic, forming lichens with fungi or living with corals. Green algae may also be found inside freshwater sponges, giving the sponges a bright green colour, and in permanent snow banks, where a secondary pigment masks the chlorophyll and turns the snow a reddish colour.

More than 500 genera and 8000 species of green algae have been identified. Some familiar green algae include the genus Spirogyra, known for its spiral-shaped chloroplasts, and the desmids, recognized by their characteristic shape—two symmetrical halves, joined by a small bridge. The green algae known as Stoneworts often grow several feet in length. Their name comes from calcium crusts that make them feel like stone.

Figure 47: Green Algae

The green algae, shown here exposed at low tide, are one of 6,000 to 7,000 species of plants belonging to the phylum Chlorophyta. Organisms in this phylum may appear as single cells, amorphous sheets, or collections of long filamentous strands. Although able to survive in marine and fresh waters, damp soil, or snow and ice, most species are found in freshwater habitats.

Most green algae reproduce both sexually and asexually. Alternation of generations, where algae alternate between gametophyte and sporophyte generations, is common among the multicellular green algae.

<u>Golden-Brown Algae, Brown Algae, and Diatoms</u>

Golden-brown algae, brown algae, and diatoms form the large and complex phylum Heterokontophyta, with organisms ranging in size from a fraction of a millimeter to more than 100 m (300 ft) long. Heterokontophyta have carotenoid secondary pigments that tend to mask the green of the primary chlorophyll pigment, giving them a golden or golden-brown appearance. Flagellated cells in this phylum have two types of flagella: One is smooth, while the other has two rows of stiff hairs running down opposite sides of the flagellum. Algae in this phylum typically have an eyespot that can detect light.

Figure 48: Giant Kelp

The largest of all marine plants, the giant kelp (*Figure 48*) grows to a length of over 60 m (200 ft). Commonly called seaweed, the giant kelp and other kelp species differ from the more advanced flowering plants in lacking true leaves, stems, roots, and a vascular system for transporting water and nutrients. The giant kelp and other kelp species are a food staple in Japan and other areas. Substances extracted from kelp are used in the manufacture of ice cream, cosmetics, and other materials.

The golden-brown algae, also known as the yellow-brown algae, include about 200 genera and 1000 species that receive their characteristic colouring from the carotenoid pigment fucoxanthin. These algae are mostly unicellular or colonial, swimming or floating in lakes and oceans as phytoplankton. In shallow ponds that dry up in summer or freeze completely in winter, golden-brown algae survive by forming protective cysts that can withstand the harsh conditions. When favourable conditions return, the algae emerge from the cysts. Like so many other algae, the unicellular algae tend to reproduce through fission, while the multicellular and colonial forms reproduce either through fragmentation or through spore production.

Diatoms are best known for their glasslike cell wall made of silica. The cell wall has ornate ridge patterns. A diatom consists of two overlapping halves that fit together like a shoebox or a petri dish, with the lid slightly larger and fitting over the base. During asexual cell division, the two glass walls separate and serve as the lids for two new glass bases. The new diatom that grew from the lid is the same size as the parent diatom, while the diatom that grew from the smaller base is slightly smaller than its parent. Sexual reproduction occurs when the succeeding generations shrink to a critical size. These smallest diatoms form gametes that shed their glass walls. Upon fertilization, the zygotes absorb water to swell and then secrete new, full-sized silica coverings.

Diatoms are significant components of the phytoplankton, tiny, floating, photosynthetic organisms that form the base of aquatic food chains

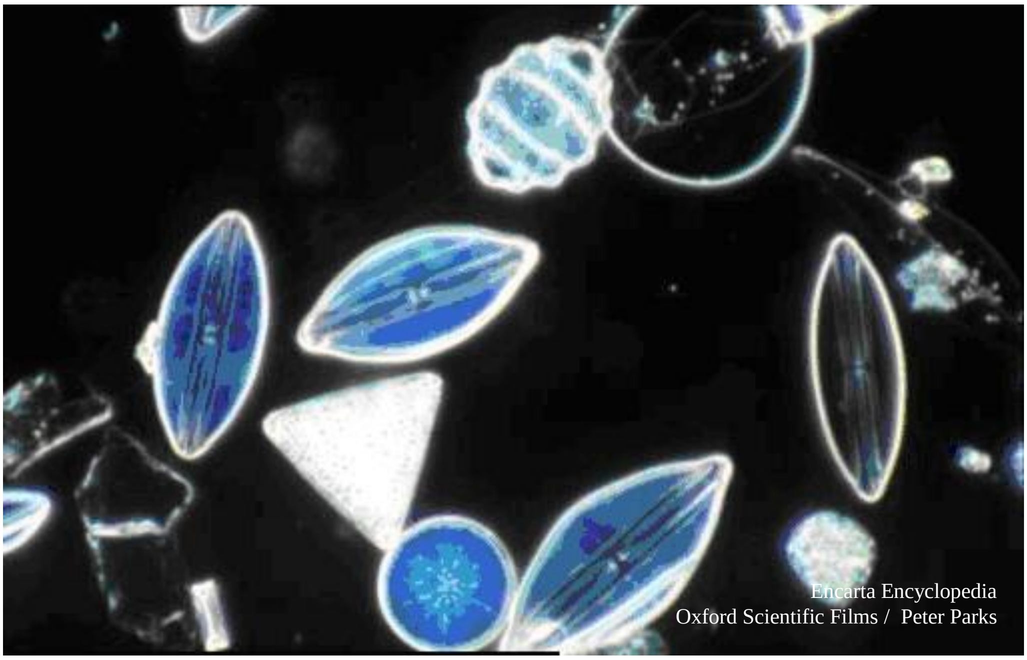


Figure 49: Various Shapes of Diatom

A very large class with more than 250 genera and 8000 species, diatoms are found floating in freshwater and seawater, growing attached to the seafloor, or growing on soil. The cells are either unicellular or form colonial chains of round cells. When an organism dies, its silica cell wall remains intact. Over time these shells have accumulated to form layers of soft rock in some geologic formations. This diatomaceous earth is mined and quarried for use in filters and bleaching agents, as an abrasive powder for cleaning and polishing metals, and for insect pest control (the broken cell walls of silica tear the insect gut).

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Dinoflagellates

Dinoflagellates of the phylum Dinoflagellata are mostly unicellular organisms that may be covered with stiff cellulose plates that resemble armoured helmets. Many species have unusual ornamentation, such as horns, spines, or wings. A narrow groove encircles the armour, and a second groove runs perpendicular to the first groove. Flagella beat within these grooves, causing the dinoflagellates to spin like tops as they move through the water. Most of the 130 genera and 2000 species in this phylum are planktonic and live in saltwater, although there are many freshwater planktonic representatives as well. Many dinoflagellate species lack chloroplasts and are dependent on other species for their food. Some are parasites, but most are carnivores, using special harpoon-like structures called trichocysts to capture other organisms to eat. In contrast, several of the photosynthetic species live inside the tissues of invertebrate animals, such as corals and giant clams. These dinoflagellates share the food they photosynthesize with their host, and in return, receive protection and some nutrients.

Figure 50: Ceratium-dinoflagellate (Photo: Peter Parks © 2001)

The dinoflagellates are the second most important group of phytoplankton, responsible for producing energy in the ocean food chain. They have a whip-like structure called a flagellum that acts as an organ of locomotion, and the organisms demonstrate both plant and animal traits. Dinoflagellates can reproduce rapidly, or bloom, and certain species bloom in toxic red tides that kill fish and contaminate shellfish.

Under favorable environmental conditions, some dinoflagellate species experience population explosions, known as blooms. If the species involved in the bloom have red pigments, their concentration can be high enough to turn the seawater red, forming red tides. Dinoflagellate blooms can be quite destructive. During the night when photosynthesis halts, such a high concentration of individuals can deplete the oxygen in the water, suffocating fish. Some dinoflagellates release toxins, some of which kill fish, while other toxins are passed up the food chain until they reach humans, where they can cause paralytic shellfish poisoning and ciguatera fish poisoning. Recently, the dinoflagellate Pfiesteria piscicida has caused fish, shellfish, and human disease in estuaries of the southeastern United States.

<u>Cyanobacteria</u>

Unlike other algae, the cyanobacteria are prokaryotes; single-celled organisms with characteristics that cause biologists to debate whether they are really algae or bacteria. Cyanobacteria are found nearly everywhere, occurring in typical aquatic and terrestrial habitats as well as in such extreme sites as hot springs with temperatures as high as 71° C (160° F) and crevices of desert rocks. Cyanobacteria make up the phylum Cyanophyta, and this phylum contains about 150 genera and 2000 species worldwide. Like other bacteria, cyanobacteria do not have organelles such as nuclei, mitochondria, or chloroplasts. Cyanobacteria are distinguished from bacteria by the presence of internal membranes, called thylakoids, that contain chlorophyll and other structures involved in photosynthesis. While higher plants have two kinds of chlorophyll, called a and b, cyanobacteria contain only chlorophyll a. Cyanobacteria colour varies from blue-green to red or purple and is determined by the proportions of two secondary pigments, c-phycocyanin (blue) and c-phycoerythrin (red), which tend to mask the green chlorophyll present in the thylakoids.

Figure 51: Cyanobacteria (formerly blue-green algae)

Cyanobacteria are among the most ancient organisms on Earth. These photosynthetic organisms can be single-celled, connected in a filamentous form (*Figure 51*), or arranged in simple colonies. Cyanobacteria are capable of enduring a wide variety of environmental conditions ranging from freshwater and marine habitats to snowfields and glaciers. They are capable of surviving and flourishing even at extremely high temperatures.

Cyanobacteria reproduce asexually by binary fission, spore production, or fragmentation, forming singular cells, colonies, filaments, or gelatinous masses. Although most cyanobacteria lack flagella and are non-motile, filamentous forms such as *Oscillatoria* rotate in a screw-like manner, and the gelatinous forms glide along their slimy mucus.

Cyanobacteria may be both beneficial and harmful to humans. Some act as natural fertilizers in some habitats, especially rice paddies, whereas others produce toxins. Mild cyanobacteria toxins in lakes and oceans cause a rash known as swimmer's itch, while powerful neuromuscular toxins released by other cyanobacteria can kill fish living in the water or the animals that drink the water. In certain conditions, cyanobacteria may form dense blooms, which may produce toxins that make seafood poisonous to humans. Even if the cyanobacteria do not produce toxins, blooms can cause water to have an unpleasant taste and odour.

Algae Uses

Human ingenuity has found many uses for algae. Algae provide food for people and livestock, serve as thickening agents in ice cream and shampoo, and are used as drugs to ward off diseases. More than 150 species of algae are commercially important food sources, and over $2 billion of seaweed is consumed each year by humans, mostly in Japan, China, and Korea. The red alga Porphyra, called nori, is the most popular food product. After harvesting, nori is dried, pressed into sheets, and used in soups, sauces, sushi, and condiments. Algae are considered nutritious because of their high protein content and high concentrations of minerals, trace elements, and vitamins. The high iodine content of many edible algae may contribute to the low rates of goitre observed in countries where people frequently eat algae.

In coastal areas of North America and Europe, seaweeds are fed to farm animals as a food supplement. Cyanobacteria species that are high in protein, such as *Spirulina*, are grown commercially in ponds and used mostly as a health food and cattle dietary supplement. Seaweeds also are applied to soils as a fertilizer and soil conditioner, as their high concentrations of potassium and trace elements improve crop production. Some species of cyanobacteria can turn atmospheric nitrogen into ammonia, a form that can then be used by plants as a nutrient. Farmers in tropical countries grow cyanobacteria in their flooded rice paddies to provide more nitrogen to the rice, increasing productivity as much as tenfold.

Algae can also serve as indicators of environmental problems in aquatic ecosystems. Because algae grow quickly and are sensitive to changing environmental conditions, they are often among the first organisms to respond to changes. For example, depletion of the diatom community in the Florida Everglades provided strong evidence of phosphorus-related changes in this unique ecosystem. Algal blooms may deplete oxygen concentrations in water and smother fish and plant life, as well as prevent light penetration for algae at lower depths, preventing photosynthesis.

Figure 52: Clear Water Representatives

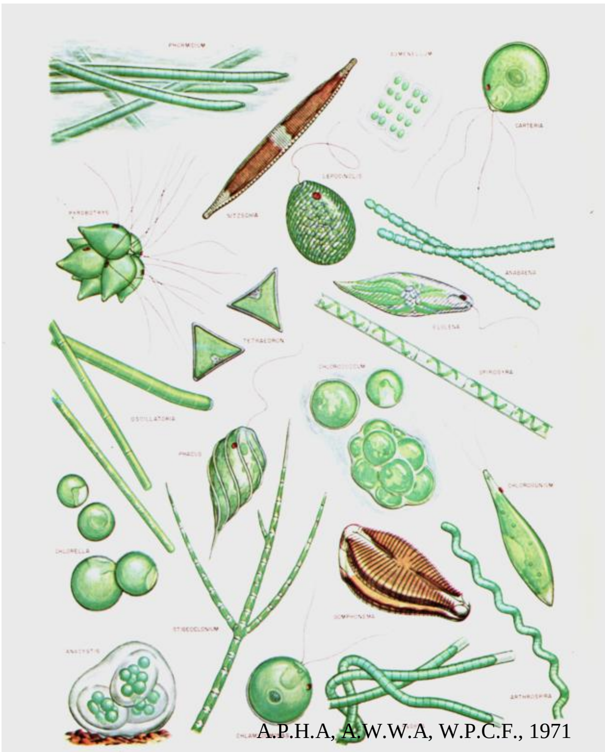


Figure 53: Polluted water representatives

2.3 Kingdom Animalia

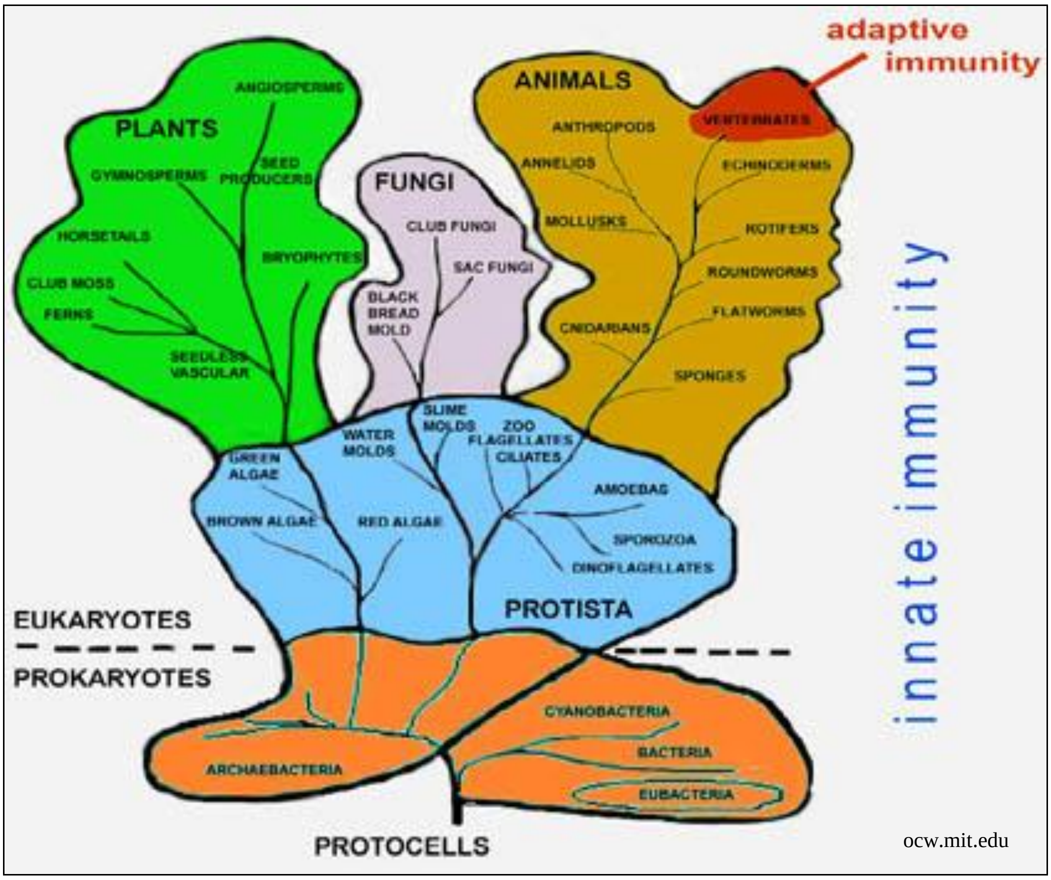


Figure 54: Phylogenetic Tree of Life

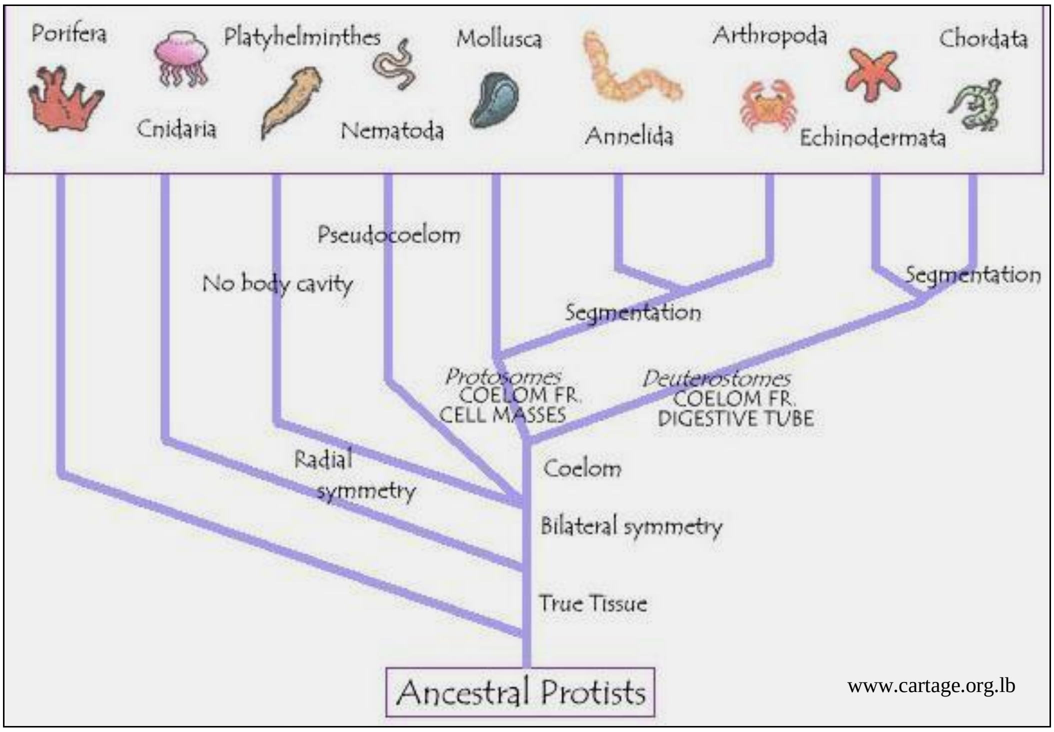


Figure 55: Phylogenetic Tree of Kingdom Animalia (showing the major characteristics that distinguish each phylum)

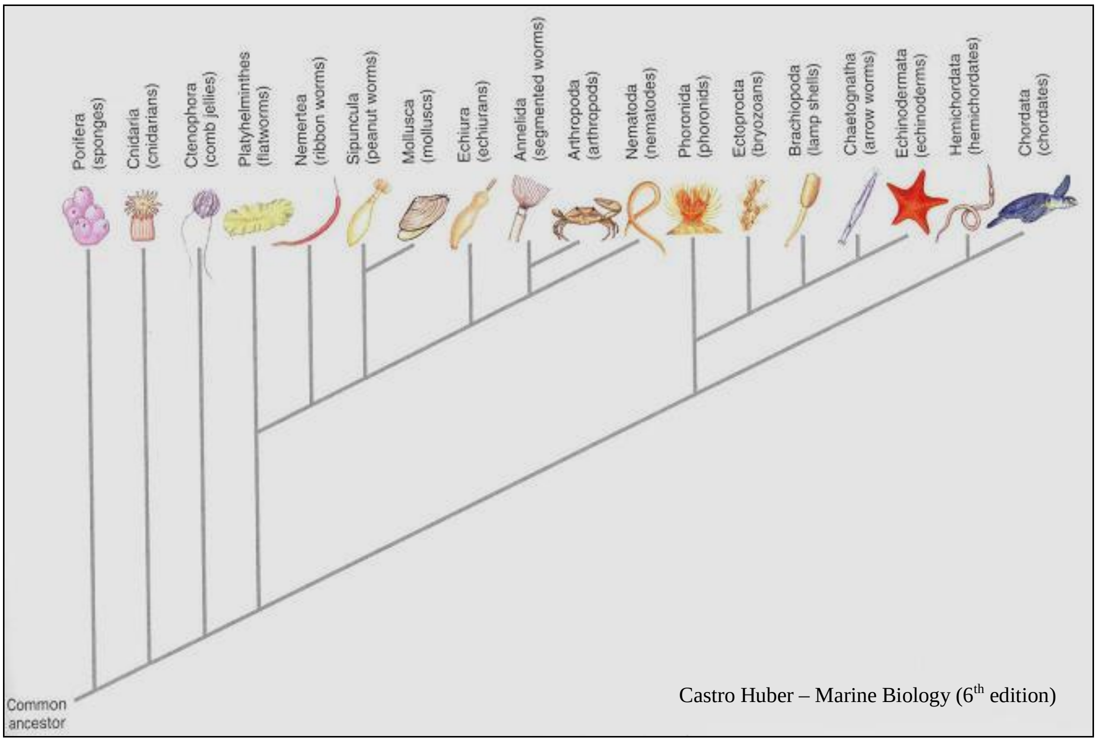


Figure 56: Phylogenetic relationships among the major animal phyla

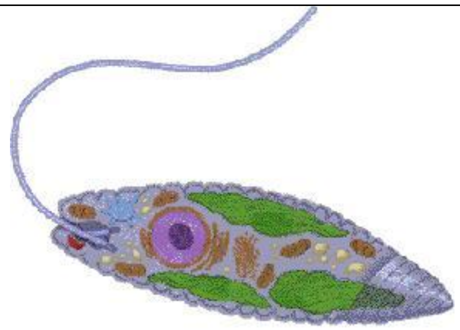
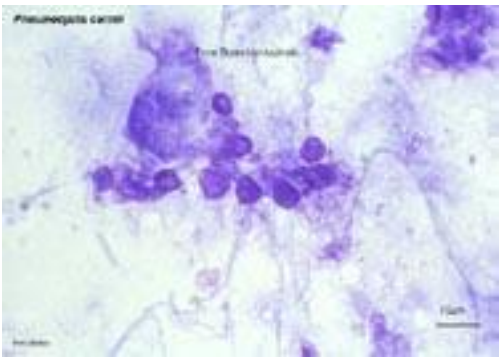
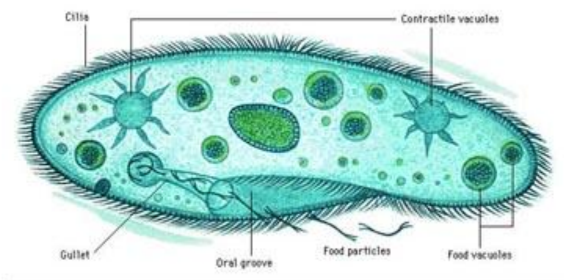
2.3.1 Protozoa

Protozoa are single-celled eukaryotes (organisms whose cells have nuclei) that commonly show characteristics usually associated with animals, most notably mobility and heterotrophy. They are often grouped in the kingdom Protista (*Figure 54*) together with the plant-like algae and fungus-like water molds and slime molds. In some newer schemes, however, most algae are classified in the kingdoms Plantae and Chromista, and in such cases the remaining forms may be classified as a kingdom Protozoa. The name is misleading, since they are not animals (with the possible exception of the Myxozoa).

Protozoa have little or no differentiation into tissue systems. Several phyla are commonly recognized. They include flagellated *Zoomastigina*, many species of which live as parasites in plants and animals; the amoeboid *Sarcodina*, which includes the *Foraminifera* and *Radiolaria* both important components of the plankton; ciliated *Ciliophora*, many with specialized structures suggesting the mouth and anus of higher organisms; *Cnidosporidia*, parasites of invertebrates, fish, and a few reptiles and amphibians; and *Sporozoa*, many species of which are parasites of animals (including humans). More than 20,000 species are known, including such familiar forms as paramecium and amoeba (*Table 5*).

Most species are found in aquatic habitats such as the oceans, lakes, rivers, and ponds. They vary in length from 2 to 70 micrometers. Protozoa obtain their food by ingesting bacteria, waste products of other organisms, algae, or other protozoa. Most species are motile, either by whip-like structures called flagella, hair-like structures called cilia, or amoeboid motion, a streaming type of movement involving the formation of pseudopods (footlike extensions).

Table 5: Protozoan have traditionally been divided on the basis of their means of locomotion, although this is no longer believed to represent genuine relationships

Protozoa	Characteristics	Image
Flagellates	Flagellates move with flagella. Image: *Euglena*, has green chloroplasts.	 www.okc.cc.ok.us
Amoeboids	Amoebas move with pseudopodia.	 www.okc.cc.ok.us
Sporozoans	Sporozoans are parasites that complete part of their life cycle inside of cells of a host organism. During much of their life cycle they are unable to move by themselves. Image: *Pneumocystis carinii.* It often causes pneumonia in AIDS patients.	 www.okc.cc.ok.us
Ciliates	Ciliates are covered with cilia that are used for movement. Image: *Paramecium*	 www.okc.cc.ok.us

These organisms are part of a group known as the zooplankton. The prefix “zoo” implies that they are animal-like, but the “plankton” part of their name tells you that they drift in the water. They do not swim as strongly as fishes, so they mostly are carried by the currents and the tides.

There are two major groups of zooplankton: holoplankton and meroplankton. Holoplankton spends its entire live as plankton. Meroplankton is typically the larval stages of organisms that can swim against the currents once they mature. While they are in their larval stage they are referred as *plankton*, because of their inability to swim against the ocean currents. In other words, meroplankton comprises by organisms that spend only the early part of their lives being plankton. Most of the zooplankton is microscopic but there are a few planktonic species that are quite large, for example an amoeba (*Figure57*).

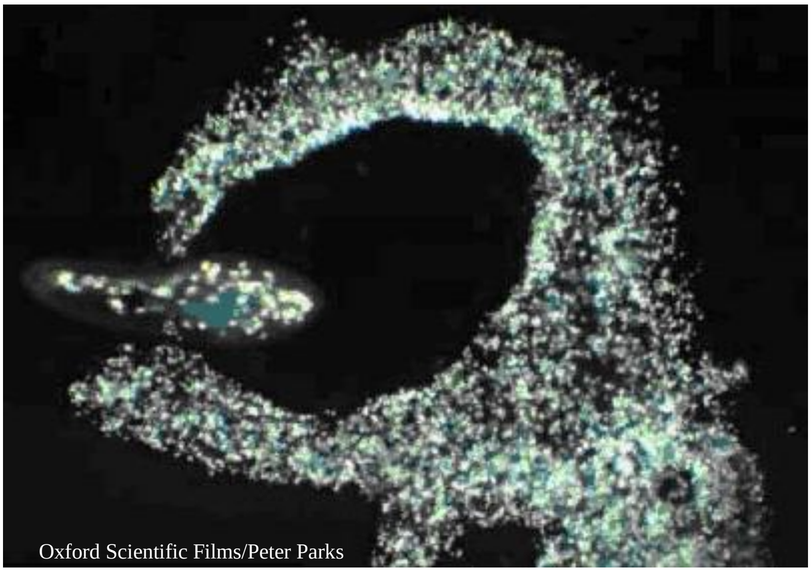


Figure 57: Amoeba engulfing a Paramecium

An amoeba, a single-celled organism lacking internal organs, is shown to be approaching a much smaller paramecium, and begins to engulf it with large pseudopodia flowing out of its cytoplasma. Once the paramecium is completely engulfed, a primitive digestive cavity, called a vacuole, forms around it. In the vacuole, acids break the paramecium down into chemicals that the amoeba can diffuse back into its cytoplasm for nourishment.

Figure 58: Ciliated Protozoan

Ciliated protozoans are single-celled organisms that are propelled by minute, hair-like projections called cilia (*Figure 58*). In addition to locomotion, cilia also create currents that help sweep food particles into a small depression in the body surface through which food is ingested. Ciliated protozoans can be found in water or soil and in parasitic or symbiotic relationships with other organisms. In soils, ciliated protozoans function as decomposing organisms, breaking down organic matter into substances that can be used by other organisms.

2.3.2 Invertebrates

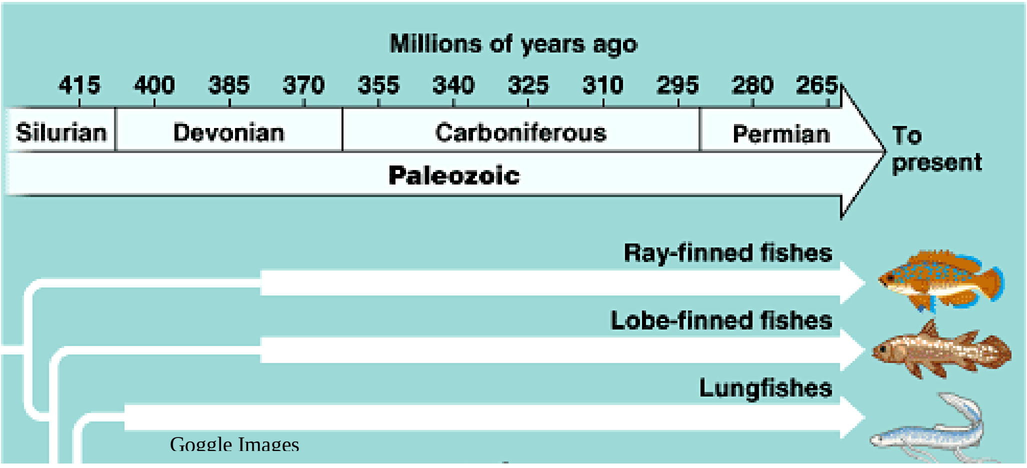
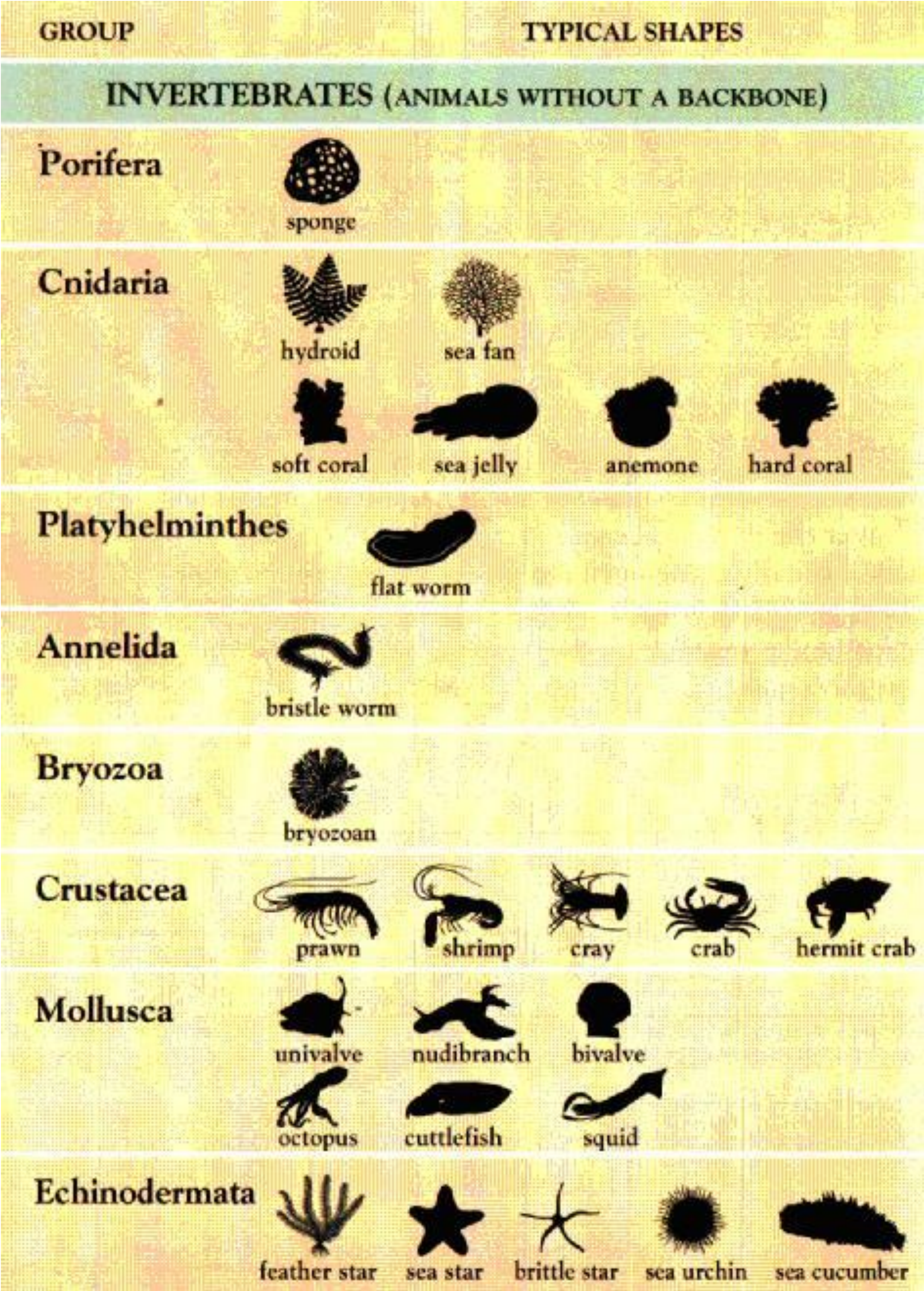


Figure 59: Appearance of a few groups of fish from the Paleozoic era to present

In the previous chart we can see a simple way of dividing organisms such as fish into various groups. The division is based on the presence or absence of the backbone and the backchord.

Almost all animal fall into one of two groups: the vertebrates who have a backbone running the length of their body and the invertebrates that do not have one. The vertebrates are often larger and have more complex bodies than the invertebrates. However, there are many more invertebrates than vertebrates.


GROUP
TYPICAL SHAPES
INVERTEBRATES (ANIMALS WITHOUT A BACKBONE)
Porifera
sponge
Cnidaria
hydroid
sea fan
soft coral
sea jelly
anemone
hard coral
Platyhelminthes
flat worm
Annelida
bristle worm
Bryozoa
bryozoan
Crustacea
prawn
shrimp
cray
crab
hermit crab
Mollusca
univalve
nudibranch
bivalve
octopus
cuttlefish
squid
Echinodermata
feather star
sea star
brittle star
sea urchin
sea cucumber

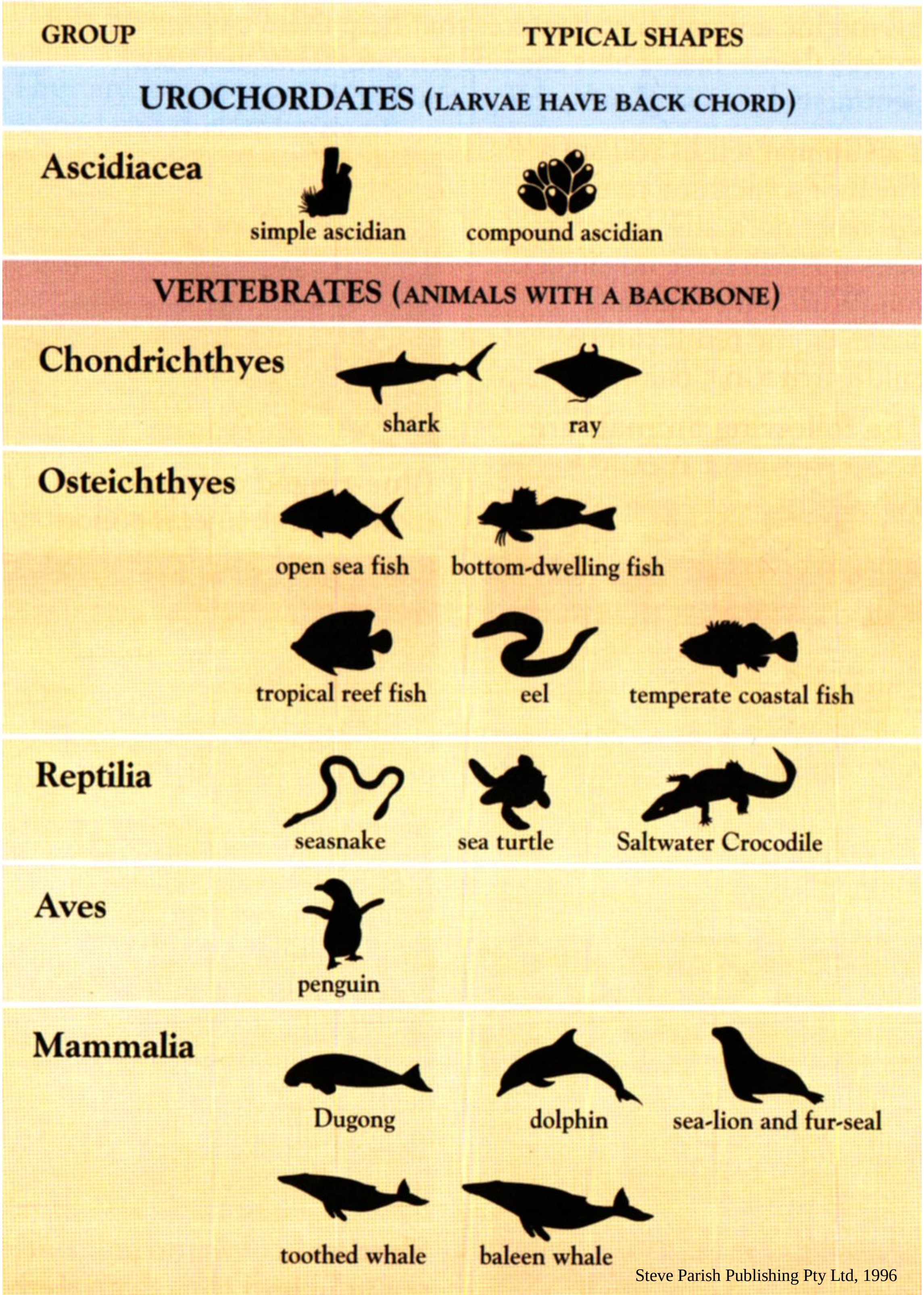


Figure 60: Guide to common animal groups

A. Phylum Porifera

Porifera are commonly referred to as sponges. An early branching event in the history of animals separated the sponges from other metazoans. Fossil sponges are among the oldest known animal fossils, dating from the Late Precambrian. Since then, sponges have been conspicuous members of many fossil communities; the number of described fossil genera exceeds 900. The approximately 5,000 living sponge species are classified in the phylum Porifera, which is composed of three distinct groups, the Hexactinellida (glass sponges), the Demospongia, and the Calcarea (calcareous sponges).

Sponges are mainly marine, with a few freshwater species. They are abundant throughout the world and especially in tropical waters, where they, and other invertebrates such as corals, are important in the formation of calcareous deposits.

All the *Calcarea* are marine, with skeletal spicules composed of calcium carbonate. The *Hexactinellida* are found in the deep sea; because their skeleton is made of silica in beautiful six-pointed arrangements, they are called glass sponges. The *Demospongiae* (95 percent of all living species) include the few freshwater forms. Their skeletal network is made of spongin, a rather flexible protein material (that of a bath sponge made from a real sponge), and in some species silica spicules are also present. One demospongiae is the carnivorous Mediterranean sponge, *Asbestopluma hypogea*. The Sclerospongiae have a combination of a thin silica and spongin skeleton that surrounds a larger, central calcareous skeleton. The purple and yellow tube sponge displays one of the many different body forms that it's typical in sponges (*Figure 61*).

Figure 61: Purple and Yellow Tube Sponge

Sponges can grow in an amazing variety of shapes, sizes, and colors, and can range in size from less than a few centimeters to many meters high! Even though they are considered animals, they do not move because they are attached to a bottom surface which is often called a substrate.

The interior body cavities of sponges provide shelter for a variety of small crabs, sea stars, and other marine invertebrates. They have many pores, holes, and channels on their bodies. This is why their phylum is called “Porifera,” which means “pore-bearing.” These pores, holes, and channels allow water to enter and move through a series of canals within the organism. Once inside, suspended plankton and bits of organic material are filtered out and consumed.

Reproduction occurs either sexually or asexually. In the former case, the sponges are usually hermaphroditic but cross-fertilize one another. Eggs and sperm unite to produce a free-swimming larva that settles on a new surface. Reproduction can also occur by small, internal asexual buds called gemules, each one able to give rise to a new sponge. Sponges have also been of great interest to developmental biologists because sponges are able to reconstitute themselves if their cells are separated into a suspension.

Six species of sponge are considered marketable, with numerous varieties. The skeleton of these sponges is composed only of spongin tissue and contains no hard spicules. The Mediterranean sponges are the softest and the best ones; those of the Red Sea are next in quality, and the West Indian species are coarser and less durable. The sponges are gathered by divers, and the living tissue is allowed to decompose. The remaining skeleton of spongin fibbers is then washed, bleached, sometimes dyed, and cut into the familiar blocks seen on store counters.

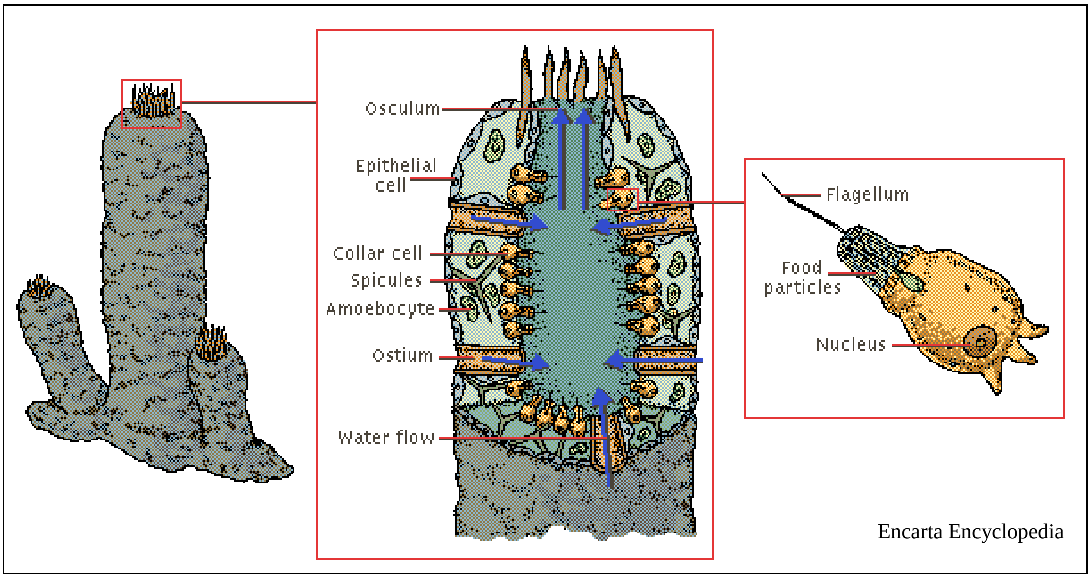


Figure 62: Generalized Anatomy of a Sponge

The structural components of a sponge include the outer, protective layer of cells and the spiny spicules, which form the skeleton. Sponges feed off microorganisms in the water that flow in through small openings known as ostia. The flagella on the inner layer of cells move the water through the sponge, absorbing food particles as the water flows past. Eventually the water exits through the osculum, the cavity at the top of the sponge.


Giorgos Panagi


Giorgos Panagi

Figure 63: Various shapes and forms of sponges

B. Phylum Cnidaria (Jellyfish, Corals and Hydroids)

Cnidaria, also known as coelenterates because they contain a coel[22], is a diverse group of aquatic, invertebrate animals armed with microscopic stinging structures. Cnidaria make up the phylum Cnidaria, which encompasses more than 9,000 species, including corals, hydras, jellyfishes, Portuguese man-of-war, and sea anemones. Cnidarians live in all oceans, and a few species inhabit fresh water.

There are two very notable characteristics of organisms in this phylum. First, they have specialized tissues that perform specific functions. This is different from the sponges, which have some specialized cells but not specialized *tissues*. Second, they have the ability to move in a more intricate way than the sponges. Although they are not very good swimmers (some rarely change their location once they have settled), they are able to perform movements to trap prey and respond to stimuli.

Cnidaria have many shapes and they range in size from microscopic hydrozoans to jellyfishes that are 2 m (7 ft) in diameter with tentacles 30 m (100 ft) long. Although they have various physical characteristics, all cnidarians exhibit radial symmetry; that is, similar body parts radiate from a central mouth. Six to ten tentacles surround a cnidarian's mouth to aid in the capture and ingestion of the animals they feed on.

Cnidaria have a saclike body with a single mouth opening. The body wall is composed of two sheets of cells—an inner layer (the endoderm) and an outer layer (the ectoderm). A gelatinous mesoglea layer holds these two cell layers together. Cnidaria are invertebrates (animals that lack a backbone), but the ectoderm of some cnidarians, including hard corals and some hydrozoans, may form a skeleton-like structure externally. The ectoderm of other cnidaria, such as some soft corals, forms an internal skeleton-like structure. The ectoderm and endoderm layers contain contractile fibers that enable the animal to move about. Invertebrate zoologists believe these fibers are primitive versions of the muscle cells found in more complex animals.

Cnidaria lack internal organs and they do not have digestive, circulatory, or respiratory systems. Secretions from endoderm cells digest food within the central

[22] coel (seel): It is a large body cavity found in cnidarians

body cavity and endoderm cells also distribute nutrients and dissolved oxygen to all parts of the body. Lacking an anus, cnidarians discharge waste matter through the mouth opening.

Scientists divide cnidarians into four classes: Hydrozoa, Scyphozoa, Cubozoa, and Anthozoa. They base this division partly on whether the polyp or medusa is more conspicuous during an animal's life cycle (*Figure 64*).

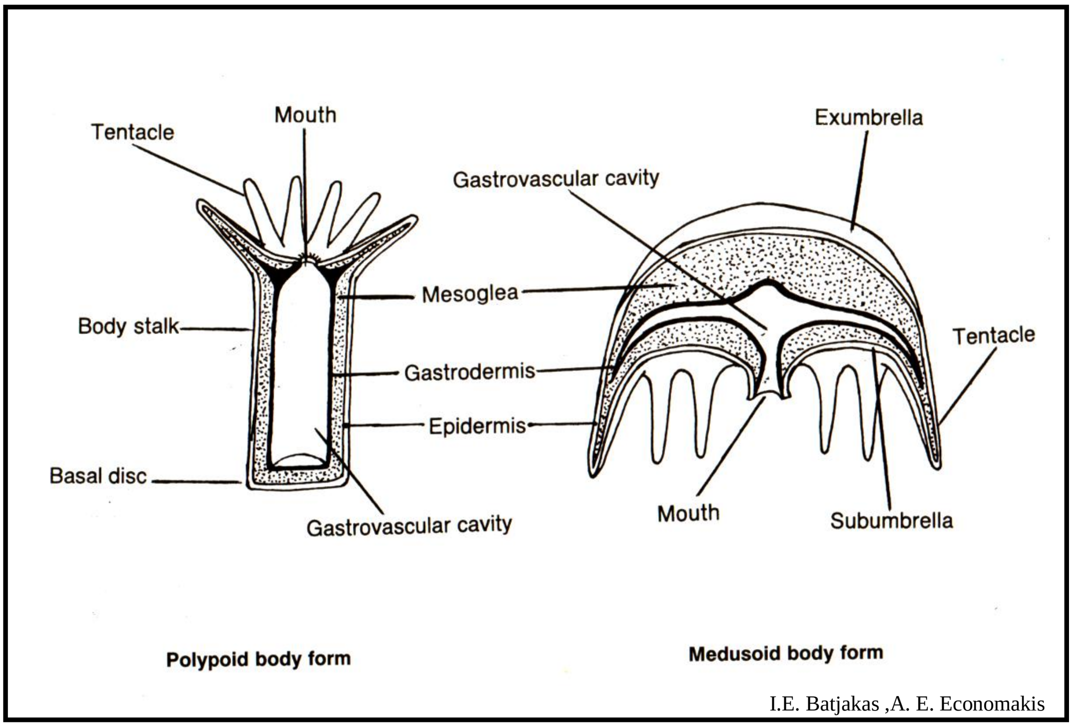


Figure 64: The two phases of a cnidarian's life cycle; the polypoid and medusoid body forms

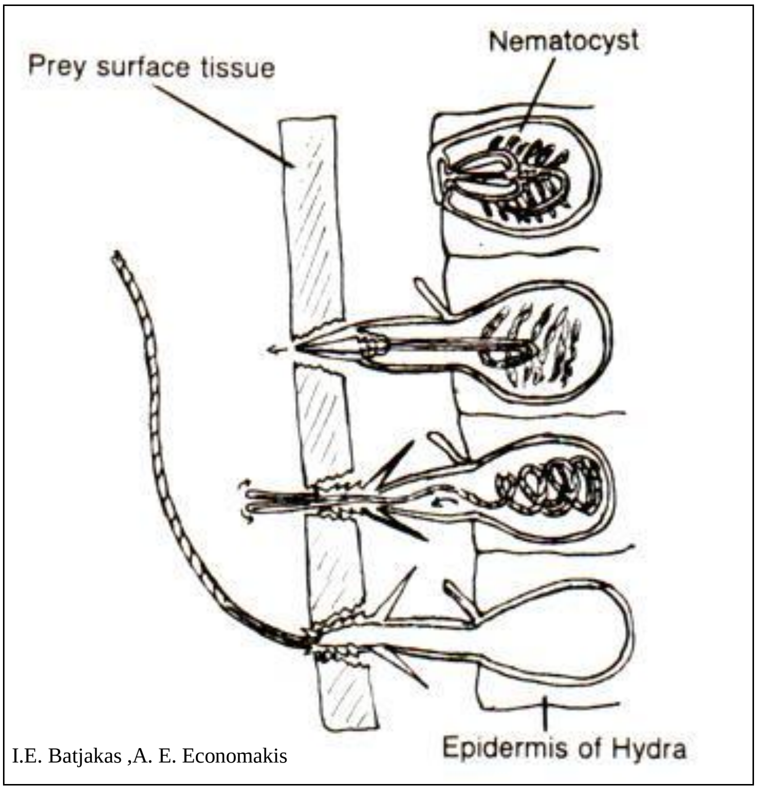


Figure 65: Discharge of a cnidarian nematocyst into prey

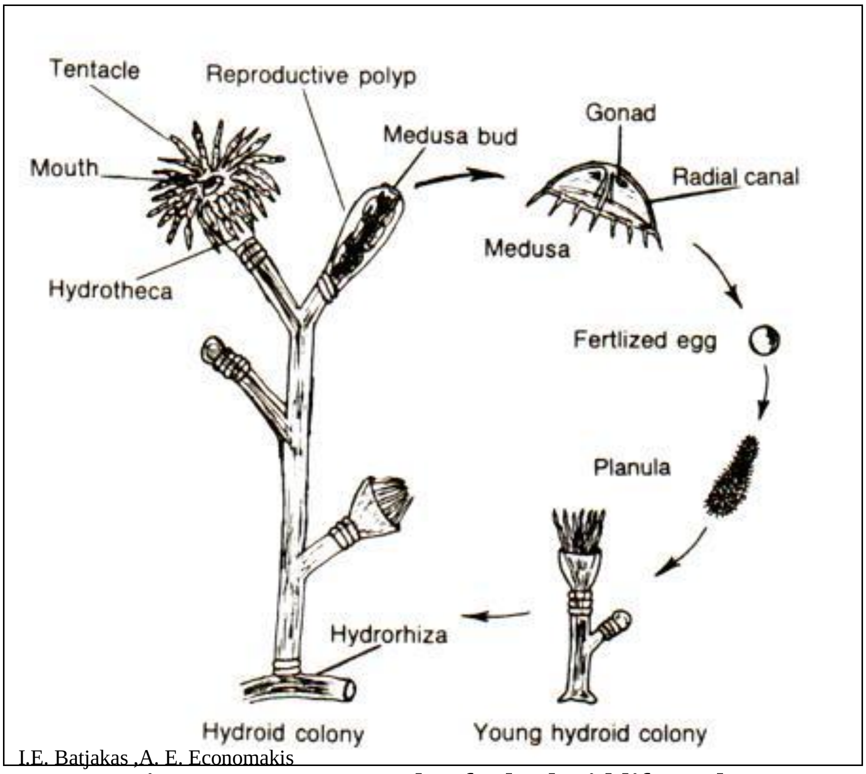


Figure 66: An example of a hydroid life cycle

Hydrozoa (hydroids)

In hydrozoa, the polyp phase dominates in the animal's life cycle. Most hydrozoa polyps reproduce by budding to form a polyp colony that fastens to solid objects such as rocks and pilings. Some hydrozoa polyps also bud to form a medusa, which is generally small and lives only a short time (*Figure 66*). This class comprises about 3,100 species, including the freshwater hydra (which lacks a medusa stage), the Portuguese man-of-war, and the fire coral.

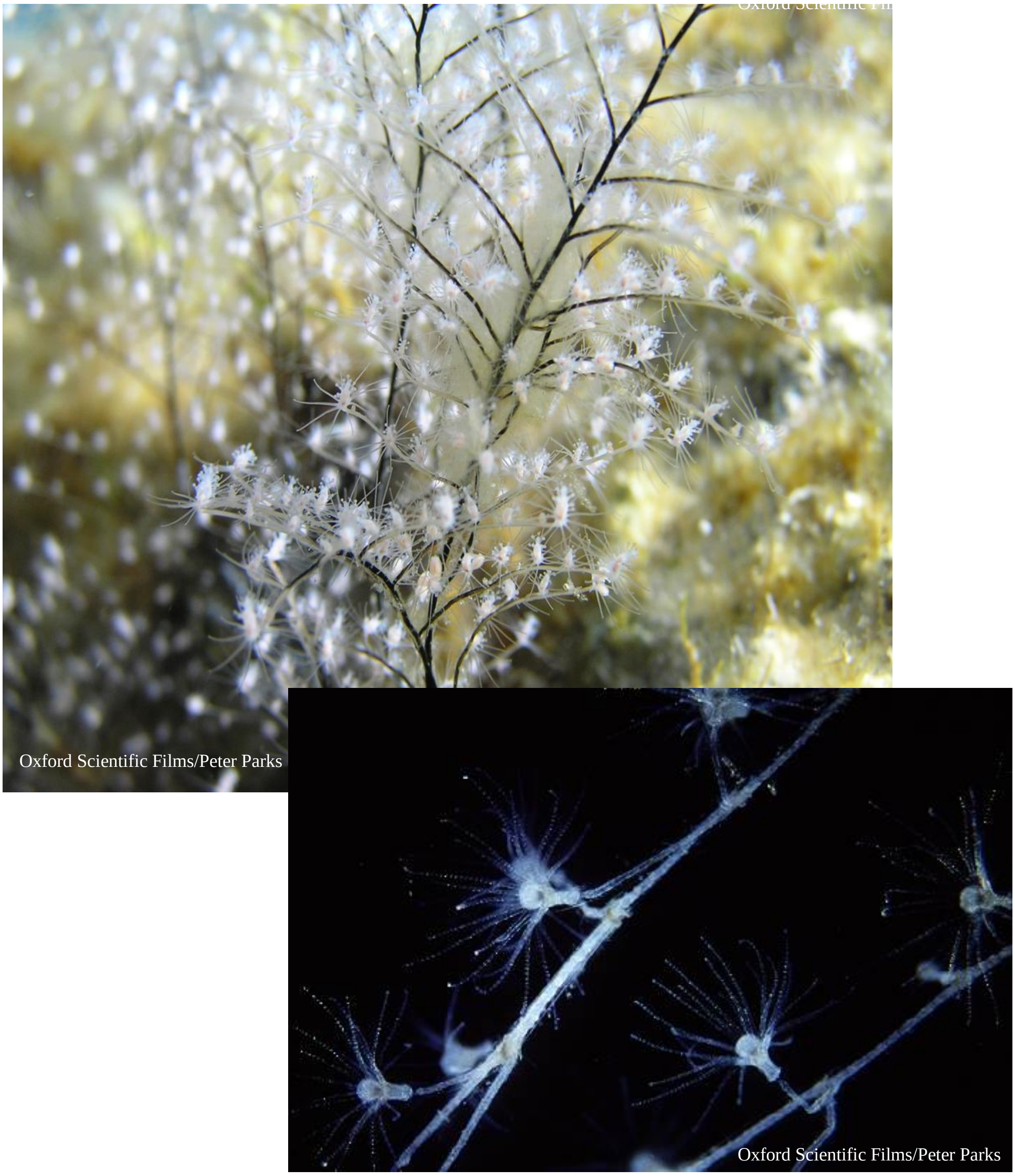


Figure 67: Obelia Colony

Cnidaria of the genus *Obelia* form colonies of polyps in their asexual generation. Two kinds of polyps, feeding and reproductive, fail to separate from an upright, anchored stalk, remaining instead as the branchlike structures (*Figure 67*). Each one, called a sub-individual because its actions are governed by the entire colony, has a transparent, horny covering into which it can withdraw. The two types differ otherwise in structure. Only feeding polyps have tentacles with which to draw food towards them, but because both are hollow, partially digested food can travel through the colony's continuous digestive cavity to nourish the reproductive polyps. The medusa, or sexual stage of the organism, emerges from the opening of the reproductive polyp as saucer-shaped mass of jelly.

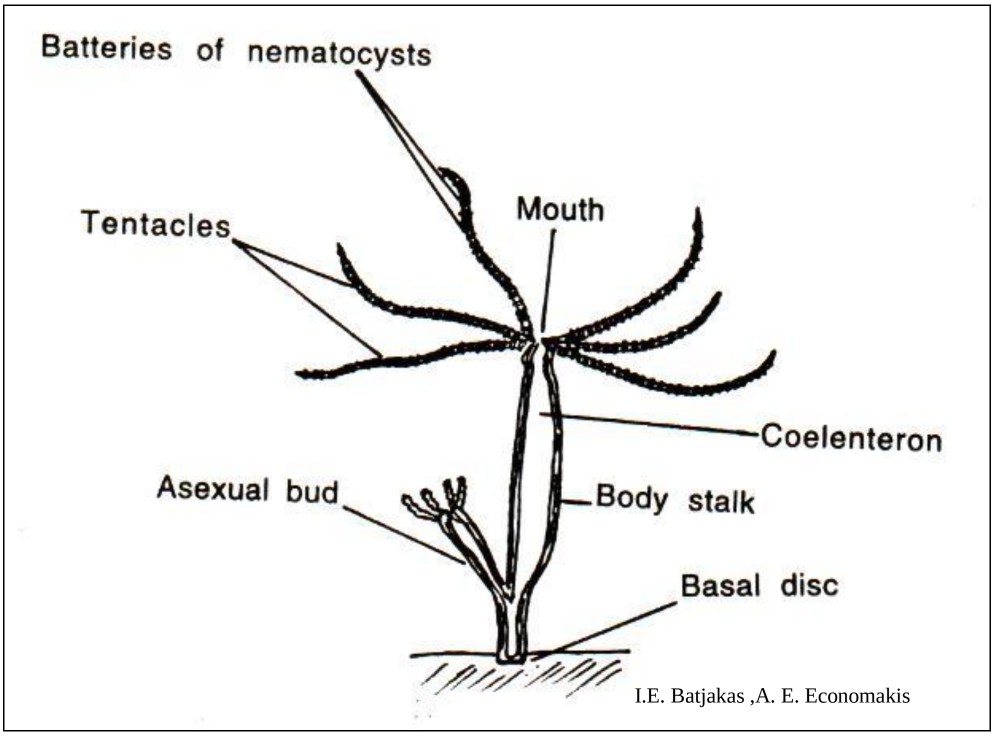


Figure 68: Section through a hydra

Scyphozoa (jellyfish)

The medusa phase dominates in most of the 200 species of scyphozoans, the cnidarians most frequently referred to as jellyfish. Scyphozoan medusae are larger and have a more complicated structure than the short-lived medusa of the hydrozoans. Scyphozoan medusa lives several months or more, reproducing sexually to form small, inconspicuous polyps. Polyps reproduce asexually to form a medusa; saucer-like structures bud off the polyp and swim away as new medusa.

- *Aurelia aurita* (common name: Jellyfish)*:*

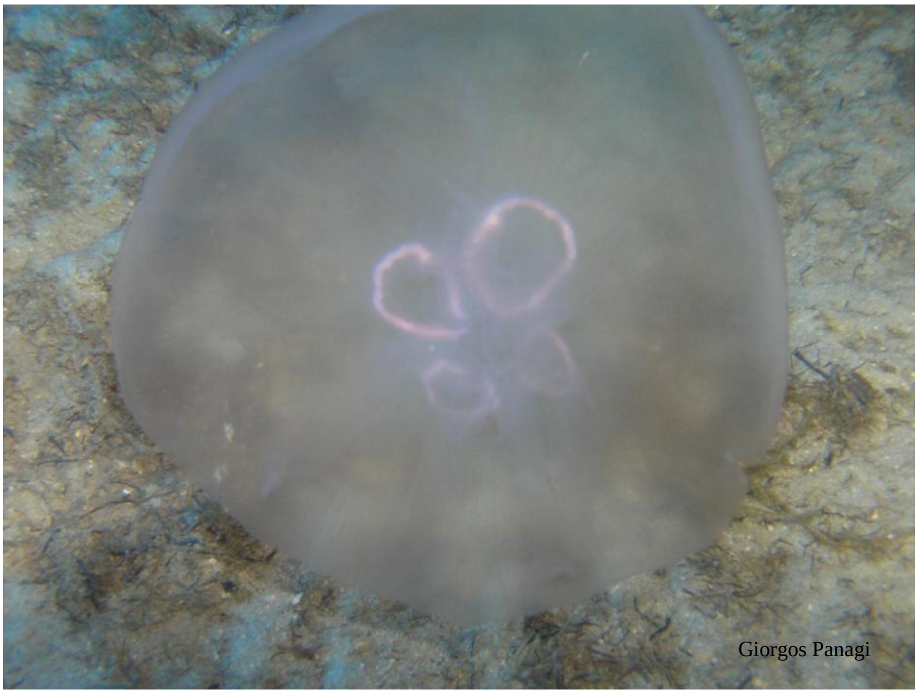


Figure 69: *Aurelia aurita* - Jellyfish

This schyphozoa has very short tentacles that do not sting (*Figure 69*). The bell can reach 40cm in diameter. Strobilation take place in winter and large individuals can be found present in the summer. They are common in Cyprus waters.

Classification: Order Semaeostomeae,
Family Ulmaridae

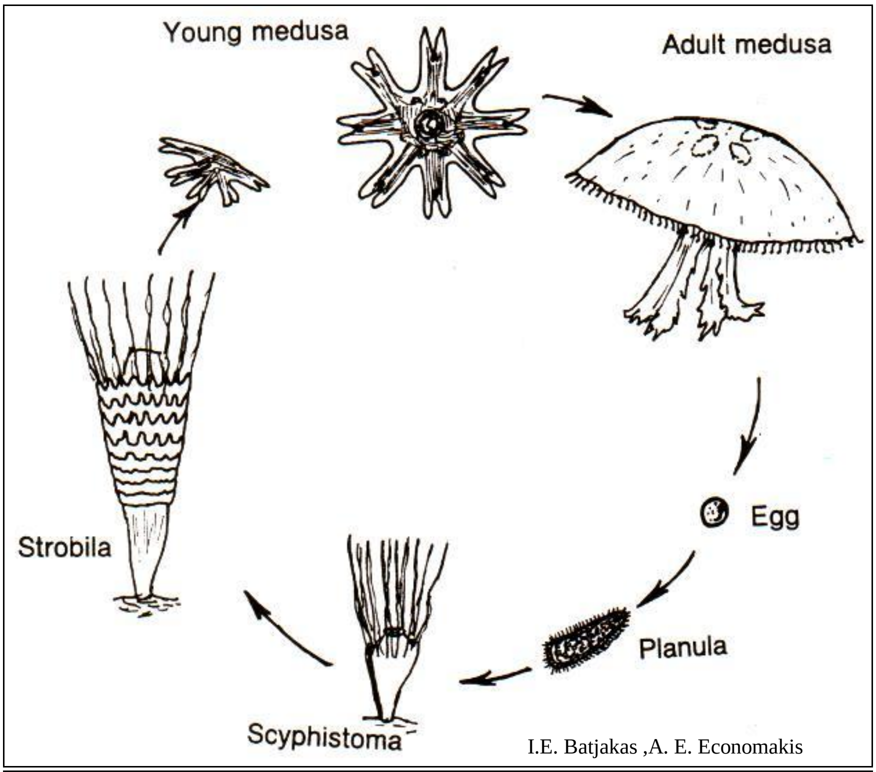


Figure 70: The life cycle of *Aurelia*

- *Pelagia noctiluca* (common name: Luminescent Jellyfish)

Figure 71: *Pelagia noctiluca*

This Scyphozoan glows at night therefore its name. It has relatively long tentacles and purple-pink coloration (*Figure 71*). Its sting is one of the strongest in Mediterranean. For this reason the swimmers avoid swimming in areas where luminescent jelly fish are abundant. The sting from this jellyfish can be very painful. Application of ammonia or urine can relief from pain. The majority of the stinging cells (nematocyst) are located on the tentacles, not on the bell. They swim like most jellyfish; by pulsing their sub-umbrella and driving water out from beneath them.

They pray day and night on a variety of animals, mostly crustaceans. The bell can reach 9 cm in diameter and they can be found between the water surface up to 10 m depth.

Classification: Order: Semaeostomeae,
Family: Pelagiidae

Cubozoa (box jellyfish)

The medusa phase dominates in animals in the Cubozoan class. Cubozoan medusae are commonly called box jellies because they have a cube shape with a single tentacle or group of tentacles hanging from each corner at the mouth end of the animal. The Cubozoan polyp is small and inconspicuous and an entire polyp transforms into a medusa in a type of asexual reproduction. Cubozoa consists of about 20 species of sea wasps and their relatives. The nematocyst sting of some cubozoans, including the Australian Sea Wasp *Chironex fleckeri*, contains poison that can be fatal to humans (*Figure 72*).

Figure 72: The Australian Sea Wasp - *Chironex fleckeri*

Anthozoa (Corals, Sea Fan, Sea Anemones)

- Sea anemone

Sea anemone is the common name for marine, flowerlike polyp having a cylindrical, or vase-like, body. Many species are coloured; large specimens may attain a diameter of 1 m. The body is closed and attached to rocks or coral at one end and, at the other end, has a central mouth surrounded by tentacles armed with nematocysts[23]. The slit-like mouth opens into a short esophagus opening into the body cavity. At each end of the mouth, a permanent pore opens into a ciliated groove, called a siphonoglyph, in the side of the gullet, through which a continuous current of water flows, carrying oxygen to the tissues and removing waste matter. The body cavity is divided into a number of sacs by septa extending from the body wall. These septa increase the surface available for the secretion of digestive juices and the absorption of nourishment, and they contain the gonads that produce the sperm and eggs.

Most sea anemones reproduce sexually; budding and fission are comparatively rare. The eggs are usually fertilized in the gastric cavity, and the young are discharged from the mouth as free-swimming larvae, which soon attach themselves to surfaces. Hermit crabs sometimes attach sea anemones to their shells (process called symbiosis). Some anemones become completely parasitic on certain species of jellyfish.

Figure 73: *Balanophylla(Leptopsammia) pruvoti*

[23] Nematocysts: They are stinging cells and thread cells that paralyze and entangle the small fish and marine animals that constitute its prey.

This small solitary coral has a bright yellow polyp (*Figure 73*). It can be found on hard substrates, at depths between 1 m and 50 m. It is nocturnal and feeds on zooplankton. The oral disc including the tentacles may reach in diameter of 2 cm.

Classification: Order: Scleractinia
Family: Dendrophyllidae

- Sea Fan

Figure 74: *Eunicella cavolinii* (common name: yellow sea fan)

The yellow sea fan attaches to hard substrates and is forming colonies that are erect and fan-like (*Figure 74*). It can be found between 10-80 metes depth and can reach over 30cm in height. The sea fan usually face in to the currents and feeds at night with plankton.

Scientific classification: Order: Gorgonacea
Family: Plexauridae

Figure 75: ***Eunicella singularis*** **(common name: white sea fan)**

The White Sea Fan does not branch as much as the yellow sea fan and prefers non shaded areas (*Figure 75*). It can be found between 5-40 meters depth and it can reach 30 cm in height.

Scientific classification: Order: Gorgonacea
Family: Plexauridae

Figure 76: ***Actinia equina (common name:*** **beadlet anemone)**

The beadlet anemone is by far the most common anemone in Cyprus (*Fugire* 76). It's likely to be found at almost any shore on which it can find a place to anchor itself and it is quite tolerant to some dilution of seawater. It has a red to light purple colour and during the day is usually contracted and at night it expose its tentacles. The oral disc may reach 5cm in diameter. Like other species is carnivorous.

Scientific classification: Order: Actiniaria
Family: Actiniidae

- <u>Coral</u>

The tiny white polyps on the red coral, *Corallium rubrum*, are independent animals outside the red coral skeleton searching for food. It is a rare and very fragile organism of the deep water (50-200m). The thoughtless and often illegal fishing (for jewellery purposes) tends to extinct these colonies.

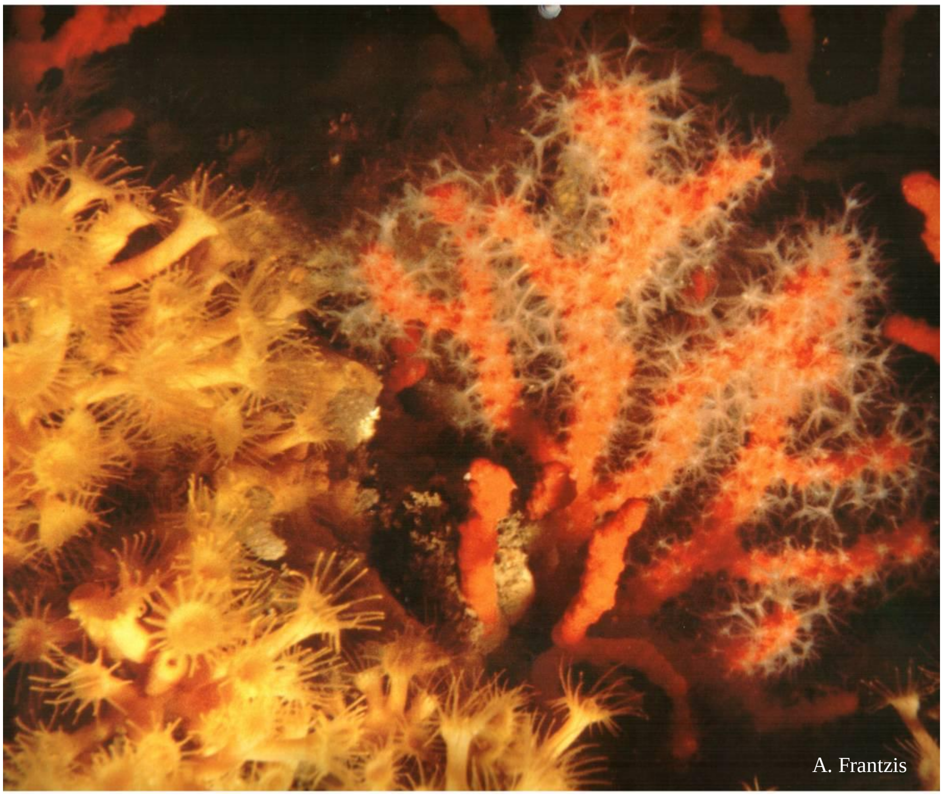


Figure 77: The Red Coral *Corallium rubrum* with the white polyps on, and the yellow anthozoan on its left, *Parazoanthus axinellae*

Figure 78: A clown fish inside a sea anemone

Clown fish have a symbiotic relationship with sea anemones (*Figure 78*). The fish chases away the anemone’s would-be predators with its territorial behaviour. The anemone on the other hand protects the fish with its stinging cells. The fish is protected from the cells’ poison by a thick mucous coat that secretes.

C. Phylum Ctenophora

Phylum Ctenophora is a smaller group of radially symmetric, gelatinous-bodied marine organisms. Commonly called comb jellies, most are small and planktonic, preying on even smaller plankton. They use two long tentacles to capture their prey. These tentacles are not covered with nematocysts like those of cnidarians. Instead, the tentacles are covered with cells called “lasso cells.” When the tentacles come into contact with the comb jelly's prey, the lasso cells burst open, releasing sticky threads that latch onto the hapless organism.

The ctenophores get their name from the eight rows of ciliary combs, or “ctenes,” located vertically within their bodies. These combs are actually long cilia fused at their bases to look like a comb you would use in your hair. They beat in undulating waves along the length of the comb jelly's body, which provides orientation in the water. Like many cnidarians, ctenophores are planktonic. They can move their bodies with their combs, but tend to do so just to remain upright in the water column. They are found in both warm and cold waters.

Figure 79: Ctenophore *Beroe cucumis*

The Bilateral Worms

Animals with this type of symmetry have a defined head end (anterior) and rear end (posterior), a right and left side, and a top and bottom surface.

Dorsal – Referring to the top (or back) surface of an animal

Ventral – Referring to the bottom (or belly) surface of an animal

Bilaterally symmetric animals are more active than the animals already mentioned, and therefore have a more complex nervous system with which to process greater sensory input and coordinate their locomotion. They also react to their surroundings more. Bilaterally symmetric animals have a brain – or at least an accumulation of nerve cells – in their anterior end that can process the large amount of sensory input they receive.

D. Phylum Platyhelminthes

Animals in the phylum Platyhelminthes are called flatworms because of their flattened shape. Their dorsal and ventral sides are flat like a pancake. The flatworms have the simplest organization of organs and organ systems among all bilaterally symmetric animals. They have a simple brain – basically just a collection of nerves in the head – and many nerve cords running through the length of the body. This simplified central nervous system coordinates the movements of their well-developed muscles. These muscles are in the area between the endoderm and ectoderm. They have a middle layer of tissue that forms muscles and contributes to other organs during development. Flatworms do have a digestive system similar to the cnidarians. This baglike structure (usually called an intestine) has only one opening, the mouth, through which food enters and wastes are expelled.

- <u>Class Turbellaria (Turbellarians)</u>

These flatworms are mainly free-swimming carnivores. They are usually less than 10cm long but are very often quite colourful. Turbellarians move with the help of cilia and mucus on their ventral side, which allow them to glide over the ocean bottom.

Figure 80: Sea ice turbellaria from Arctic sea ice.

- <u>Class Trematoda (Flukes)</u>

It is the largest class of flatworms, with more than 6,000 species. These trematodes engage in parasitism, feeding on the tissues of other organisms. In other words, flukes are parasites. The organism upon whose tissues the flukes are feeding is called the host and this relationship harms the host. Most parasites have a complex life cycle. In flukes, for example, the larval stage will inhabit clams, snails, or even fish. The adult fluke always inhabits a vertebrate, however, so a vertebrate must eat the organism that is host to the fluke's larva in order to become infected. Many fish and whales are hosts to adult flukes (*Figure 81*).

Figure 81: Flukes hosting a whale

- <u>Class Cestoda (Tapeworms)</u>

Most tapeworms have long bodies made up of repeated units (*Figure 82*). They are parasites that live in the intestines of many species of both land and aquatic vertebrates. These organisms attach to the wall of the intestine with suckers or hook-like structures (*Figure 83*). There is a reason that tapeworms need to live in a host's intestines. Tapeworms do not have a gut or a mouth, so they rely on their host to digest food for them. They can then absorb the needed nutrients directly into their bodies. Since they always live in the intestines of a host, their size can vary with the length of the host's intestines. In sperm whales, a species of tapeworm has been found that is nearly 50 feet long!

Figure 82: Tapeworms have long bodies made up of repeated units

Figure 83: Tapeworms' suckers / hook-like structures

E. Phylum Nemertea

Phylum Nemertea is composed of organisms commonly called ribbon worms. Most ribbon worms are marine, living at the bottom of shallow waters. They look like long, flat ribbons. Although they look like some flatworms, they are usually more elongated and have a more complex body structure. These worms have a one-way digestive tract starting with a mouth and ending with an anus. This is a much better arrangement than the one-opening digestive system of the flatworms and the cnidarians, because the ribbon worm can eat continuously. This type of digestive system is called a "true" digestive system (or gut), because the one-way flow allows various parts of the digestive tract to be specialized for different stages of digestion. Ribbon worms also have a circulatory system that transports nutrients and oxygen via blood. Possibly the most interesting feature of the ribbon worms is a long, tubular proboscis used for defence and to capture prey (*Figure 84*). When a worm or crustacean is nearby, the ribbon worm will quickly extend its proboscis (like a long, flexible tongue) to entangle it. Some of these worms have a spine on the tip of their proboscis that can secrete and inject toxins. Once the prey is captured, the proboscis pulls the prey back into the mouth for dinner.

Figure 84: Tubular proboscis of Nemertea

F. Phylum Nematoda

The members of phylum Nematoda are known as roundworms. Though rarely seen, they are present in remarkably large quantities in the ocean sediments, feeding on bacteria and other organic matter. Many species are parasitic, residing in most groups of marine animals. Their larvae usually live in host fishes. It is the larvae from these species that are notorious for causing reactions among people eating raw fish, a popular food item in some restaurants today. Even though raw fish dishes may taste good, people should realize the possible risks from nematode larvae.

Nematodes are well designed for their lives in the ocean sediments or as parasites. Most are small and have slender, tube-like bodies that are tapered on both ends. Inside is a true digestive tract that is open at both ends. Estimates indicate that up to half a million yet-to-be-discovered nematode species exist in the world today.

Figure 85: A roundworm (Nematode)

G. Phylum Annelida

The segmented worms belong in phylum Annelida. Segmented worms have a body design made up of a series of similar compartments, or segments. This situation is known as segmentation and can be seen in the earthworm in its many rings. Segmented worms have a more complex body cavity than any other organism previously mentioned. They have a distinct circulatory system for transportation of nutrients and gases. Their gut travels throughout the length of their body (through all the segments) and is inside a larger body cavity called a coelom.

The coelom inside annelids is partitioned into sections that correspond with the segments of the animal. It is filled with fluid that helps support the body's structure much the same way that a water balloon holds its shape when filled. The muscles inside the body walls can contract in sequence against the fluid-filled coelom, allowing for movement.

Annelids can wiggle and squirm in any number of ways, allowing them the ability to move through the water or on the ocean bottom. It is very difficult for these animals to completely control their motion. When one part of their body is moved, the other parts usually follow along. Although this characteristic makes it harder for the animal to control its movement, it actually helps the animal in case a few of its segments are damaged. If an annelid has a few damaged segments, it can still move around, because its damaged segments just follow the segments that are not damaged.

- Class Polychaeta

The most diverse and abundant class of marine segmented worms is class Polychaeta. The members of this class are usually called polychaetes. On each of the segments of a polychaete, there is a pair of small, flattened extensions called parapodia. Some species have sharp bristles on their parapodia. In small polychaetes, oxygen can be absorbed directly from the surrounding water into their tissues. In the larger polychaetes, however, this process does not supply enough for their needs. As a result, larger animals are equipped with gills[24] on their bodies in order to increase the oxygen absorption.

Figure 86: Examples of Polychaetes: *Sabellidae spp* and *Ceratonereis costae*

Figure 87: *Hermodice carunculata*

[24] Gills: Extensions of the body containing thin-walled blood vessels that allow for easy absorption of oxygen from the outside surface.

Polychaete reproduction is usually a result of separate sexes releasing gametes into the water column. Fertilization and development yield a larval stage called a trochophore, which is a free-swimming, ciliated, planktonic stage that eventually metamorphoses into an adult polychaete.

Many polychaetes crawl on the ocean floor, while others burrow in the mud or sand. Some are carnivorous, capturing small prey. Some polychaetes produce a tube made from limestone, mucus, and other materials such as mud particles, cemented grains of sand, or bits of shell. That is why they are sometimes given the name “tube worms.” Tube worms have long ciliated tentacles containing mucus for capturing tiny bits of food.

H. Phylum Mollusca (Classes: Scaphopoda, Cephalopoda, Bivalvia, Gasteropoda)

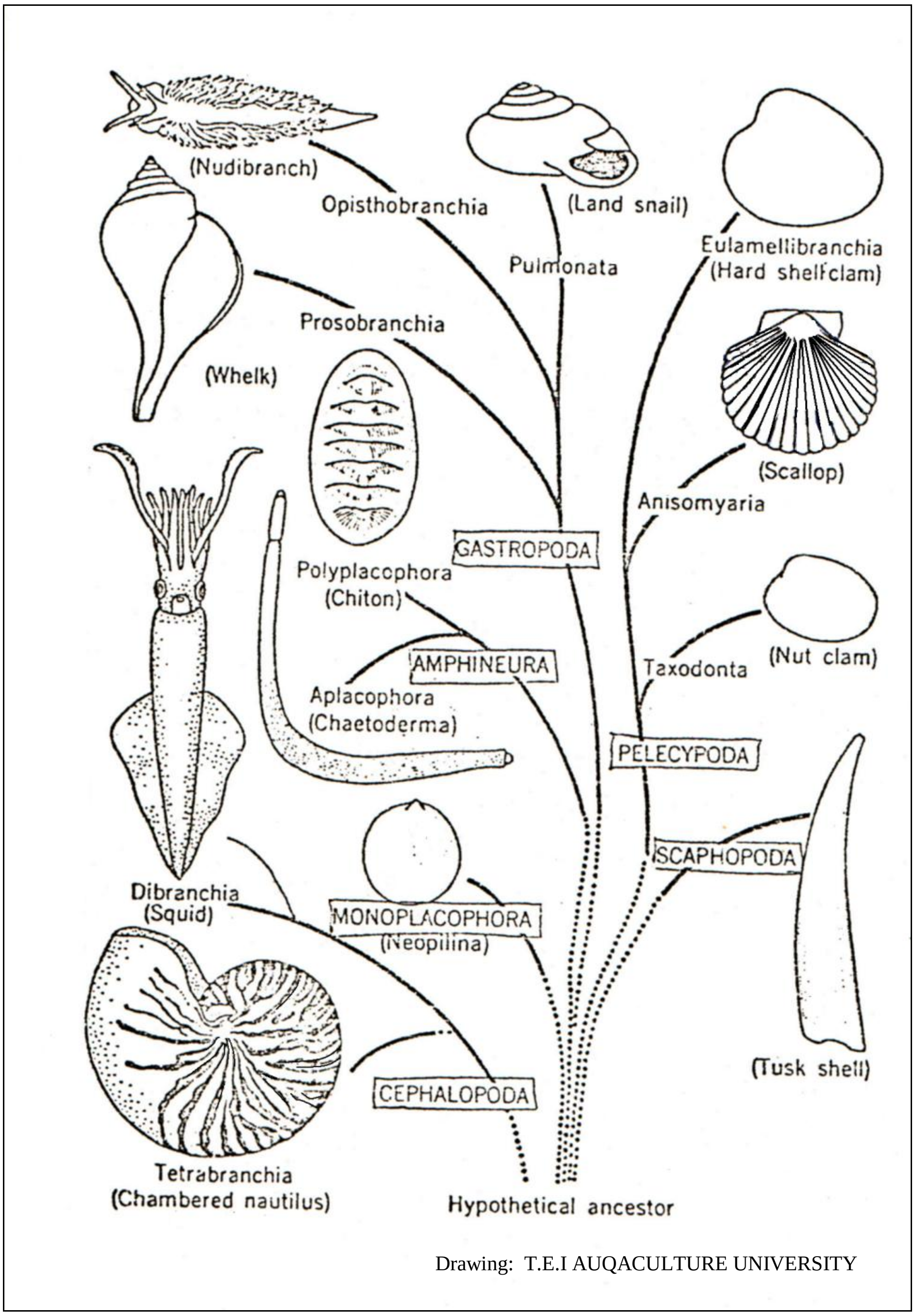


Figure 88: Mollusca classes

The molluscs present a diverse group of marine, freshwater, and terrestrial invertebrates, including such varied forms as snails, chitons, limpets, clams, mussels, oysters, octopuses, squid, cuttlefish, tusk shells, slugs, nudibranchs, and several highly modified deep-sea forms (*Figure 88*). They all have one anatomical feature in common, the presence of a shell at some stage in their life cycle. Although most molluscs have a shell as adults, the octopus, squid, and deep-sea forms do not. They do however have a small, shell-like structure, called a shell gland, present for a short time during embryonic development.

- Chephalopoda (octopus,squid,cuttlefish, Nautilus)

Figure 89: Various types of Cephalopoda

Cephalopod is the common name for the actively predatory marine mollusca including the squid, cuttlefish, octopus, and nautilus (*Figure 89*). The word *cephalopod* means “head footed” and they took that name because of the presence of the arms around their mouth. Cephalopods are highly evolved animals in terms of structure and physiology, and the complexity of their behaviour is equal to that of fish. Ecologically successful, they are among the more common predators in the sea; in turn they are eaten by many other animals, including humans. Giant squid, which can weigh as much as 900 kg (1980 lb), is the largest of all the invertebrates. About 650 species of cephalopoda are known.

The class is an ancient one, first appearing in the fossil record during the Cambrian period, about 600 million years ago. Primitive cephalopods, like other molluscs, had large external shells, but these were gradually reduced as the animals grew faster and more active. The remaining primitive cephalopod, the nautilus, retains many archaic traits, such as an external shell with gas-filled chambers that aid flotation.

More advanced cephalopods are exemplified by the squid and cuttlefish, in which the shell is reduced and covered by tissue. The squid has a thin, horny, internal shell called a pen. The two-gilled mantle cavity is surrounded by muscles and provides much more effective jet propulsion, which is aided by the fins. The squid has ten sucker-bearing arms, one pair of which is longer than the rest. The eyes are comparable in structure to the human eye, and the brain and nervous system are fairly complex. The octopus and its allies are even more modified. The shell is entirely absent, and the animal has eight arms. Most octopuses are bottom dwellers, and a few attain a large size.

Digestion in cephalopods is rapid, and the circulatory and reproductive systems are well developed. The animals avoid predators mainly through flight or concealment, including an ability to change colours for camouflage, and some cephalopods eject a black secretion, called ink, to confuse predators. The sexes are separated; some species engage in complex mating displays. Cephalopod embryos develop in egg masses that are often cared for by the female.

- Nautilus

Any of the molusca species that has a primitive marine coiled shell mollusc, belongs to the only surviving genus of the nautiloids, which were the largest predators in the seas during the Ordovician period, 450 million years ago. Modern nautiluses are much smaller than their ancient predecessors, the ammonites, a cretaceous species that reached a diameter of over 2.5 m.

Today's species inhabit the warm waters of the Indian and eastern Pacific oceans. Unlike other cephalopod molluscs, the octopus and squid, the eyes of the nautilus lack lenses and they operate on the principle of a pinhole camera. Its nervous system is fairly simple. The front of the nautiloid body protrudes from the opening of the shell and bears many sucker-less arms. Below the head is a mantle cavity with four gills; a funnel around its opening ejects water to provide weak jet propulsion. Prey is grasped with the tentacles and can be bitten with the mouth's sharp beak. Its most familiar characteristic is its smooth, coiled shell, up to 28 cm in diameter (*Figure 90*). The shell is lined with mother-of-pearl and is separated into a series of progressively larger compartments, the most recent of which is inhabited by the animal. The walls (septa) dividing the chambers are pierced by a tube (siphuncle) connected to the nautilus. Gas and liquid exchange occurs through the siphuncle walls, by means of which the nautilus can regulate its buoyancy.

The nautilus apparently rests on the ocean bottom during the day, at depths ranging to 600 m. At night it swims about by forcing water through a primitive funnel; it eats diatoms, shrimp, and algae. When the animal is feeding, its tentacles are extended to catch whatever swims into them; the tentacles are small, contractile, and adhesive but have no suckers. Little is actually known about the behaviour and life cycle of nautiluses.

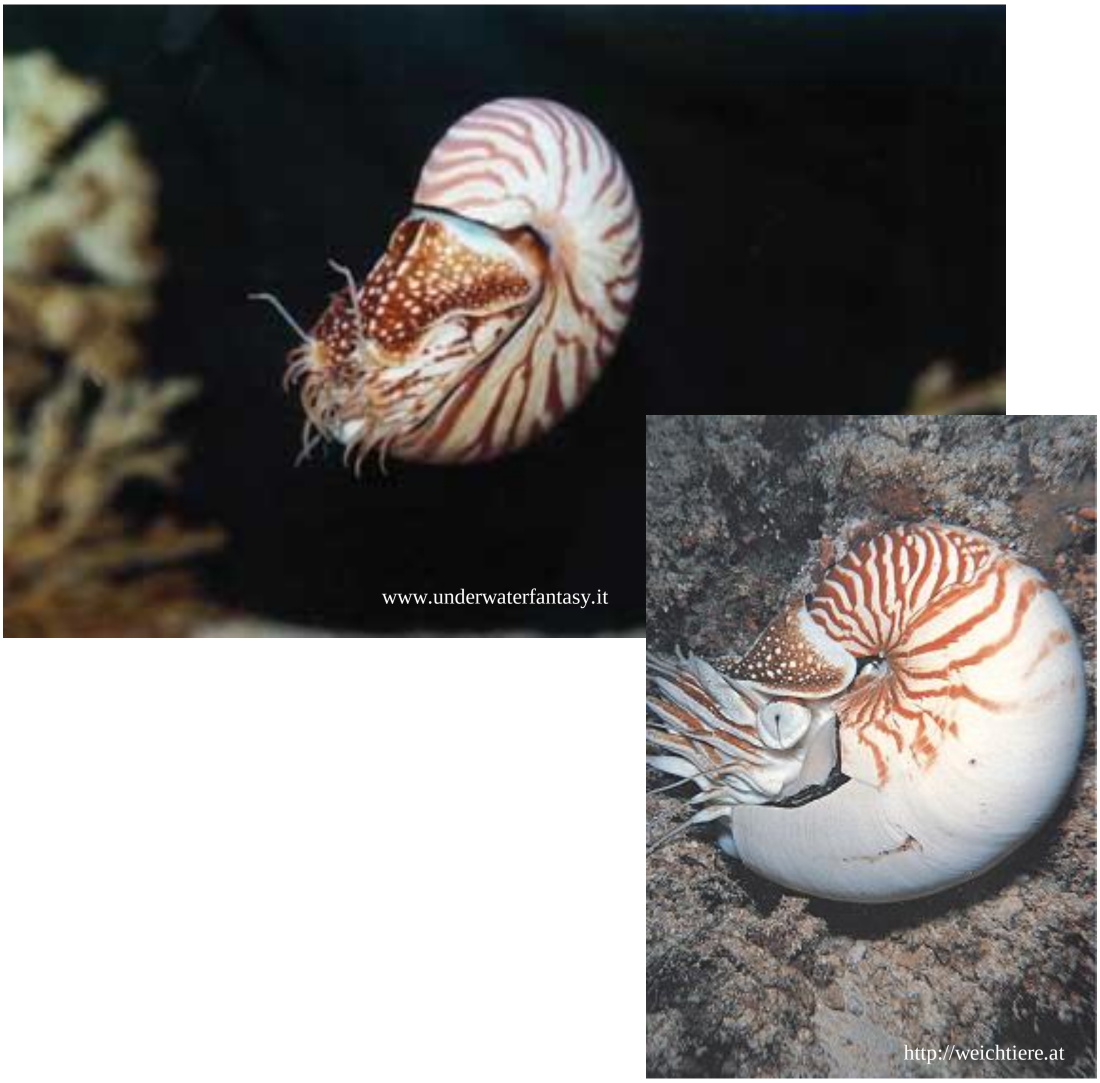


Figure 90: ***Nautilus pompilius***

Figure 91: Chambered Nautilus

A cutaway view of the shell of the chambered nautilus reveals the compartments that housed the nautilus when it was smaller (*Figure 91*). These smaller chambers are connected together by a small calcified tube, and they regulate the buoyancy of the nautilus as it swims along. The compartments are filled with nitrogen gas, which is produced by the nautilus.

- *Sepia officinalis* (common name: Cuttlefish)

Figure 92: *Sepia officinalis*

Like octopus, cuttlefish have poison glands that are used to immobilize their pray (*Figure 92*). The cuttlefish is an open water, or pelagic, species that swims using its marginal fin. It feeds on fish and invertebrates and it is the object of commercial fisheries in many parts of the world. Cuttlebone, a supporting rod of calcium carbonate found only in cuttlefish, is used as a polishing agent as well as a calcium and salt supplement for captive birds and other animals. Fertilization is internal similar to the octopus; eggs are laid at the end of summer attached to substrate.

- *Loligo vulgaris* (common name: Squid)

Figure 93: *Loligo vulgaris*

The squid is the fastest cephalopod. Its body is elongated and torpedo shaped and their fins cover 2/3 of the body length (*Figure 93*). Acceleration at high speed is reached by multiple ejection of water through the funnel that drives water out of the body cavity. This enables the squid to move backwards.

It can be found at the costal areas during fall and winter (breeding period) that comes to breed. Eggs are left hanging on in clutches. After mating, the majority of the adults die. Males can reach a size of 40 cm whereas females can reach 32 cm.

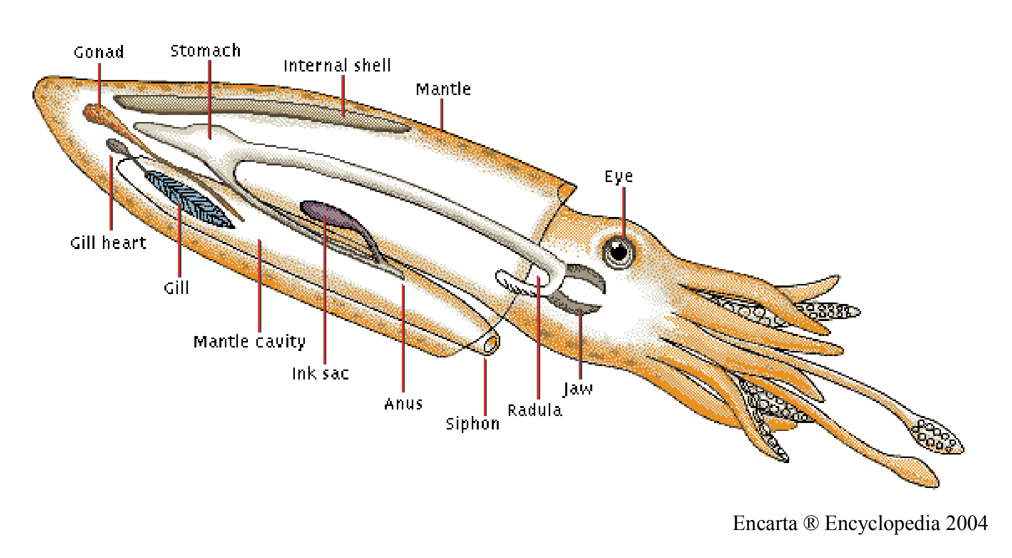


Figure 94: Generalized Anatomy of a Squid

- Octopus

The octopus is a carnivorous marine mollusc, found worldwide in tropical and warm temperate waters. The octopus is characterized by a soft body with a well-developed brain and by eight arms bearing two rows of suckers each (*Figure 95*). As in the vertebrates, the two large, complex eyes of the octopus are camera like in structure, and their vision is acute. The animals can change the colour and texture of their skin rapidly. Camouflage is achieved as a result of chromatophores, which can rapidly change the animals' colour to match their surroundings (*Figure 96*).

Much of their life is spent in hiding and many species, such as the common octopus (*Octopus vulgaris*) which can grow to about 1 m long, choose a natural hole among rocks or in a pile of rubble. A small species, however, such as the Atlantic pygmy octopus, which is about 2 cm long, may prefer an empty clamshell having both valves still connected by a ligament; settling into one half, it pulls the shell shut with its suckers.

When an octopus emerges to find food such as crustaceans and bivalve molluscs, it often lures its victim by wiggling the tip of an arm like a worm, or it glides near and pounces on a crab, sinking its beak into the shell and injecting a poison that kills. The poison of a very few species is dangerous to humans. Octopuses are preyed upon in turn by a number of fishes, including the moray eel. When an octopus is attacked, it draws water into its mantle cavity and expels it with great force through a funnel. The result is a jet-propelled exit, usually behind a cloud of "ink," a dark substance the octopus ejects for defence. The ink of some species seems to have a paralyzing effect on the sensory organs of the predator.

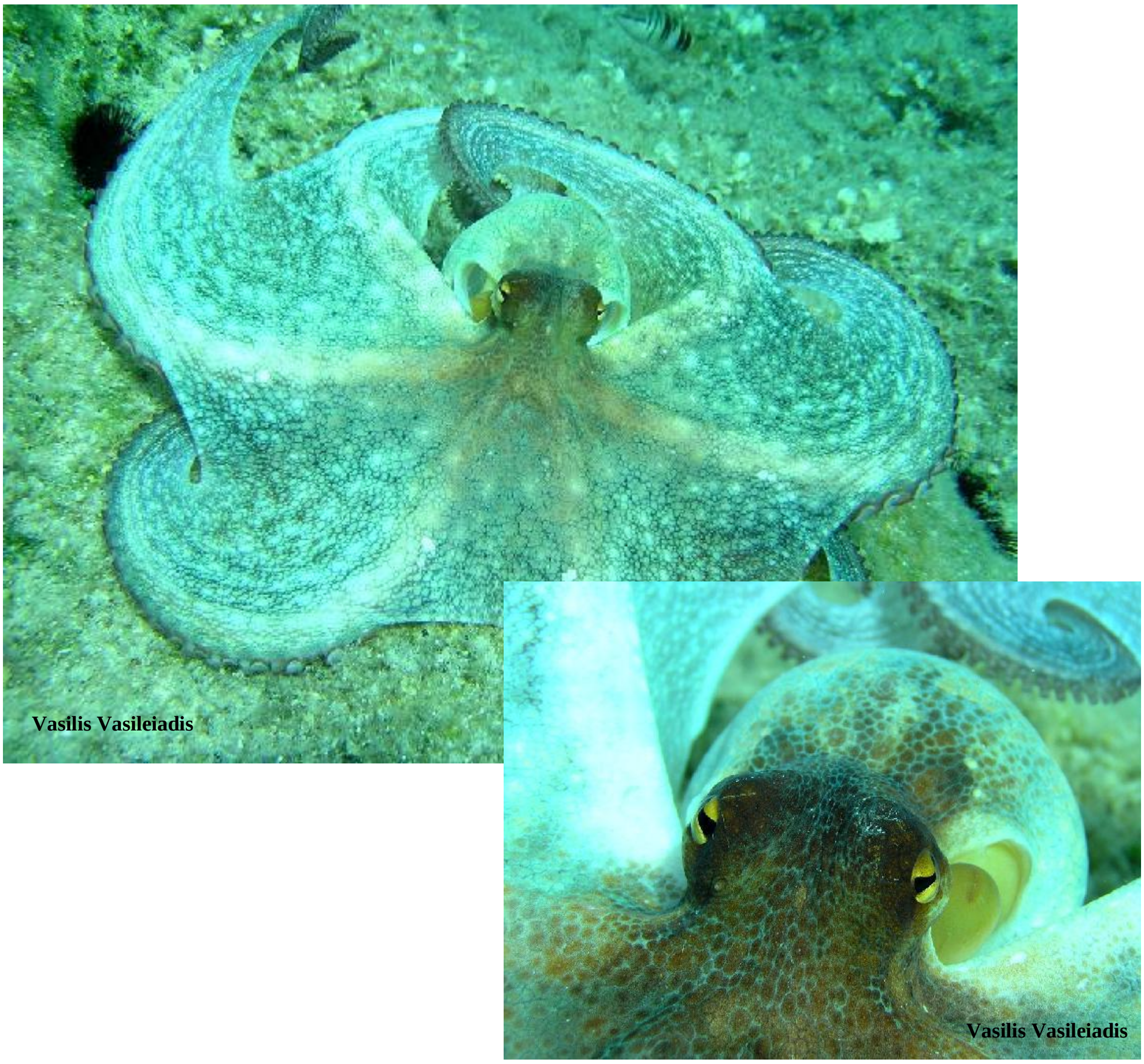


Figure 95: ***Octopus vulgaris***

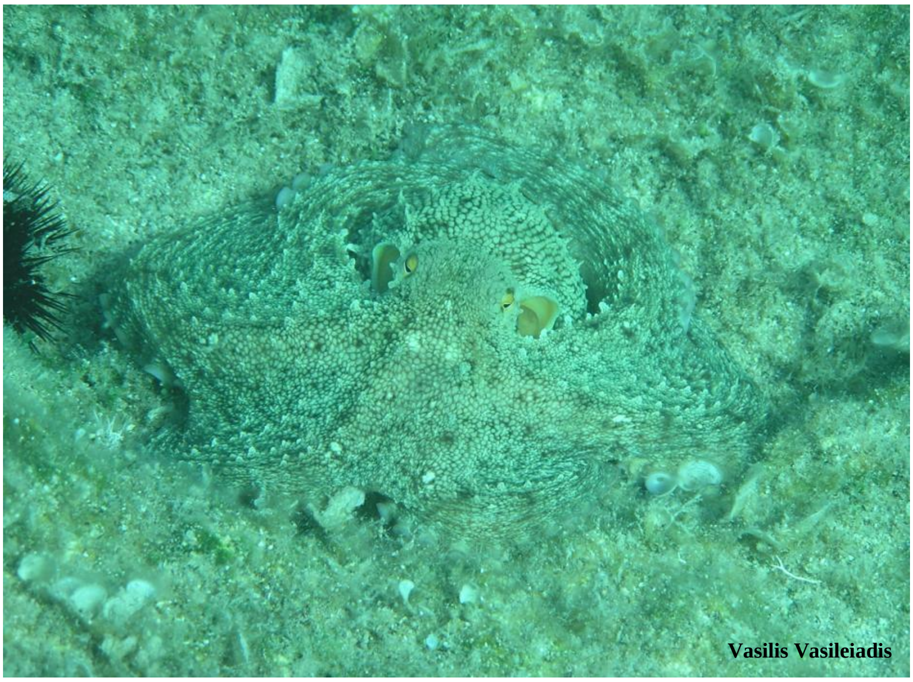


Figure 96: ***Octopus vulgaris*** **changing its colour and texture for camouflage**

A male interested in mating approaches a female just close enough to stretch out a modified arm, the hectocotylus, and caress the female. This arm has a deep groove between the two rows of suckers and ends in a spoon like tip. After a period of love play, the male inserts its arm under the mantle of the female, and the spermatophores travel down the groove on the hectocotylus's to the female's oviduct. Soon after mating, the female begins to lay eggs, each enclosed in a transparent capsule, in its lair, producing about 150,000 in two weeks. The female guards them for the next 50 days, jetting water to aerate and clean them. The young of such species as the white-spotted octopus are only about 3 mm long. They float to the surface and become part of the plankton for about a month, then sink and begin their normal life on the bottom. Octopuses generally stay in one area as adults, but those species with planktonic larvae are found all over the world because the currents and tides move them. The female *Octopus vulgaris*, the common octopus that we meet in Mediterranean, reproduces once in her life time and when the young hatches, she dies.

- *Argonauta argo*

They also have 8 tentacles like octopus and only the female has a very thin external shell that is very compressed by the sides with many radiant channels (*Figure 97*). The two sexes have very deferent sizes with the female reaching 30cm and the male just 1.5cm length. They usually live together in the shell while the female lays her eggs (*Figure 98*). It is an oceanic surface species that is not met at the costal areas.

Figure 97: A female Argonauta

Figure 98: The egg case with some eggs (orange colour)

- <u>Gasteropoda (Snails, Limpets, Abalone)</u>

Figure 99: ***Haminea navicula***

Figure 100: ***Leiostraca subulata***

Gasteropoda include snails and slugs. The Gasteropoda (Greek gaster, “stomach”; pous, “foot”) are generally characterized by a single shell and an asymmetric body. They form the second largest class in the animal kingdom, outnumbered only by insects. The most recent estimate of the number of known species is 37,500, a revision downward from an earlier estimate of about 80,000.

The first gastropods appeared in the early Cambrian period, about 600 million years ago. The most primitive living gastropods are of the subclass Prosobranchia and are mostly marine, with a few freshwater and terrestrial species. The three suborders are Archaeogastropoda (archaic forms such as abalone and limpets), Mesogastropoda, and Neogastropoda (advanced forms such as oyster drills and cone shells).

The subclass Opisthobranchia is almost entirely marine. The shell tends to be reduced, and the gill migrates toward the rear of the body. There are eight orders, including the less modified tectibranches (bubble shells, sea hares, and allies), the shell-less nudibranchs, and two groups of pteropods that swim in the plankton. In the subclass Pulmonata the mantle cavity has become a lung, and the operculum is lost. The group has a few marine forms. Most terrestrial snails and slugs belong to the order Stylommatophora, and most freshwater snails belong to Basommatophora.

- Nudibranch

Nudibranchs are sea slugs belonging to the suborder Nudibranchia, the largest suborder of the order Opisthobranchia. There are more than 3,000 described species. These sea slugs are soft-bodied snails. The adult form is without a shell or operculum[25]. The word "nudibranch" comes from Latin nudus meaning "naked", and Greek brankhia meaning "gills". The gills are visible at the top of the animal exposed to the water.

They are hermaphroditic, but can rarely fertilize themselves. Nudibranchs typically deposit their eggs within a gelatinous spiral. They are carnivorous. Some feed on sponges, others on hydroids, others on bryozoans, and some are cannibals, eating other sea slugs, or, on some occasions, members of their own species. There is also a group that feeds on tunicates and barnacles.

They occur worldwide at all depths, but they reach their greatest size and variation in warm, shallow waters. Among them can be found the most colourful creatures on earth (*Figure 101*). Because sea slugs, in the course of evolution, have lost their shell, they have had to evolve another means of defence: camouflage, through colour patterns that make them invisible or warn off predators as being distasteful or poisonous. The nudibranchs that feed on hydroids store the hydroid's nematocysts in the dorsal body wall. This enables the nudibranch to ward off potential predators.

Figure 101: Nudibranch

[25] Operculum: it is a bony plate covering the opening of the shell, when the body is withdrawn.

- *Murex brandaris*

Figure 102: *Murex brandaris*

Murex was much valuable for Phoenician fishermen as a source for the famous purple pigment that was used to dye clothes for the nobility. To get 2 gr of this pigment, 10,000 animals were needed, therefore, do this activity, the Murex was almost driven to extinction. Ironically this pigment is a defence device against predators.

- *Sea Hare*

Sea hares exhibit in a variety of body colours, usually designed to blend in with their environment (*Figure 103*). The sea hare's body is coiled even though it lacks a coiled shell. Instead of being twisted to the right like a snail, the body is twisted to the left so that its one gill is on the right side of the body and the penis is just to the right of the head. The head has two pairs of sensory tentacles. The front tentacles sense touch while the rear pair, called rhinophores, may sense chemicals. The sea hare's rhinophores resemble rabbit ears.

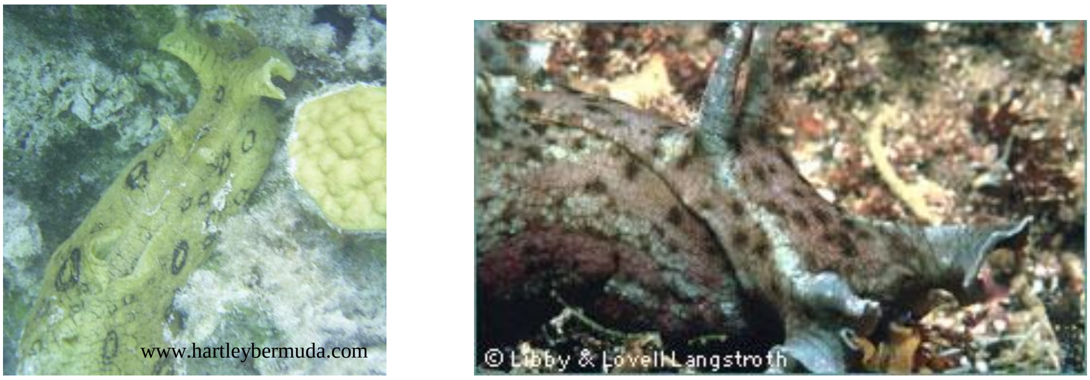


Figure 103: Various body colours of *Sea Hare* designed to blend in with their environment

Between the tentacles are two eyes, which detect changes in light intensity. Extensions of the body wall also cover the sea hare’s back, giving it a hump resembling the back of a rabbit.

The sea hare is herbivorous, feeding on plant foods including algae, eel grass, kelp, and diatoms. It has a toothed tongue like organ called *radula*, which it uses to tear off pieces of food. The food is passed to a gizzard with sharp grinding teeth. Sea hare movement is slow and inchworm-like, but some species can swim by flapping the extensions of their feet. When threatened, one group of sea hares protects itself by producing clouds of purple ink extracted from the red algae on which it feeds. Many other species are simply distasteful to predators.

Sea hares are simultaneous hermaphrodites, meaning that individuals have both male and female sex organs. Individuals cannot fertilize themselves. Sea hares may mate in pairs, each giving and receiving gametes. More commonly they form chains of several animals, each passing sperm forward to the individual in front; sometimes the animals at either end will join, forming a circle. Eggs are usually laid in long, anchored strands that may contain 2 million eggs each. Several egg masses may be laid by an individual in its lifetime of about one year. After hatching, sea hare larvae usually float freely in the ocean for about two weeks, and they are often eaten by many other animals.

- Bivalvia

Bivalve, common name for any mollusc characterized by a shell divided into two valves hinged at one side, gills specialized for feeding, and a reduced head. Bivalves first appeared in the fossil record in the late Cambrian Period, more than 500 million years ago. More than 6000 species are known, including such familiar forms as the clam, cockle, mussel, oyster, scallop, and shipworm. All are aquatic, and most are marine, but freshwater forms are also common. Bivalves typically range in length from 1 to 10 cm, but the tropical giant clam reaches 1.35 m and weighs up to 200 kg.

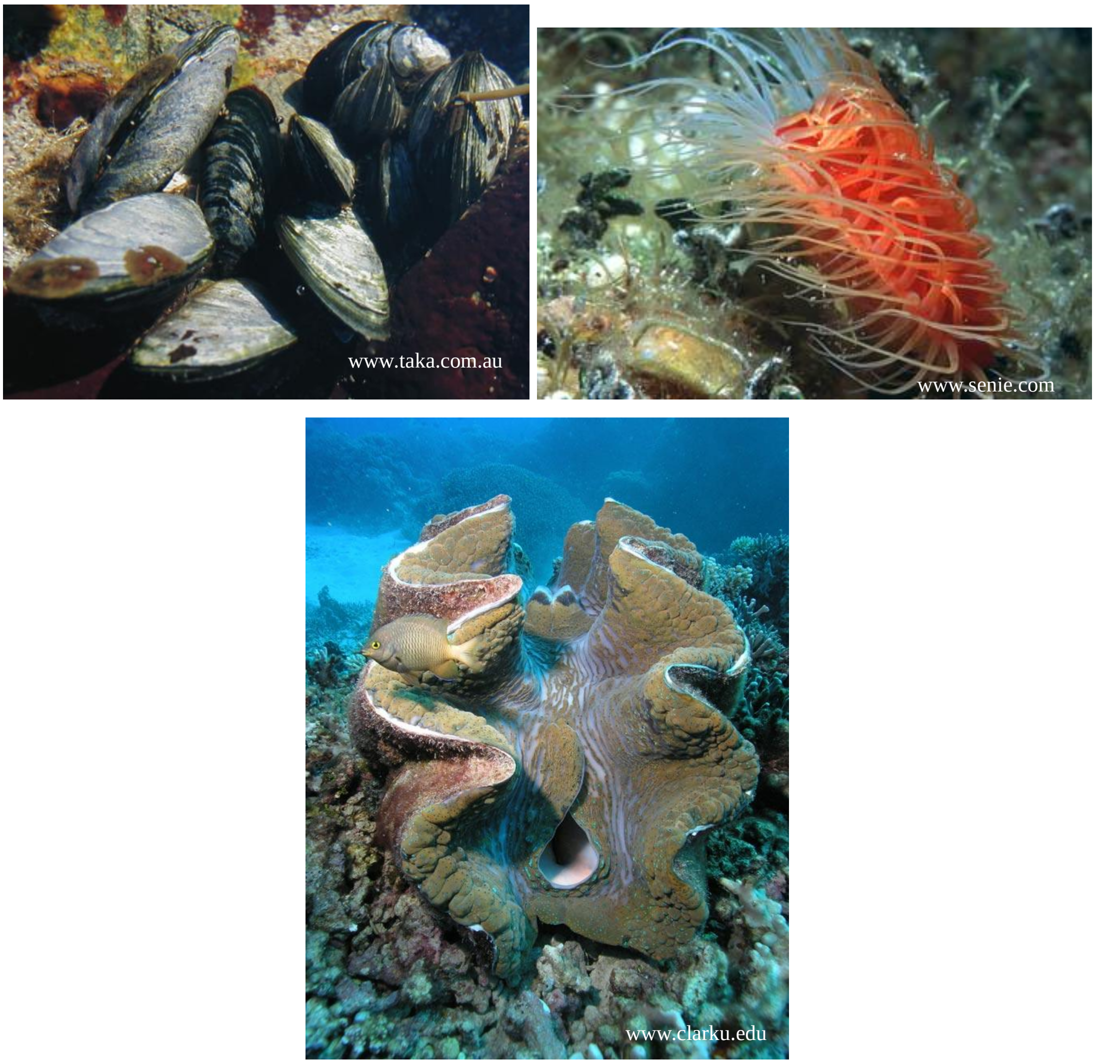


Figure 104: Examples of Marine Bivalves: Mussels, Scallop, Giant Clam

The usual reproductive pattern is to have separate sexes. Sperm and eggs are released into the water, where passive fertilization occurs. The young bivalve, or larva, swims until it locates an appropriate habitat in which to mature. Sometimes, however, the larval stage is omitted, and the young are cared for within the mantle cavity of the adult.

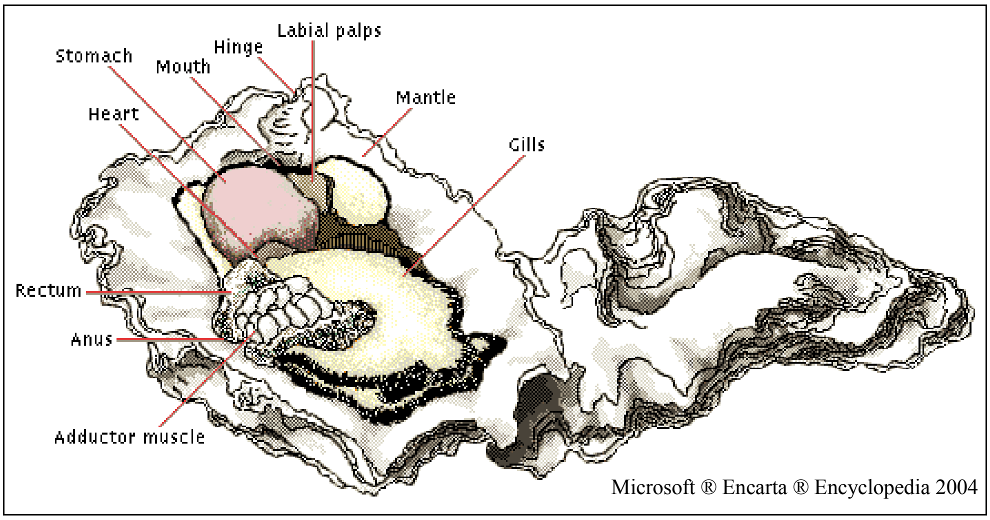


Figure 105: Generalized Anatomy of an Oyster

Enclosed within a thick, sturdy shell, the soft body of an oyster is adapted for filtering minute planktonic organisms from the surrounding water. The gills filter and collect food that the stomach then digests. The mantle is a thin membrane that covers the body and lines the inside of the shell. The adductor muscles and the hinge between the two halves of the external shell help keep the shell closed.

Figure 106: The interior of a mussel

A view of the interior of a mussel shell reveals the mussel's visceral mass containing the gills and internal organs. The circular white structure at the upper right hand corner of the visceral mass is the adductor muscle, which helps to keep the shell tightly sealed against predators or during low tides when the mussel is exposed to the drying air. Most species of mussels are edible and are important ingredients in a number of seafood dishes throughout the world.

Figure 107: Examples of bivalvia – *Arca noe* and *Nucula pella*

I. Phylum Arthropoda

Phylum Arthropoda is a group of organisms that have literally taken over our planet. There are more species in this phylum than in all the other phyla in the animal kingdom combined. Arthropods can be found in all types of environments in creation and are represented in the ocean by many species. Some of the more common marine arthropods someone may recognize are shrimp, lobsters, barnacles, and crabs.

All arthropods are bilaterally symmetric. Their bodies are covered with a jointed suit of armor encompassing not only their abdomens but also their appendages and mouth parts. This armor is called an exoskeleton and it provides body support from the outside of the animal. It is made of chitin (a tough, flexible material) combined with minerals. This combination makes the exoskeleton hard. Muscles are attached to the various segments of the exoskeleton. The muscles are attached to the inside of the exoskeleton, which means that the exoskeleton lies on top of the muscles. As the muscles contract, the exoskeleton bends at its joints, providing movement.

Arthropods must shed their exoskeleton in order to grow, and they must then develop a new, larger one. This process is called molting[26]. In the ocean, once an arthropod begins to molt, it sheds its exoskeleton and takes in water to expand itself. Its bloated body then forms a new, hardened exoskeleton. Once the exoskeleton hardens, the excess water is lost, and the arthropod's reduced body rattles around in a larger exoskeleton with plenty of new room for it to grow. Molting is a dangerous process for an arthropod. Once an individual molts, it takes a few days for its new exoskeleton to harden. Its soft, unprotected body is vulnerable to predators during this time, so the animal will go into hiding. This perilous episode must occur often during an arthropod's life as it matures.

The rigid exoskeleton provides great protection, but also gives the arthropods limitations. The larger their bodies get, the heavier their exoskeleton becomes, and the more difficult it is to carry. The marine arthropods can get much larger than their terrestrial counterparts, because of the added support of the water around them. Some marine crabs can grow larger than 3 meters across.

[26] Molting: The process of shedding an exoskeleton and replacing it with a new one/

- Class Crustacea

Figure 108: ***Palinurus elephas***

Crustaceans are among the most successful animals, abundant in the sea much as insects are on land; thus they are considered to be the "insects" of the sea. Crustaceans are well suited for a marine environment. They have gills for obtaining oxygen, special appendages for swimming (and many other functions as well), and an exoskeleton hardened by calcium carbonate. Crustaceans also have two pairs of antennae to help in sensing their surroundings (*Figure 108*).

Tiny crustaceans are found in countless numbers throughout the ocean. They can be found on reefs, floating as plankton, or hiding among other animals. An abundant group found among the plankton is the copepods. Some copepods filter the water for their food. Others capture prey, and still others are parasitic. The planktonic species have an enlarged set of antennae that helps them to stay afloat in the water.

Although most crustaceans are small, they vary widely in form and include such large members as lobsters up to 60 cm (24 in) long and a spider crab with a leg span of 3.6 m (12 ft). The subphylum contains about 26,000 known species.

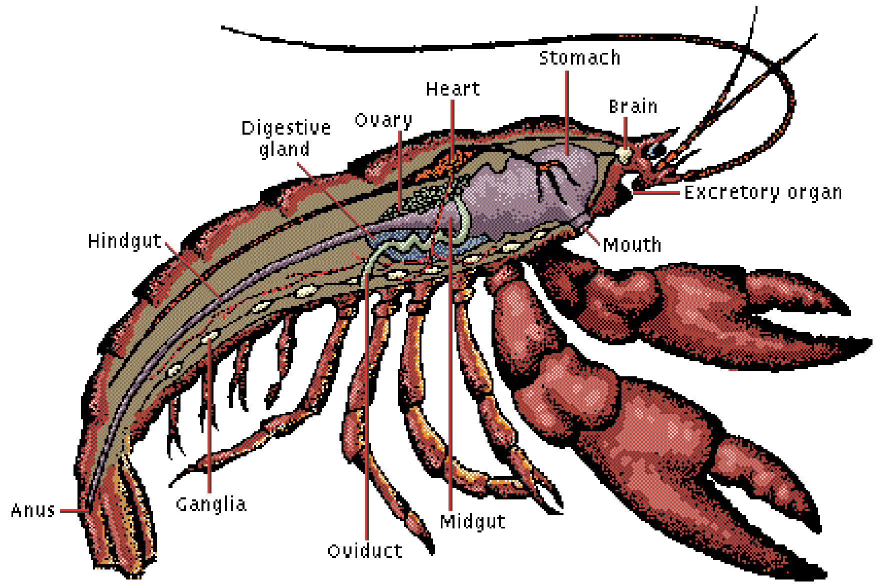


Figure 109: Generalized Anatomy of a Crustacean

Crustacean anatomy is characterized by an external skeleton and a segmented body (*Figure 109*). In different crustacean species these segments and the accompanying limbs have evolved into specialized appendages for respiration, swimming, crawling, and feeding. The extended inner cavity contains the digestive and nervous systems.

The use the moulting or ecdysis process in order to grow bigger. Crustaceans also have the ability to regenerate any part of their body that was lost before moulting. The new part will be slightly smaller and weaker than the original part that was lost and may reach the original size after another moult.

Crustacea are gonochoristic. They male usually have sexual organs called gonopodia and are placed in the abdominal area (*Figure 110*). Usually the claws of the male are stronger and bigger than the claws of the female. After mating the eggs are laid and stick on the abdominal area of the female until they hatch (*Figures 111 and 112*).

Figure 110: ***Procambarus clarkii*** **- the gonopodia are visible here performing, in mating process**

Figure 111: A female ***Procambarus clarkii*** **crayfish with eggs**

Figure 112: ***Palamon elegans*** **- the eggs are visible in the abdominal area**

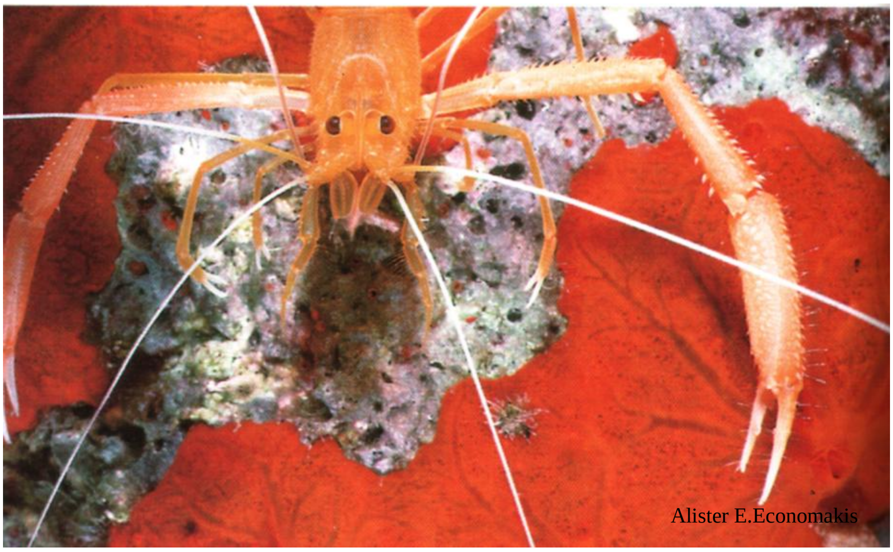


Figure 113: Stenopus spinosus

- **Barnacles**

Barnacles are commonly mistaken for mollusks because they have calcium plates surrounding their bodies, but they are true crustaceans. In the first of two larval stages, they look a bit like shrimp. In their second larval stage, they permanently attach themselves to a hard substrate (*Figure 114*). Because the adhesive used for attachment is strong and impervious to water, marine biologists continue to study these remarkable animals. Once attached, they are dependent on waves or ocean currents to bring them planktonic food. The way a barnacle feeds is almost like an animal lying on its back and kicking its food into its mouth with its feet. Their "legs" are feather-like appendages that sweep the water, capturing tiny plankton. In most species, the barnacle extends them outside of its protective plates while it is feeding.

Figure 114: Barnacles attacked at a hard substrate

- **Amphipods** and **Isopods**

They are slightly larger than 1cm in length. Amphipods generally have laterally compressed bodies while isopods have ventrally flattened bodies (*Figures 115 and 116*). They are both found among seaweeds and on seashores. Some are found living among the plankton. Others are parasitic, burrowing into the skin of whales or fish.

Figure 115: *Gammaridea* spp of the order Amphipoda

Figure 116: *Zenobiana prismatica* of the order Isopoda

- Krill

They are a little larger than the amphipods and isopods, growing to about 5cm. They are planktonic organisms that resemble shrimp. Most krill are filter feeders, eating other plankton. Arthropods typically have three body segments: head, thorax, and abdomen. Like the shrimp and some of the larger crustaceans, the head and thorax of the krill are fused together, forming a cephalothorax[27]. It is covered with an armored covering called a carapace[28], protecting the anterior part of its body.

Tremendous quantities of krill are found in cold polar waters where whales and penguins feed.

- **Decapoda**

The shrimp, lobsters, and crabs belong to the order Decapoda, meaning “10 legs,” and are the largest of the marine arthropods. Decapods have five pairs of legs for walking. The first pair is usually larger and has claws for obtaining food and for defence. Their body is divided into two major parts. The carapace covers the fused head and thorax sections of the cephalothorax. The other part is the abdomen.

- Shrimp and lobsters

The have a long abdomen and many live on the ocean bottoms where they scavenge for leftover bits of food (*Figure 117*). Some shrimp actually feed on the parasites of fish. They set up “cleaning stations” where a fish can swim up and allow the shrimp to crawl all over its body (and even inside its mouth), picking off and eating the various parasites. Sometimes there will be lines of fish waiting for the shrimp to do this service. This is another example of symbiosis: mutualism. Both animals benefit from this situation. The shrimp gets plenty of food to eat and the fish gets all its parasites removed.

Lobsters feed in the same way as shrimp, but they usually do it at night. They also have been known to capture prey with their large, ominous claws. Hermit crabs,

[27] Cephalothorax: the anterior part of an arthropod body, consisting of a head and other body segments fused together.
[28] Carapace: an armored shield that covers the anterior portion of crustaceans.

which are not really crabs, fit their elongated soft abdomens into abandoned gastropod shells. Many cover their shells with algae or even other animals, like sea anemones and sponges, in order to camouflage themselves.

Figure 117: The lobster *Palinurus elephas*

- Crabs

They have a small abdomen that is folded under their larger, usually rounded cephalothorax. The males have a small, narrow abdomen, but the females have a wider, flattened abdomen for carrying eggs (*Figure 118*). There are more species of crabs than all the other decapods. Most scavenge for their food in the same way as shrimp. Because the hard exoskeleton keeps the moisture on their gills from evaporating, crabs can survive on land for quite some time. In fact, there are some species that spend their entire adult lives on land, returning to the water only to reproduce.

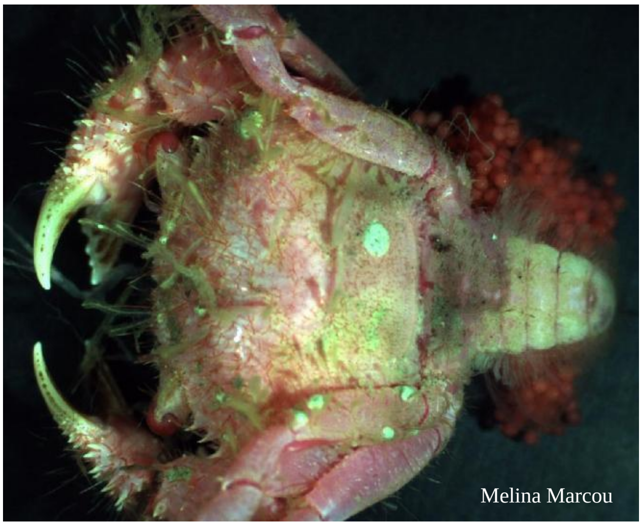


Figure 118: A female *Eriphia verrucosa* carrying eggs

- <u>Other classes of Arthropoda</u>

Members of class **Pycnogonida** are more commonly called sea spiders. Although they look like spiders, sea spiders are not true spiders. They can have eight or more paired legs and a tiny body. They feed on soft invertebrates, like sponges, and are usually found in cold waters. There are a few true insects (class Insecta) found in ocean areas, too. More commonly found at the water's edge, they live among algae, barnacles, and rocks, foraging for food.

The members of class **Merostomata** are known as the horseshoe crabs, although they are not true crabs (*Figure 119*). They live in the soft bottoms of shallow water and have a horseshoe-shaped carapace covering their 10 paired legs.

Figure 119: Horseshoe Crab

These organisms are notable because they are widely represented in the fossil record. Some scientists call them "living fossils" because they have not changed in appearance from their fossilized ancestors. This is particularly significant, as they are found deep in the fossil record, in rock that evolutionists say is hundreds of millions of years old. In the supposed hundreds of millions of years in which they have lived on earth, they should have changed their forms through the process of evolution, yet they have not. This is typical of what we see in the fossil record, and it is a huge stumbling block for those who want to believe in evolution. Perhaps the best explanation of this phenomenon is that there are not millions of years recorded in the fossil record. Instead, the organisms we see were created in their kind to fit into a specialized niche in creation by an intelligent Designer.

J. Phylum Echinodermata

Phylum Echinodermata is an exclusively marine phylum. Echinoderms include organisms such as: sea stars, sea urchins, and sand dollars. The phylum name is derived from their spiny skin.

They usually show a superficial five-part radial symmetry, and generally are equipped with peculiar tube feet. However, their larval forms are not radially symmetric. Instead, they are bilaterally symmetric. As a result, scientists consider their radial symmetry as secondary, occurring after their larval development. Another interesting fact about their radial symmetry is that it is pentamerous, based on five radiating parts (*Figure 120*). Since these organisms are radially symmetric, they have no head, dorsal, or ventral sides. Instead, we refer to these animals as having oral (mouth) and aboral (opposite the mouth) sides.

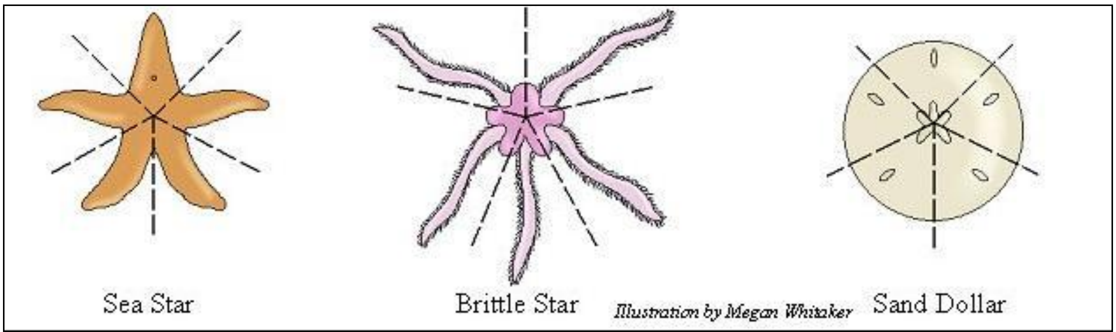


Figure 120: Echinoderm species displaying pentamerous symmetry

Echinoderms are slow-moving bottom dwellers that, with few exceptions, are unable to swim. Nevertheless, they have been given amazing abilities that help them thrive in the ocean. Sea stars, brittle stars, and crinoids have simple, short guts. Most sea stars are carnivorous. Many can evert their guts for digestion before eating. The brittle stars feed mainly on bottom organic material and small live organisms, while the crinoids are primarily suspension feeders. Sea urchins and sea cucumbers have long, coiled guts. The sea urchins need this in order to digest the plant material they feed upon. Sea cucumbers need extra length in order to sort out their food from the sediments through which they crawl and ingest.

Most echinoderms do not have a distinct circulatory system. Instead, their body cavity is filled with a fluid, called coelomic fluid that transports nutrients and gases throughout their bodies.

Although they do not have a head, it is evident that echinoderms have an ordered nervous system, as evidenced by some of their behaviours. One example of this behaviour is that when you turn an organism upside-down, it will quickly re-orient itself to a righted position. If it did not have an ordered nervous system, it would not be able to sense its orientation or right itself when it became disoriented. Thus, even though an echinoderm might look simple, its behaviours show it to be a complex organism.

In most echinoderms, there are separate sexes. Many of them broadcast their gametes directly into the water. As a result, you might think that it would be very rare for the gametes from specific species to come into contact with each other, but there are several mechanisms that increase the possibility of a meeting. Usually, the gametes are released in the same short time period during a particular season of the year. Also, when the gametes of a like species pass by another individual, they actually trigger the release of its gametes. Upon fertilization, the egg develops into a bilaterally symmetric, ciliated larva. Each class of the echinoderms has a characteristic larval form (*Figure 121*).

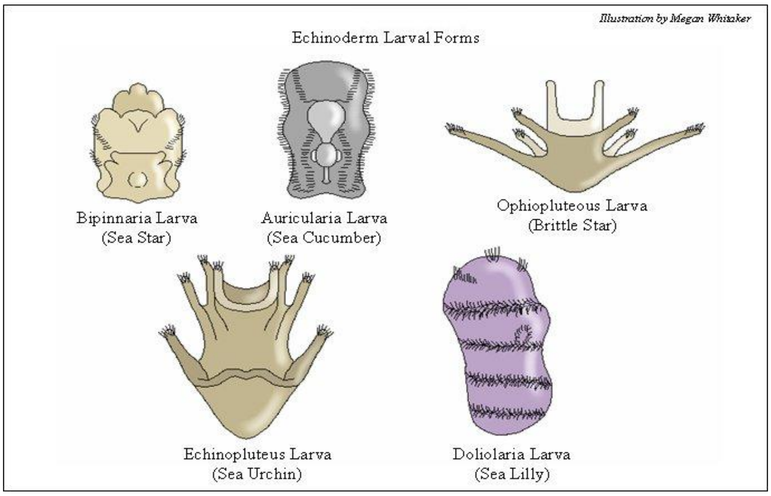


Figure 121: Various forms of echinoderm larvae

One final aspect of many echinoderms: their remarkable ability to regenerate (*Figure 122*).

Figure 122: A Sea Star regenerating

The sea star in the photo looks a little strange because the entire sea star is being regenerated from a single arm. The large arm in the photo is the arm that was separated from the original sea star. The rest of the organism is being regenerated from that one arm. Sea stars not only can they regenerate an arm, they can regenerate the rest of the body from an arm! Actually, all echinoderms can replace substantial portions of their bodies if necessary. As we mentioned before, a sea cucumber can regenerate its intestines when they are eviscerated.

There is an interesting story regarding the importance of studying the ocean and its creatures. Certain species of sea stars are well known for preying on oyster beds. This, of course, reduces the population of oysters, which can adversely affect the finances of oyster fishermen. At one time, oyster fishermen would catch the sea stars, cut them up, and throw them back into the ocean, hoping to reduce their populations and save the oysters. But, of course, this actually had an opposite effect. They were unknowingly increasing the sea star populations, since the sea star parts could regenerate multiple individuals! If these oyster fishermen had learned about the biology of sea stars before trying to reduce their populations, they would have known about the sea stars' ability to regenerate, and that would have kept them from taking actions that resulted in a further reduction of the oyster population.

- <u>Class Asteroidea</u>

Perhaps the most commonly recognized echinoderms are those of the class Asteroidea: the sea stars. Sea stars, or starfish, are usually found on sandy bottoms, in turtle grass beds, or under rocks and coral at depths greater than 1 meter. Most species are five-armed, but the number of arms may vary. Some have six, 10, and even up to 50 arms that radiate from a central disc. Along the oral surface of each arm is a channel called an ambulacra groove[29] from which their tube feet project. The tube feet allow sea stars to move slowly along most any surface.

Sea stars are distributed throughout the sea. Most of them are carnivorous, preying upon snails, barnacles, and bivalves. A sea star can evert its stomach, or push it out of its body in order to digest something without having to eat it. In the case of a bivalve, a sea star needs only to open the valves to produce a gap of one-tenth of a millimetre in order to fit its stomach inside for feeding.

Figure 123: Asterina gibbosa (dorsal and ventral views)

[29] Ambulacral groove: a channel along the oral surface of echinoderms through which the tube feet protrude.

- <u>Class Ophiuroidea</u>

Figure 124: The brittle star *Amphiura chiajei*

Organisms in class Ophiuroidea are known as the brittle stars (*Figure 124*). They are smaller than most other echinoderms and are found on rocky bottoms and coral reefs. Like sea stars, they usually have five arms, but they are long, thin, and flexible to aid in movement. Since they use their arms for locomotion, their tube feet are used more for feeding. Most brittle stars eat tiny animals and bits of organic matter they find on the ocean floor. Brittle stars have the simplest digestive system of the echinoderms. They have a mouth, an esophagus, and a sac-like stomach, but no intestines or anus. Even though this is a very large group with over 1,800 species, they are rarely seen because they are sensitive to light. They seek the dark shadows of crevices and holes and tend to come out at night.

* <u>Class Echinoidea</u>

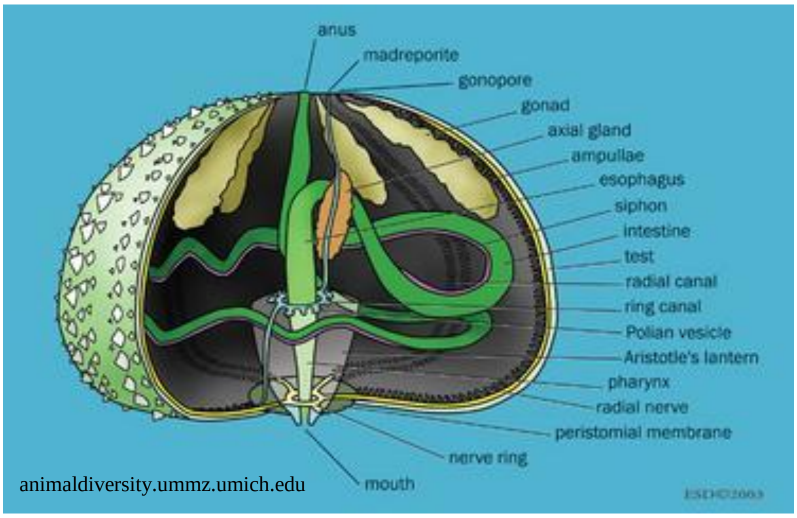


Figure 125: Echinoid anatomy

Class Echinoidea includes the sea urchins, sea biscuits, and sand dollars. A sea urchin resembles a ball with many spines protruding from it. This is actually a rounded endoskeleton with movable spines jointed into sockets. Both spines and tube feet provide locomotion. The tube feet in sea urchins have suckers on the tips for greater traction. The ambulacra grooves (and the tube feet that come from them) travel along the endoskeleton, from the mouth at the bottom up to the anus at the top. They feed on algae, sea grasses, and dead organic matter. Because these food sources are rather hard to digest, sea urchins have a much longer gut than sea stars and brittle stars. The sea urchin's mouth is made up of a very powerful system of muscles and five teeth called an Aristotle's lantern. Some species of sea urchins can actually bore into rock or coral with their Aristotle's lanterns.

Figure 126: The Heart Urchin *Brissus unicolor*

Sea biscuits and sand dollars have a round, flattened endoskeleton with many smaller spines and tube feet (*Figures 127 and 128*). They live in soft bottoms and feed on the organic deposits found there. They use their tube feet to pick their way through their food.

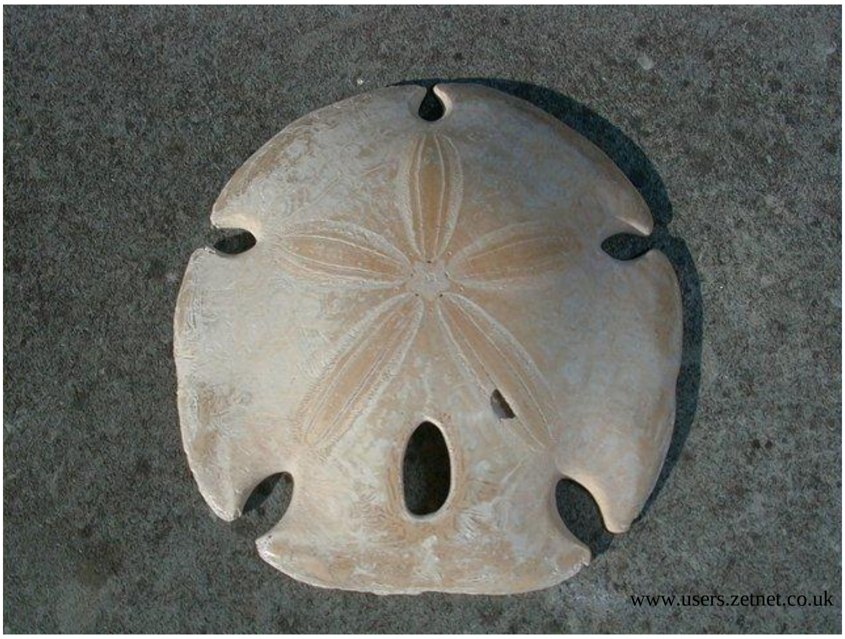


Figure 127: Sand dollar

Figure 128: Sea biscuit

- Class Holothuroidea

The members of the class Holothuroidea commonly known as the sea cucumbers bear little resemblance to the other classes in this phylum. Their bodies are sausage-shaped, and they do not have notable radial symmetry. They have a patchy endoskeleton made up of tiny calcareous spicules scattered throughout their skin. Why, then, are they in this phylum? Among other things, most sea cucumbers have five rows of tube feet extending along their bodies, just like the sea urchins. They eat the sediments of the ocean floor or strain plankton from the water with tentacles near their mouths. Since they eat sediments, they have a long, coiled gut similar to that of a sea urchin. The long gut allows the digestive system to “sort through” the sediments to find what is digestible and what is not.

Figure 129: Leopard sea cucumber (Australia)

Since they have less protection than other echinoderms, many species of sea cucumber have an odd strategy for avoiding predators. When startled or handled roughly, a sea cucumber will eviscerate part of its internal organs. That means it will release its insides to distract a predator. It turns out that most of these creatures have viscera (internal tissues) coated with a sticky substance that can glue a predator's gills or esophagus shut, leading to its death. While the predator begins to eat the jettisoned material, the sea cucumber, which will eventually grow back its lost organs, has time to escape. This is a perfect model of a brilliant military strategy. The sea cucumber is willing to take a few “acceptable losses” (some internal tissue) in order to save the majority of the army (the rest of its body). This is just another incredible example of the creative ingenuity of nature. Sea cucumbers are harmless. Unfortunately, they are good to eat and are considered a delicacy by many cultures.

- <u>Class Crinoidea</u>

Figure 130: Crinoid – Sea Lilly

Class Crinoidea includes animals more commonly called feather stars and sea lilies. These are appropriate names for organisms with many long, feathery arms used for filter feeding. Sea lilies are found in deep water, where they are attached to the bottom. Feather stars move around both shallow and deep waters, crawling over rocks and coral. The crinoids orient their bodies upside-down in relation to the sea urchins, sea stars, and brittle stars. Their mouth and ambulacral grooves are facing up so that the multiple-branched or feathered arms can collect suspended food particles in the mucus of the tube feet. The food is then transferred "foot by foot" until it reaches the mouth for digestion.

2.3.3 *Phylum Chordata*

This phylum is a bit different from the ones already discussed. This is because it is actually composed of two invertebrate subphyla and one vertebrate subphylum. The vertebrate subphylum is the largest of the three and includes all the vertebrates in creation, including humans.

Phylum Chordata is indeed a very diverse group, ranging from tiny gelatinous zooplankton to large fishes and whales. But all chordates share a few main characteristics at some stage of their lives. One characteristic is the presence of a supportive notochord[30] made of cartilage-like material that lies between the nerve cord and the gut.

All members of this phylum have a notochord at some point in their development. In some organisms, the notochord turns into vertebrae during their early development. Those organisms are vertebrates. If an organism's notochord does not turn into vertebrae, the organism is a member of one of the two invertebrate subphyla described below. Another common characteristic of the chordates is the presence of a hollow dorsal nerve cord[31] that runs along the dorsal length of the animal.

Finally, all chordates have folds of skin located along the neck during their embryonic development. These folds are called pharyngeal pouches. In most aquatic chordates, these pouches develop openings that allow water to flow over the gills located inside the pouches. In non-aquatic organisms (like humans), no openings form, but the folds of skin develop into various structures on and near the neck (like the thymus gland).

[30] Notochord: a flexible supportive rod that runs the length of the body of the chordates.
[31] Dorsal nerve cord: a long bundle of nerve cells located along the dorsal part of an organism's body.

A. Subphylum Urochordata

Subphylum Urochordata is entirely marine, and its members are commonly called tunicates. Members of this subphylum are called “tunicates” because as adults, the animals cover themselves with a leather-like “tunic.” The tunicates have a notochord and dorsal nerve cord throughout their larval stage, but they disappear when the organisms become adults. Some of the more common individuals are the sea squirts and the ascidians (*Figure 131*). These animals are attached to a soft substrate, and are often mistaken for sponges due to their rounded appearance.

Figure 131: Sea squirts

Tunicates filter the water for food by taking it into their mouth through a siphon and passing it through a ciliated sac (*Figure 132*). The openings of the sac are developed from gill slits. When food is filtered from the water it is passed to a U-shaped gut and released out of another siphon. The sea squirts get their interesting name from the jet of water that squirts out of both siphons when they are disturbed.

Figure 132: Lightbulb Tunicates or "Chrystal Bells" *Clavelina lepadiformis*

In its larval stage, the sea squirt resembles a tadpole and is therefore called a tadpole larva. It has both a dorsal nerve chord and a notochord. It swims around for a brief period, and then it attaches itself to something on the bottom of the sea. Once attached, the sea squirt begins to develop into its adult form. The nerve chord and notochord are recycled to form new tissues, the organs rotate so that the siphon openings point upwards, and a leathery "tunic" is formed around the animal's exterior for protection and support.

Some tunicates live their entire lives as plankton. The salps are shaped like tiny barrels, with a siphon on the anterior end and a siphon at the posterior end. Colonies of salps float in warm waters and can grow up to many meters in length.

B. Subphylum Cephalochordata

This tiny subphylum, Cephalochordata**,** consists of less than 30 species. These organisms, commonly called lancelets, are shaped much like a fish. They retain their notochords and dorsal nerve cords throughout their lives. They tend to spend the majority of their time buried in the sand (*Figure 133*). This allows them to hide from predators without hampering their ability to obtain food. Like the sea squirt, the lancelet takes in food by filtering the water.

Figure 133: Lancelet buried in the sand

Water is drawn into the creature by the beating of cilia located just inside the mouth. This water is first filtered through the oral cirri, which clean it of large, indigestible debris (such as the sand in which the lancelet is buried). As the water passes into the pharynx, it travels through slits. The food particles in the water are trapped in the slits, and the water flows out into the atrial cavity, eventually leaving the body through the atriopore. The food particles that have been trapped in the slits of the pharynx get sent into the gut, where they are digested. Any undigested remains leave through the anus.

Lancelets generally grow to lengths of about 1 inch. The lancelet is very common in tropical, marine environments. At Discovery Bay, Jamaica, for example, biologists have reported populations of up to 5,000 lancelets per square yard of sand! In many parts of the world, particularly in certain regions of Asia, the lancelet is actually a very important food item. There are some fishermen who make their living solely by harvesting lancelets.

2.3.4 Marine Vertebrates

Organisms in the two subphyla previously mentioned, have a notochord and a dorsal nerve cord, but they are considered invertebrates because they do not have a backbone.

A third subphylum within phylum Chordata is the Vertebrata. The organisms in this group have a backbone, or vertebral column, that replaces the notochord during development. The vertebral column is a series of integrated bone (or other hard substance) units that provides support for the body. Furthermore, these skeletal elements enclose and protect the nerve cord, which is called the spinal cord. Vertebrates display bilateral symmetry and have an endoskeleton. One of the great advantages to an endoskeleton is that it is made of living material that can grow with the animal. This is in contrast to the exoskeletons of arthropods, which must be shed in order for the organisms to grow.

There are many organisms in this subphylum, including marine fishes (fishes: referring to many kinds of fish). Fishes have a tremendous impact on the ocean environment. They feed on most types of marine plants and animals. They are host to many parasites and other symbionts (organisms involved in a symbiotic relationship). Moreover, they are a resource of food for humans. Fish products are found in fertilizers, livestock food, vitamins, and various other materials. There are three major types of marine fishes: jawless, cartilaginous, and bony.

A. Class Agnatha

The creatures in class Agnatha are commonly called jawless fish. This group is characterized by what they don't have. Not only do they lack jaws, but they also lack the paired fins and scales of most other fishes. They also lack true bones. Their skeletons are made of flexible cartilage. Since they do not have jaws, they feed by suction, using their round, muscular mouth and multiple rows of teeth. Only two orders of these fishes are known to exist: the hagfishes and the lampreys.

Hagfishes are bottom-feeding scavengers that live in tunnels they dig in the muddy bottoms of cold waters. These animals could easily be featured in a scary, midnight movie. They bore into their prey and then eat them from the inside out. They also can secrete a thick slime onto their skin that deters predators. Hagfishes occasionally will tie their eel-like bodies into a sliding knot in order to clean the excess slime from their bodies and to give them leverage when tearing apart food (*Figure 134*).

Figure 134: Hagfish in a sliding knot

The lampreys are found in temperate waters and are primarily fresh water fish. Many lampreys are hatched in fresh water rivers and streams, but they then move into marine water for their adult lives, returning back to fresh water to reproduce. Creatures with this type of life cycle are called anadromous[32].

[32] Anadromous: a life cycle in which creatures are hatched in fresh water, migrate to salt water when adults, and return to fresh water in order to reproduce.

As adults, most species of lampreys are parasites of bony fishes (*Figure 135*). These interesting fish use multiple, hook-shaped teeth within their round, muscular mouth to attach to their hosts. They then scrape through the skin with a raspy tongue until blood begins to flow. Lampreys suck down the blood of their hosts with the help of anti-clotting salivary enzymes that aid its flow. They continue to feed until the host has lost most of its blood supply and is near death.

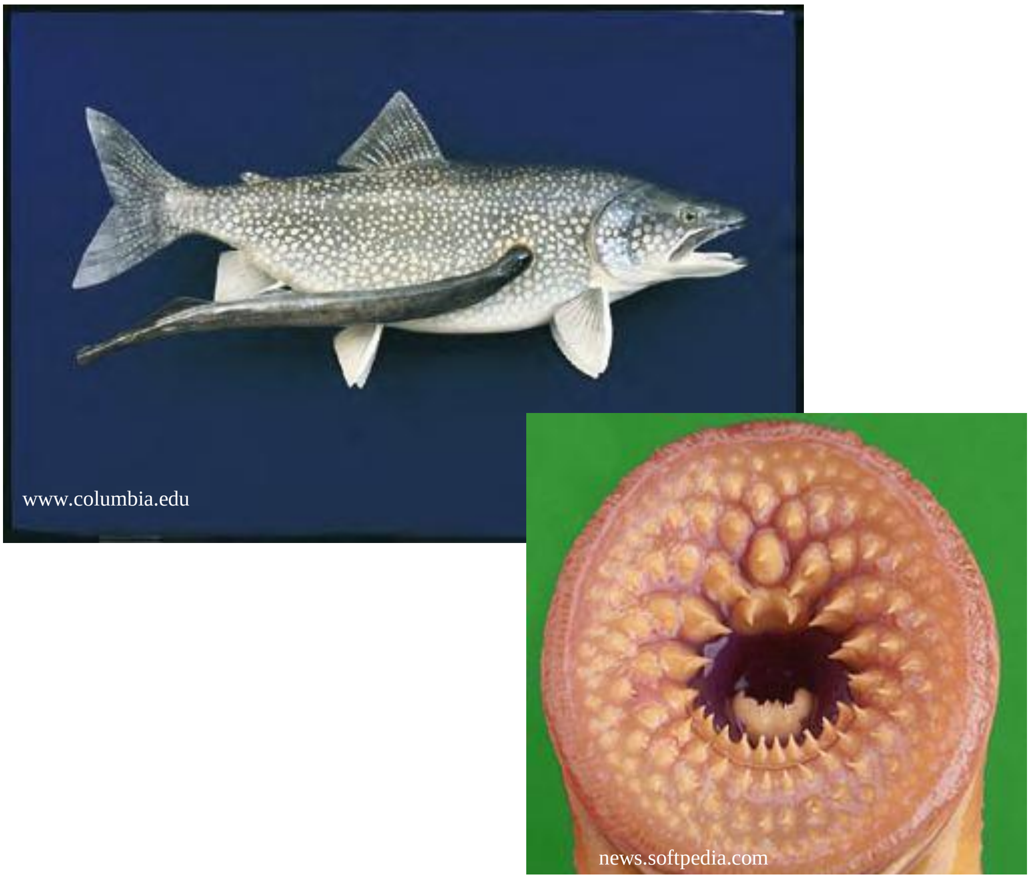


Figure 135: Sea lamprey attached to a bony fish

B. Class Chondrichthyes

This class is home to the sharks, rays, and skates. The name “chondrichthyes” comes from the Greek *khondros*, meaning cartilage, and *ichthyes*, meaning fish. Thus, the name tells you that this group is composed of cartilaginous fish. In deed, the sharks, skates, and rays do not have bones in their bodies. Instead, their endoskeletons are made entirely of cartilage and are very flexible. It is flexible because it is composed of cartilage covered by skin. The thicker the cartilage, the less flexible it will be.

There are a few creatures in this class that do have some pretty hard parts in their skeletons. In these creatures, some of their cartilage has become hardened with calcium salts and is quite strong. Although you might be tempted to call these pieces of hardened cartilage “bone,” they are not true bones. In a true bone, the cartilage is hardened by calcium salts (calcified) while the bone is being formed. In these creatures, the pieces of skeleton are calcified after they are completely formed. In addition, true bone contains bone-producing cells called osteoblasts and mature bone cells called osteocytes. Neither of these cells is present in the skeletons of the members of class Chondrichthyes.

Their mouth is usually located on their ventral side and, in the case of sharks, is curved downward, giving the appearance of a threatening frown. Also, members of the class Chondrichthyes have paired, lateral fins that provide much more efficient swimming than fins of the eel-like agnathans. An interesting feature of the cartilaginous fishes is that, technically, their entire bodies are covered with teeth. They have rough, sandpaper-like skin because of the presence of tiny scales made from the same material as that of teeth. These scales are technically called placoid scales, but they are also appropriately called denticles.

- Sharks

Sharks are magnificently designed for fast swimming and maneuverability. They are torpedo-shaped, which helps them move easily through the water (Figure 136). Sharks are amongst the most ancient vertebrates in the sea; ancestors of modern sharks originated almost 400 million years ago. Today sharks live in essentially the same way they did more than 200 million years ago, before the rise of the dinosaurs. Scientists have identified nearly 375 species of sharks living today, ranging in size from the dwarf dogfish, less than 20 cm in length, to the massive whale shark, which reaches lengths of more than 15 m. Most sharks inhabit tropic or temperate marine waters, but some species have been found in polar seas. The bull shark leaves ocean waters to enter freshwater rivers and lakes, including the Zambezi River in southeastern Africa, the Mississippi River in the United States, and Lake Nicaragua in southwestern Nicaragua. Depending on the species, sharks inhabit either shallow coastal waters or the open ocean. Some species, such as the sixgill shark, live at depths of more than 1,800 m.

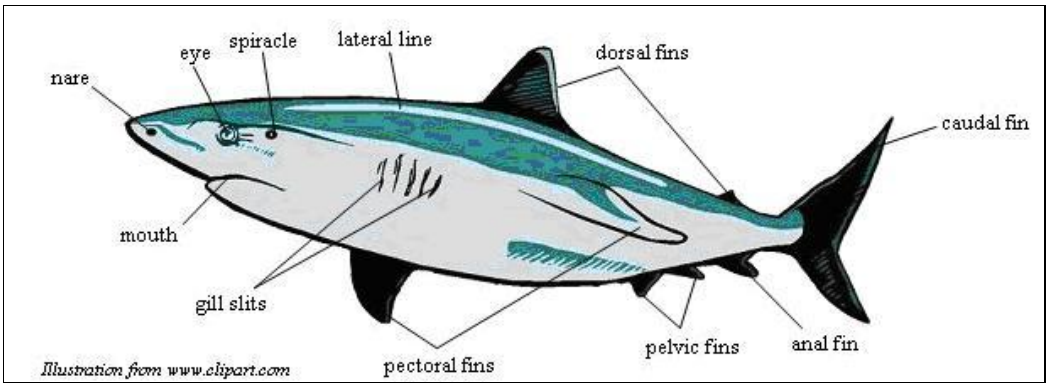


Figure 136: Exterior features of a shark

Sharks have a series of fins that help them steer through the water. The caudal fin, or tail fin, is composed of two lobes; the upper lobe is usually longer than the lower lobe. Interestingly, the sharks that spend more of their lives in the deep open ocean have caudal fin lobes of nearly equal length, which helps to provide greater lift while they swim. On the back side of the body are two dorsal fins. The most anterior dorsal fin is usually larger and is the stereotypic triangular shape you see sticking out of the water's surface in movies. Their paired pectoral fins are typically long and pointed, giving them excellent steering ability as well as much-needed lift in the water column. The pelvic and anal fins are used for stabilization.

Sharks have a sharp sense of smell. Unlike humans, shark's sense of smell is not connected to the shark's breathing. Humans smell things by breathing air in through our nose. The olfactory (smell) organ in our nose samples the air as it passes to our lungs and sends messages to our brain. The brain then interprets the signals as smells. In a shark, the olfactory organs are blind sacs that do not lead anywhere. These sacs have external openings called nares that allow water to flow into the sacs, and the receptors in the sacs sense the water and send messages to the brain. Those messages are then interpreted by the shark as smells. They are the most perfectly evolved hunter that lives today in the ocean. It can sense vibrations and distinguish those of a dying fish, and those of a healthy one.

Most sharks continuously swim their entire lives. This aids in helping them to breathe. When sharks swim, water is forced into their mouths and passes over their gills. It then moves out through their gill slits. When most sharks stop swimming, the water moving past their gills is greatly reduced, diminishing the available oxygen. Scientists used to think that sharks would literally drown if they did not swim. That is not the case, however, because it has been shown that they can pump water over their gills if needed. Many sharks have spiracles, which are actually the shark's first gill slits. They aid the sharks in pumping water through the gills when the sharks are at rest. This is more of an effort than allowing the water to pass over their gills while swimming, however, so sharks usually swim. To aid in getting water to their gills while swimming, sharks often swim with their mouths open (*Figure 137*).

Figure 137: Scalloped Hammerhead Shark

Since swimming with its mouth open often shows its teeth, it might look like the shark is being aggressive. However, it is simply “breathing with its mouth open.”

There are a few species of sharks, such as the nurse shark (genus *Ginglymostoma*), that can obtain plenty of oxygen from the water without swimming. These sharks are often found resting on the ocean bottom (*Figure 138*).

Figure 138: Nurse Shark resting on the ocean bottom

Sharks present a threatening appearance, baring row after row of razor-sharp teeth. Their triangular, calcified teeth vary in shape depending on the species. One reason for this variation is that different types of sharks tend to feed on different prey, and they have teeth specifically designed for the prey they tend to eat. If you were to find a lone shark tooth washed up on the seashore, you could probably determine the type of shark from which it came (*Figure 139*). Sharks' teeth are a common find among sport divers because sharks regularly lose their teeth. Sharks' teeth are a common find among sport divers because sharks regularly lose their teeth. When one is lost, another from the row behind it will advance forward to take its place (*Figure 140*). It has been calculated that some sharks replace an entire row of teeth in 10 days. This is a perfect design that enables them to always have fresh, sharp tools for feeding.

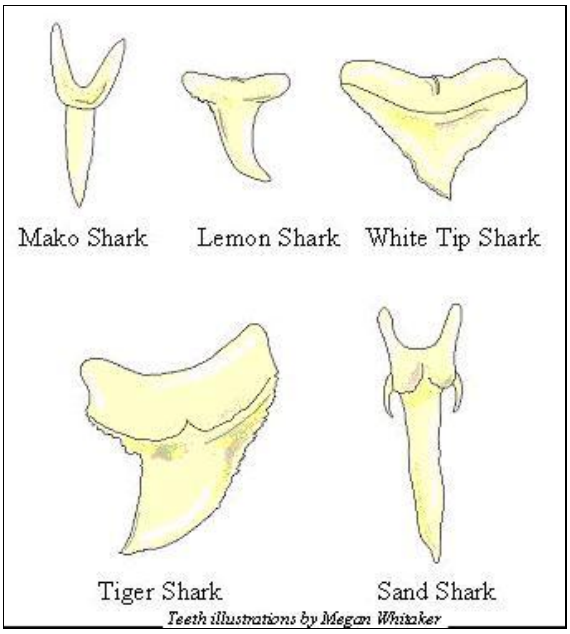


Figure 139: Shark teeth

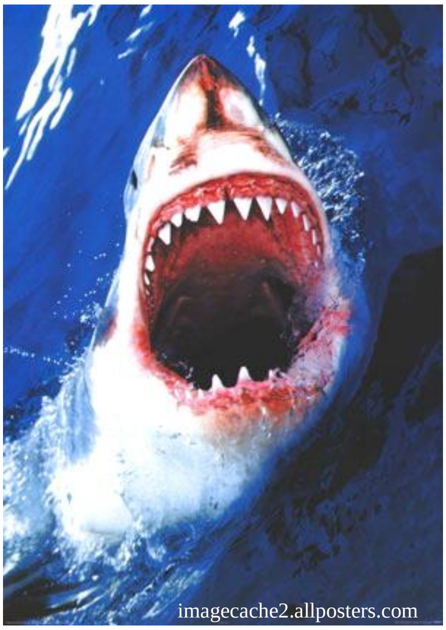


Figure 140: Great White Shark (rows of teeth visible on the bottom of the jaw)

Some shark species have a different head shape. Hammerhead and bonnet head (genus *Sphyrna*) sharks have a flattened head shape with their eyes on the outer edges. This unusual head shape helps the sharks make very tight turns in the water, and it also increases their abilities to sense prey. Sawsharks (genus *Pristiophorus*) have a flattened head that extends into a blade, edged with teeth for slicing at fish that swim above. Some shark species have varying tail shapes. The upper lobe of the caudal fin of thresher sharks (genus *Alopias*) is as long as their body length. It is used to corral schooling fishes together so that the shark can prey upon them. Other species have horns or horny projections on their bodies. The goblin shark (genus *Mitsukurina*) has a horn-like extension from its forehead, and the dogfish (genus *Squalus*) has spines anterior to its dorsal fins.

The size of sharks varies drastically among species as well. The smallest known species is the spiny pygmy shark (genus *Squaliolus*), whose full-grown size is about 15 centimeters. The largest sharks (in fact, the largest of all fishes) are the basking shark (genus *Cetorhinus* – up to 45 feet long) and the whale shark (genus *Rhincodon* – up to 60 feet long). These sharks are not even carnivorous. They swim through the water, straining plankton through large gill rakers. Because they are not carnivorous, their teeth are very tiny, and they most likely help with the filter-feeding process.

With the exception of whales, these are creation's largest living animals. Sharks inhabit nearly all parts of the ocean at almost all depths. They are commonly found in tropical waters, and that's where they more often come into contact with people Sharks do not hunt humans as a natural prey. In fact, of all the genera of sharks, only about two dozen have actually been documented to attack people. The most notorious of those are the great white shark (genus *Carcharodon*), the tiger shark (genus *Galeocerdo*), and the bull shark (genus *Carcharhinus*). Most cases of shark attacks on people are due to a case of mistaken identity. Many surfers are the unfortunate victims of these accidents. It seems that, when viewed from below, the silhouette of a surfer paddling on his surfboard is similar to that of a seal or sea lion – these sharks' favorite food. Some parts of the world try to prevent this threat by removing the shark populations from the coastlines, but this actually can have an adverse effect. In one case, large sharks were netted off the coast of South Africa. As a result, the number of small sharks, which were being eaten by the large sharks, increased. The small sharks then began to feed on the bluefish population, which was a commercially important resource in that area. It is evident from this situation that sharks play an important role in the balance of nature.

- <u>Rays and Skates</u>

There are about 500 species of rays and skates in the ocean. In contrast to that of a shark, a ray or skate's body shape is flattened with a thin, distinct tail (*Figure 141*). Their pectoral fins are very large and wing-like (usually undistinguishable from their heads), enabling many of them to appear to "fly" through the water. Most of these creatures are bottom-dwelling organisms. Scientists use the term demersal to refer to bottom-dwelling fish.

Figure 141: Stingrays

Another distinctive feature of this group is that their five gill slits are located on the ventral side of their bodies. Because they are so flattened, their eyes are located on the top of their head (*Figure 142*). This is obviously helpful to a bottom-dwelling animal.

Figure 142: Thornback Skate

Stingrays have a whip-like tail that has stinging spines at its base. These spines usually have barbs oriented in a reverse direction, so they look much like a fishhook. When a spine goes into flesh, it will not easily come out, because of the barbs. To make this defence mechanism even more powerful, the spines usually have a groove used to inject venom. These animals do not use their spines for aggression, but strictly for defence. An unsuspecting person may accidentally step on a stingray lying on the sandy bottom of the ocean and receive a terrible surprise. To avoid such nasty surprises, you can simply scuff your feet as you walk in shallow water. The commotion your feet make as they scuff along the ocean bottom will scare away any stingrays before you have a chance to step on them.

Stingrays live on the sandy bottom of the ocean because this is where their food lives. They rest on the ocean floor, partially covered with sand for camouflage. This allows them to easily feed on clams, shrimp, crabs, and other small animals found there. To eat these hard-shelled organisms, rays have a set of plates instead of teeth. The plates are large and flat, and are made of calcified material in order to crush the hard shells of their prey. They generally feed by suctioning prey into their mouth and then crushing the prey with their mouth plates.

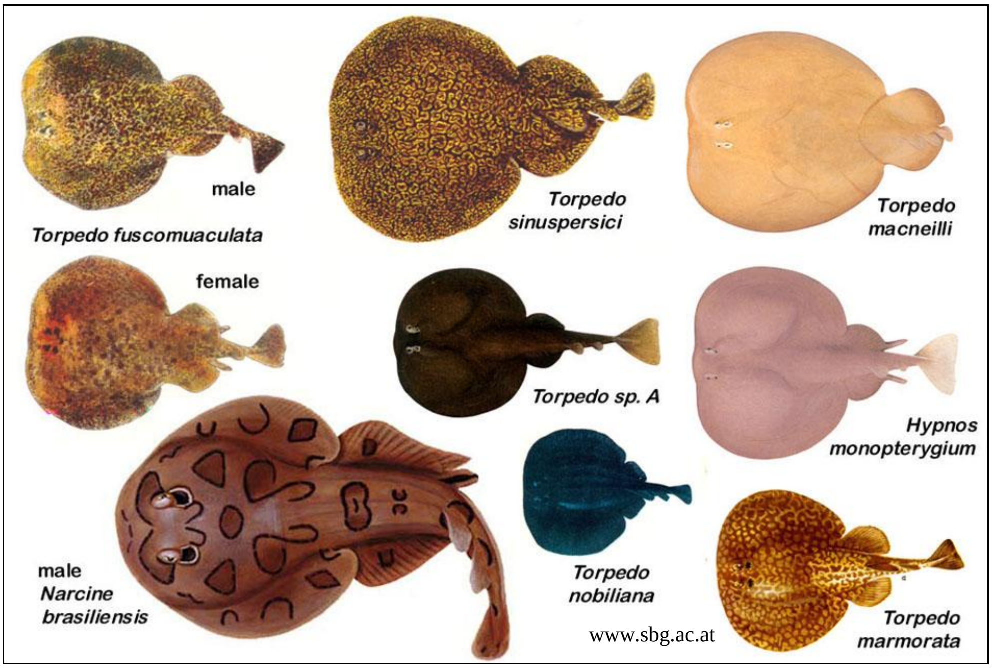


Figure 143: Selection of electric rays

Electric rays stun their prey and protect themselves with two groups of special muscles located near the head. These muscles produce a powerful electric charge that can deliver electricity with a potential of over 200 volts. Electric rays have a disc-shaped body and a well-developed caudal fin. They are found in all oceans and all depths. Electric rayes of the order Torpediniformes have torpedo-shaped bodies (*Figure 143*).

Now there are some rays that are not demersal. Manta rays (genus *Manta*), also called devil rays, and eagle rays (genus *Aetobatus*) have pectoral fins that resemble wings for “flying” in the water (*Figure 144*). Mantas feed on plankton as they move through the water column. Eagle rays rummage through the sandy bottoms with their fleshy snout, looking for clams. These “flying” rays can grow quite large. The mantas can grow to 6.7 meters from one pectoral fin tip to the other. Skates are very similar to rays with the exception of the whip-like tail and spines. Instead, they have a more fleshy tail. They also lay egg cases, while rays usually have live young.

Figure 144: Manta (devil) ray and Eagle ray

C. Class Osteichthyes (The Bony Fishes)

Most of the fishes in creation are in class Osteichthyes and they are typically called bony fishes. This is because the Greek word *osteon* means “bone,” and *ichthyes* means “fish.” Members in this class have a skeleton made at least partially of bone. Their numbers represent about 98% of all fishes and nearly half of all the world's vertebrates.

Both groups, bony and cartilaginous fishes, are indeed true fish, but you will see that there are many physical differences. Bony fishes have a flap made of bony plates called an operculum (*Figure 145*). It covers and protects their gills. Like a cartilaginous fish, a bony fish opens its mouth and draws water inside. It then closes its mouth and, unlike a cartilaginous fish, opens its operculum to allow the water to exit. The water first passes over the gills, where dissolved oxygen is taken in and carbon dioxide is diffused out. The operculum provides a more efficient process than the gill slits of cartilaginous fishes by acting as a “back door” and keeping the water from flowing in the wrong direction.

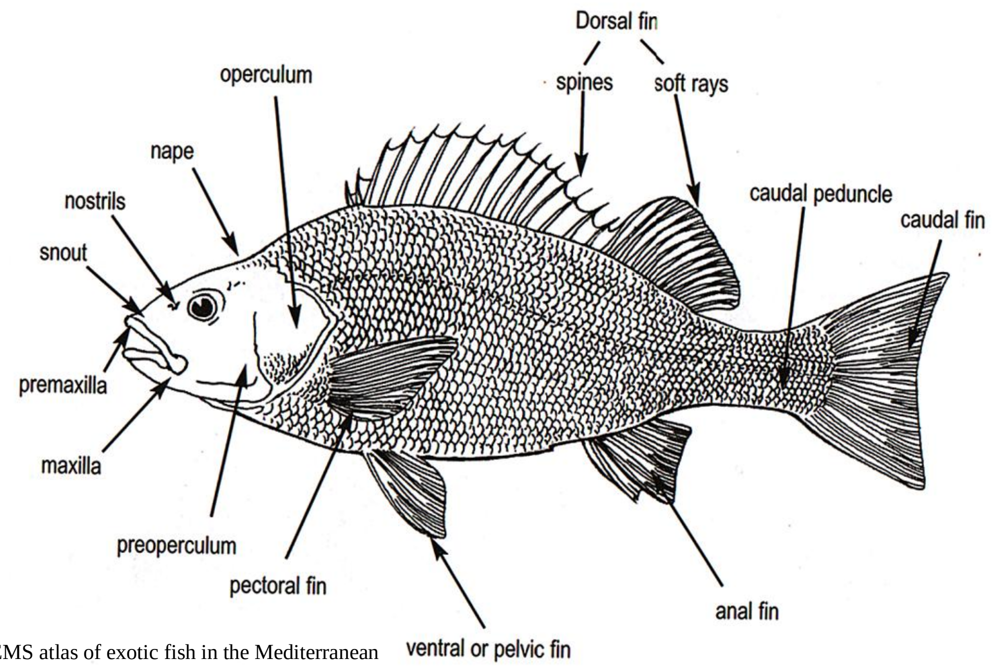


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Figure 145: Exterior features of a fish

There is a tremendous diversity in the marine fishes (*Figure146*). A fish's body shape is dependent upon its swimming habits. The most common idea of a fish is a streamlined creature, slightly flattened on its sides, with fins for steering and manoeuvrability. This is generally called a *tapered* body shape, and it allows the fishes to “slice” their way through the water. Parrot fishes, squirrel fishes, and wrasses have this body shape. The fast, open-water swimmers like sharks, jacks, and barracuda also have this same body shape, which allows for the least resistance possible while these fishes move through the water. The bottom-dwelling (demersal) fishes are flattened from top to bottom, like a pancake. This ray-like shape aids in camouflage, which is helpful in both hiding from predators and capturing unsuspecting prey. Along with the skates and rays, batfishes have this shape.

In contrast to the fishes with tapered body shapes, fishes that are *disc- and box-shaped* do not need to move quickly through the water. They tend to spend their time swimming around coral reefs, travelling short distances in no particular hurry. Puffer fish have box-shaped bodies while damselfish have the disc body shape.

Some fishes have *elongated* body shapes as well as eel-like body shapes. Examples include eels, trumpet fish, and cornet fish. The shapes of these fishes are perfectly suited to their habitats. The snake-like eels, for example, are fish that live in narrow crevices of rocks or coral. Their eel-like body shape makes it very easy for them to navigate in close quarters. The elongated pipefish orients its body so that its tail points up. This position allows it to live hidden among beds of long, thin turtlegrass. For this fish, then, its elongated body shape aids in camouflage.
Some fishes have irregular shapes. These shapes allow them to blend in among corals and rocky surfaces underwater. For example, frogfishes have a bumpy, irregular shape that strongly resembles the seafloor or the surface of a coral reef. Their multiple hues and un-fish-like shape help them blend in well with their surroundings. This is important, because frogfishes hunt prey by flicking a specialized dorsal spine that has a fleshy “lure” on its end. When a frogfish flicks the dorsal spine, the lure moves enticingly near the frogfish's mouth. Smaller fish think this lure is food, so they are attracted to the lure and then sucked into the frogfish's mouth. If the frogfish did not blend in with its surroundings so well, its prey would never be fooled by the lure.

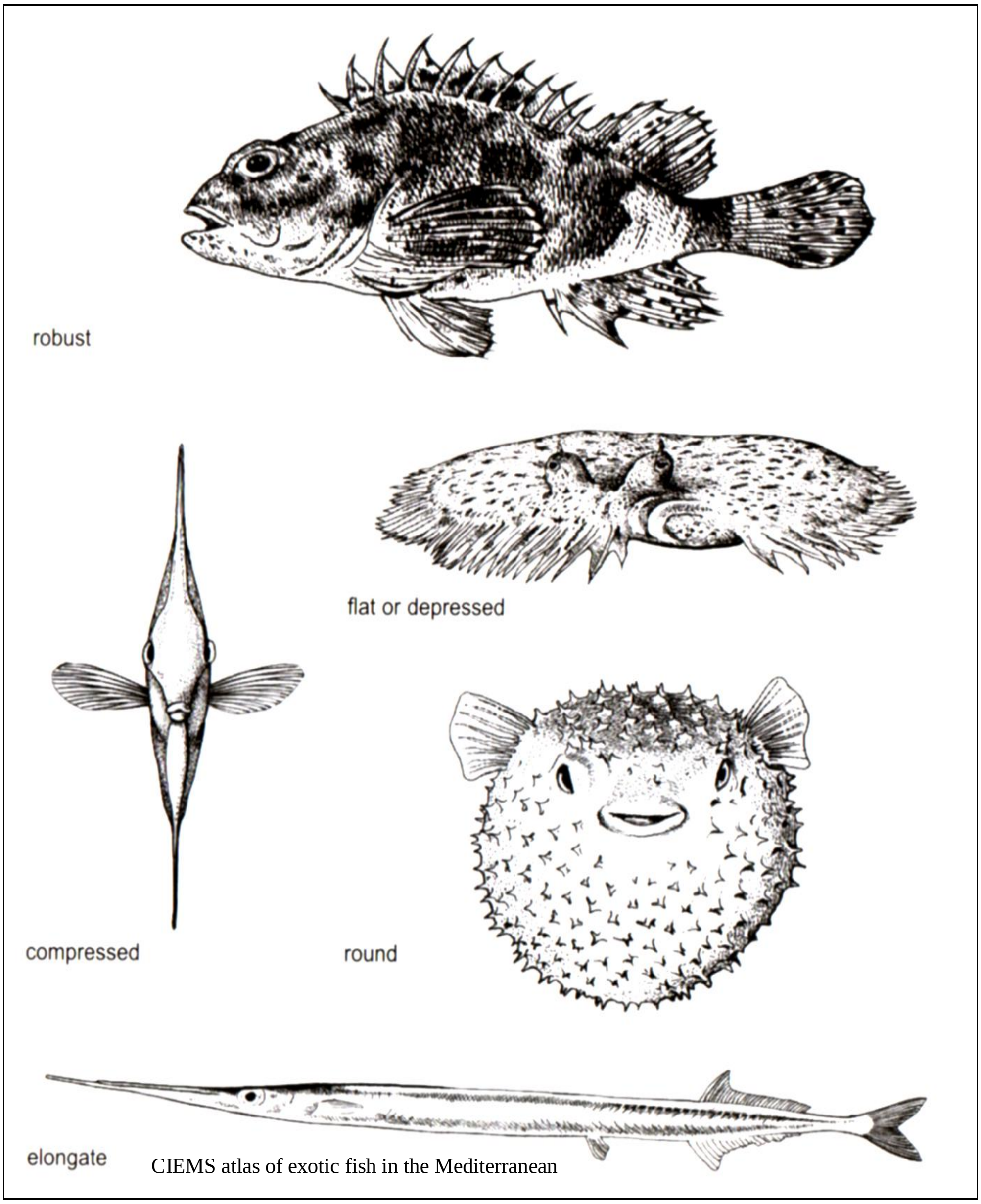

Figure 146: Fish present a big variety in shapes

Just as there is a vast array of shapes among the fishes, there is a tremendous diversity in their coloration. Some examples can be seen in *Figure 161*. Some bony fishes use muted, irregular colour for camouflage, such as the flounder and frogfish. On the other hand, others have brilliant hues and colour patterns to mix with the colourful background of the coral environment or to boldly stand out on their own. These various colours are a result of specialized cells called chromatophores.

These irregularly shaped cells have varying amounts of different pigments. By expanding or contracting the pigment inside, chromatophores allow many fishes to rapidly change their colour or appearance. Again, the flounder I mentioned earlier can actually change its colour patterns while it swims to match the ground over which it is moving. Some fishes even have an iridescent appearance due to crystals within their chromatophores. It is almost as if the fish is covered with tiny mirrors reflecting an entire spectrum of colours.

There are three basic categories for the use of colour in fishes: camouflage, disguise, and advertisement (*Figure 147*). Camouflage is used to help fishes blend in with their surroundings. Although the most obvious use of camouflage is to hide from predators, many of the fishes that employ this coloration technique use it to hunt prey as well, such as the frogfish. Camouflage coloration can also be found in blennies, rockfishes, and hawkfishes.

Figure 147: Purposes of colour use in fishes

Several fishes disguise themselves with disruptive coloration. They have bold, contrasting marks to hide various body parts. For example, the butterfly fish has a dark band across the eye (*Figure 147*). That is meant to hide the eye from predators. Jackknife fish and angelfish also have this coloration strategy. In addition, the butterfly fish has a large dark spot in its posterior region. It looks like a big eye. Since the real eye is hidden by the band, a predator fish will often think that the big spot is the fish's real eye, and it will attack the back of the fish. This gives the fish a chance to swim away from the predator. Also, it can confuse some predator fish, making them think that the butterfly fish is actually a larger predator.

Some fishes use a disguise known as mimicry to fool potential predators. They have colouring to make them appear like other fish that would not be considered prey. Another form of disguise is used by open-water fishes, such as sharks and jacks (*Figure 148*). Many of these fishes are not very colourful but have silver or white ventral sides and dark grey or blue-grey dorsal sides. This is called counter-shading, and it effectively hides the fish in the open water. When viewed from above, the dark side of the fish blends against the dark, deep water below. When viewed from below, the silver-white side of the fish blends against the light coming down through the surface of the ocean.

Figure 148: Sharks use counter-shading for disguise

Finally, some fish advertise their presence by having bright colours. One example of this is the brightly collared cleaner fish, which make themselves known to other fish that want to be cleaned. Some species of fishes assume brighter colours during periods of mating to attract one another. Also, some fishes (like the lionfish – *Figure 147*) advertise with colour in order to warn potential predators of their sharp, venomous spines or other dangerous features.

Unlike the tiny, tooth-like scales of the cartilaginous fishes, bony fishes have thin, flexible, overlapping scales formed from bone. They are translucent and provide some degree of protection from predators. There are two basic types of bony fish scales: cycloid and ctenoid (*Figure 149*). The cycloid scale has a smooth, rounded edge on both its inner and outer sides. The ctenoid scale has comb-like extensions on the inner edge and a toothed outer edge. Fish with ctenoid scales feel rough to the touch, while fish with cycloid scales feel much smoother.

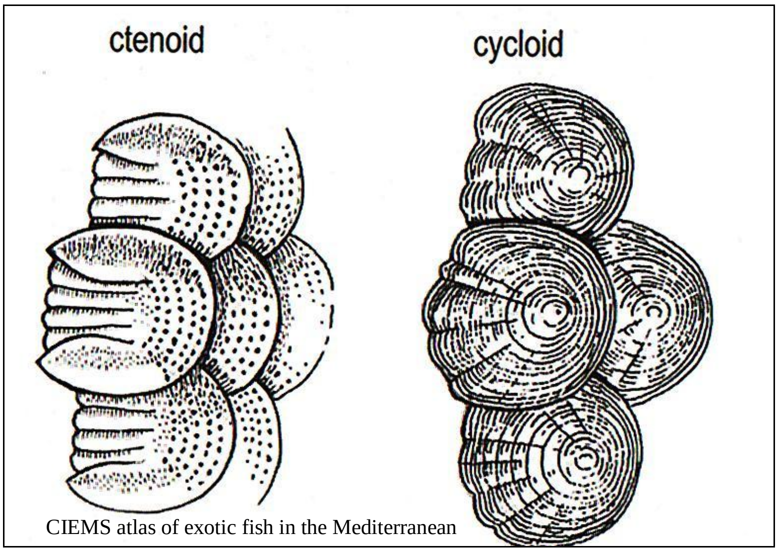

Figure 149: Different types of scales

Fins of bony fishes are very different from the fleshy fins of cartilaginous fishes. They are basically a thin membrane supported by bony fin spines, or rays. Some rays are very rigid to provide protection or structure, while others are flexible and aid in swimming (*Figure 149*). Again, in contrast to most cartilaginous fishes, the upper and lower lobes of the caudal fin of bony fishes are usually the same size.

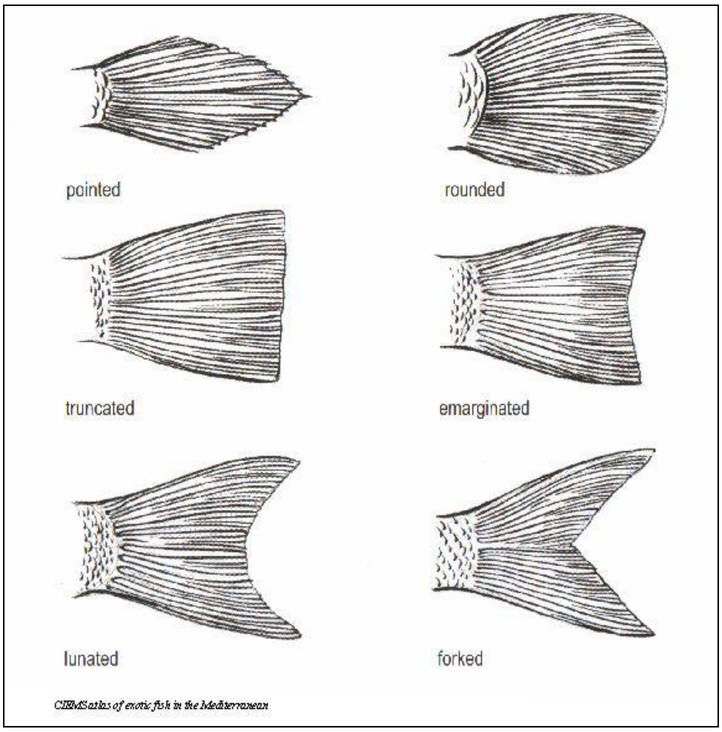

Figure 150: Various types of fish fins

The number of spines, rays and scales on the lateral line provides a good tool for identifying and distinguishing the various fish species (*Figures 151 and 152*).

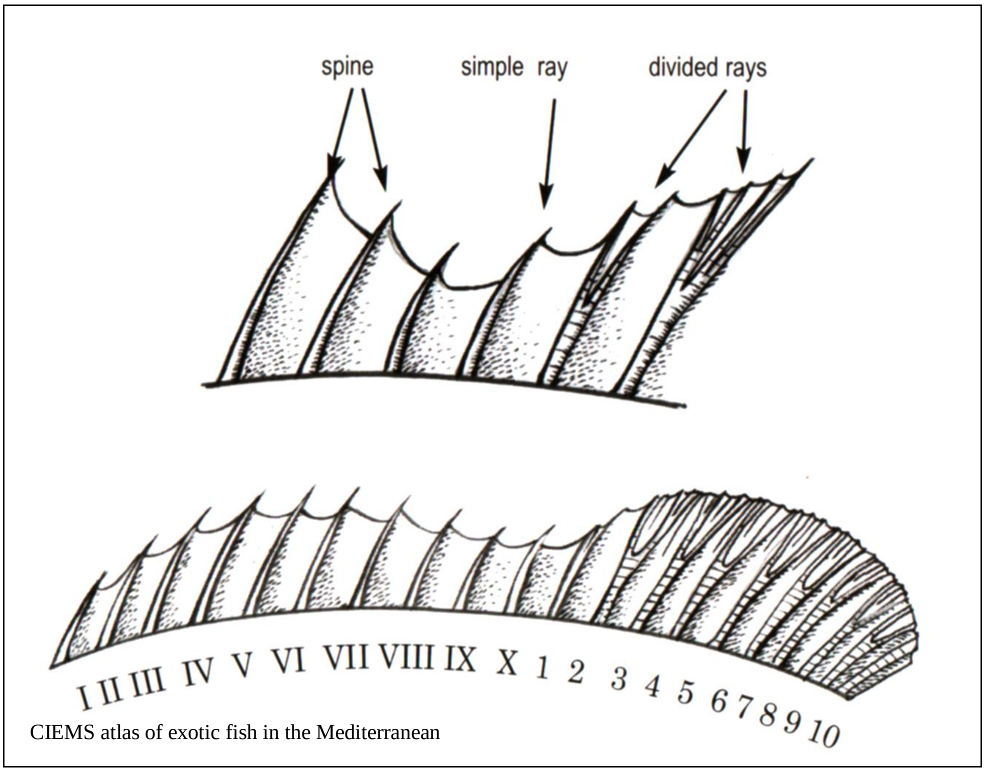

Figure 151: Using rays to identify various fish species

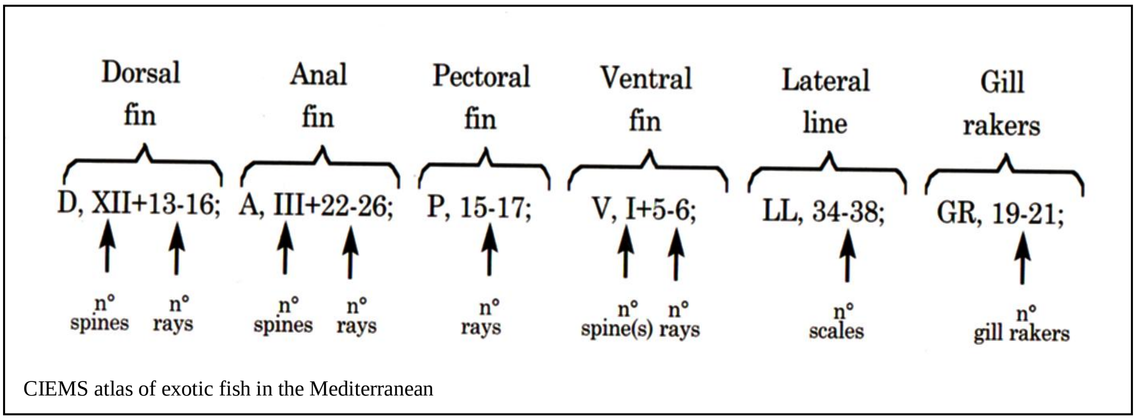

Figure 152: Meristic formula for *Siganus luridus*

For example the Siganus *luridus* has a meristic formula (*Figures 152 and 153*)

D: XIV+10, Dorsal

A :VII+8-9, Anal

P :16-17, Pectorial

V :I+3+I, Ventral

GR:,18-22 Gill rakers

Figure 153: Siganus *luridus*

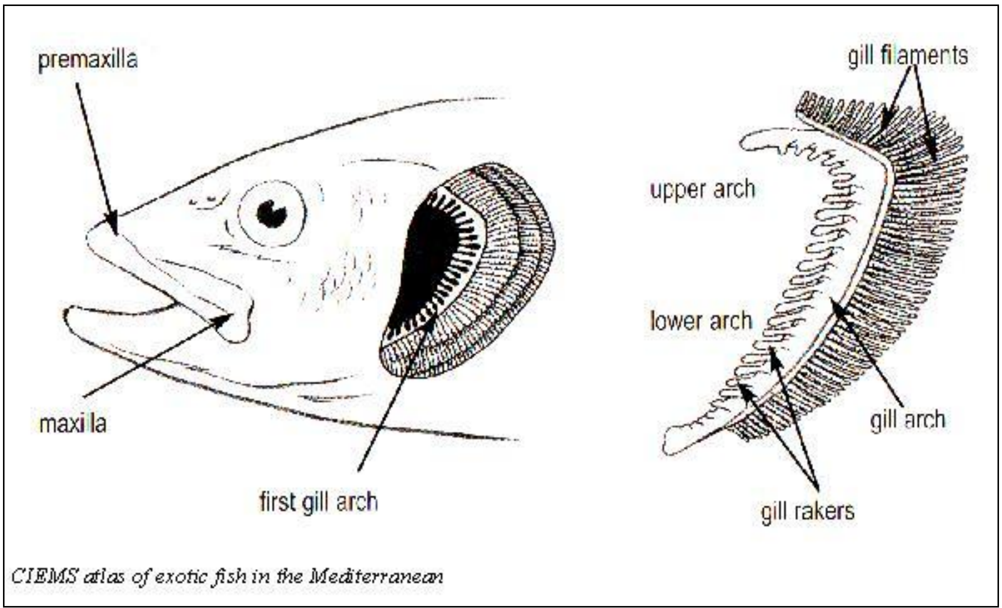

Figure 154: Physical characteristics of bony fish

The bony fishes have terminal mouths, located at the anterior tip of their bodies (*Figure 154*). This allows for more movement of the jaw. There are many different types of fish mouth (*Figure 155*). The teeth are attached to the jawbone and do not move forward in rows (like sharks) when any are lost (*Figure 156*).

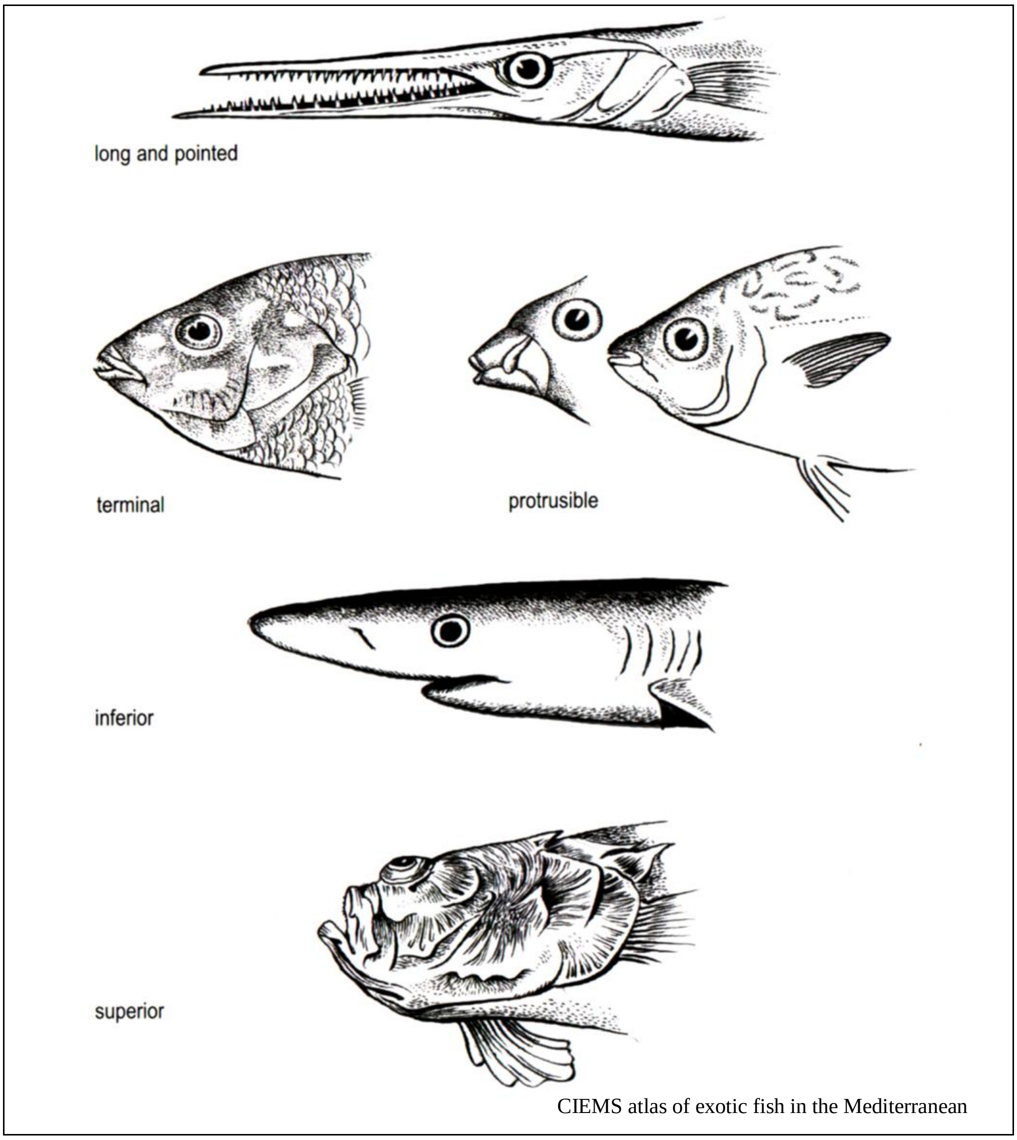

Figure 155: Various mouth forms of Osteichthyes and one of Chondrochthyes

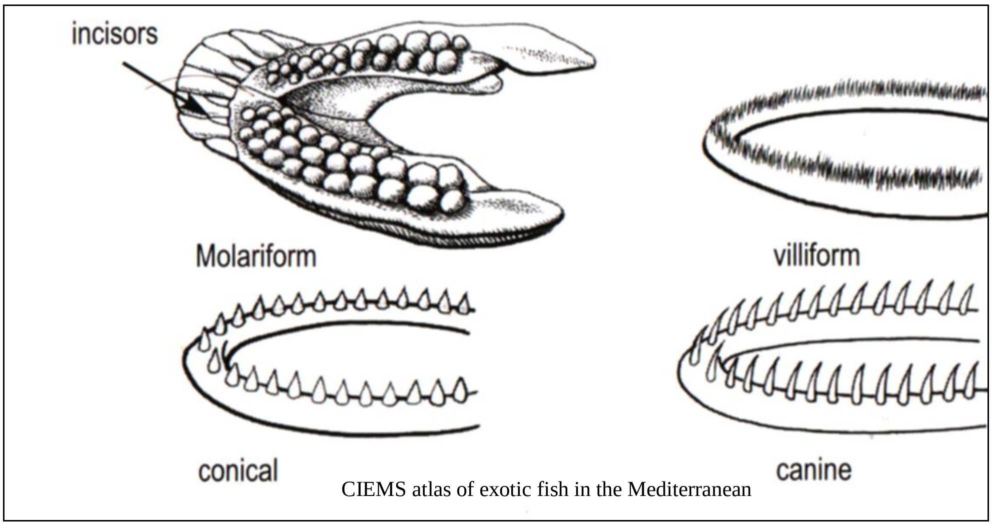

Figure 156: Types of teeth of the Osteichthyes

One more characteristic present in the bony fishes for controlling buoyancy is the swim bladder. When sharks and other cartilaginous fishes stop swimming, they usually begin to sink. They do not have the ability to float in the water column. Sharks are given a relatively large liver that stores buoyant fats and oils, but that is not enough to provide neutral buoyancy – the ability to remain at a certain depth without moving. Most bony fishes, on the other hand, have a special feature that allows them to attain neutral buoyancy. They have a gas-filled sac located near their stomach called a swim bladder or air bladder. It behaves much like a balloon and, depending upon how much gas is inside, it allows a fish to sink or rise in the water column. With the proper amount of gas inside, it also achieves neutral buoyancy, neither sinking nor rising in the water column. The fish controls the amount of gas inside the swim bladder, so in the end, the fish controls its own buoyancy.

The lateral line is a sense organ that gives the ability to a fish to sense the presence of a predator when it is near or the presence of any obstacle around it before it can even see it. This organ is exploiting the ability of the water to carry and maintain pressure waves. This can explain the behaviour of fish when someone swims and/or creates a small pressure wave or sound; fish are seen to move away even though they don't have visual contact with the person creating the movements or the sounds.

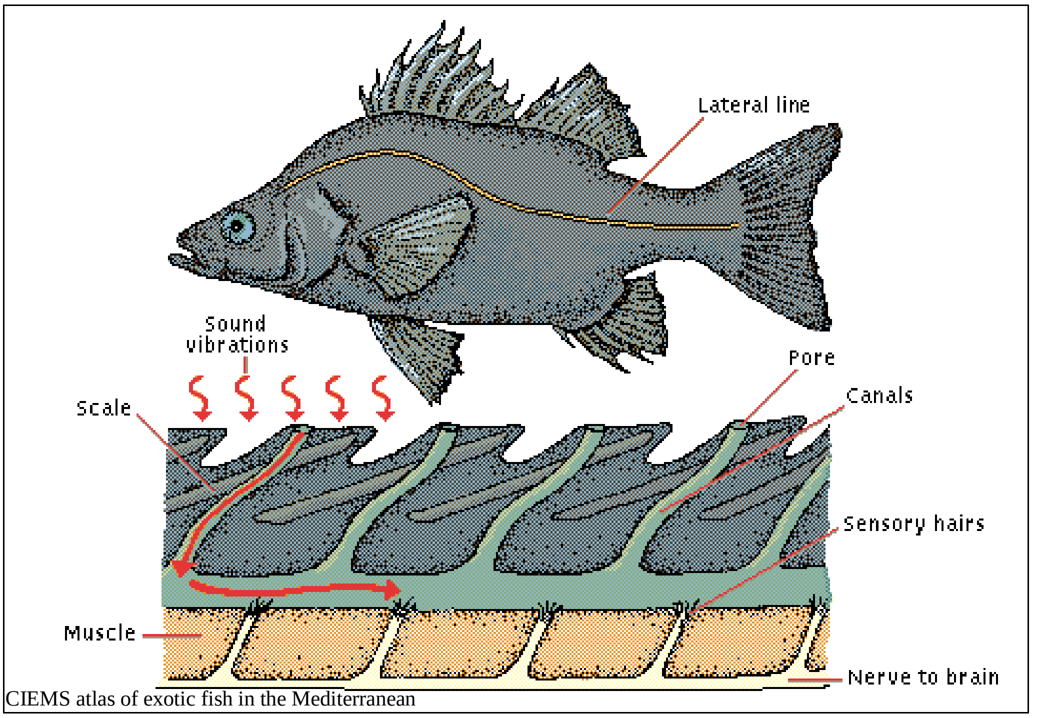

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Figure 157: Lateral Line

Water carries sound vibrations through small pores in a fish's skin and into the lateral line, an inner fluid-filled canal (*Figure 157*). Moving through the canal, the vibrations stimulate the hairs of sensory organs. The branching lateral nerve connects these sensory organs to the fish's brain, transmitting information about the flow of surrounding water and the movements of other organisms.

Fish have an interesting reproduction activity. Eels for example reproduce once in there lifetime and then they die. They have a specific place to give birth (Sargasso Sea 400 m depth) a certain time of the year. This happens when they reach the 14^{th} year of age. From all over the word they exit fresh waters, where they lived since then, and they start a long journey to reach their destination. Moreover, salmon always returns to the same river that was born in order to lay its eggs. Scientists are trying to find out how salmon fish manage to do that.

Some species build nests and guard their eggs until they hatch, while others lay their eggs and leave. The number of the eggs laid depends on many things including the kind of fish (i.e. if they guard their eggs they lay a small number of eggs), and the size of the fish (i.e. the bigger the fish the bigger the number of the eggs laid). In general only 0.01% of the eggs that one fish lays will manage to reach to a sexually mature organism.

Many types of fish reproduce yearly, some of them in the ocean and some at the costal areas. Some fish reproduce during winter and others during summer. They also have various ways of behaviour due to the hormones that are produced by various glands. The reproduction procedure is initiated by abiotic and biotic factors like the length of the day, temperature of the water, presence or not of a sustainable number of zooplankton in the water, as well as the presence or not of aquatic plants.

Many species of fish are hermaphrodite. For instance a young adult, sexually mature, sea bream acts as a male. It then alters into a female. The opposite happens with the grouper that starts first as a female and then becomes a male. In other species, sexes are separated and the fish don't change.

- <u>Seahorse</u>

A very interesting behaviour is the one of the sea horse. Maybe it is the only known example of monogamy in fishes. As far as it's known the pair never divorces, nor do they cheat. The male is receiving the eggs form the female in a specially developed pouch that is placed in the abdominal area (*Figure 158*). The species that is present in Mediterranean is the *Hippocampus hippocampus.*

Figure 158: Sea horses mating and a male sea horse giving birth

- <u>Grouper (*Epinephelus marginatus*)</u>

Figure 159: Grouper (Family Seranidae)

E. caninus (Vlahos), *Myctoperca rubra* (pinga), *E. malabaricus* (stira), and *E. aeneus* (sphirida) are included in the same family with *Epinephelus marginatus*. Grouper is a solitary fish that can be found in small teams (2-3 individuals) in rocky areas of depth 5-300 metres (*Figure 159*). It lives in a determined area and it is usually found in a hole that generally has two exits.

It has a big head and the eyes are located in the upper part of the head and are very agile. His colour is brown infra red with yellow grey blots. The body is bulky and has 11 hard spines and 14-16 beams dorsal and 3 spines and 8 beams anal.

It is usually found resting at its hole that usually shares with moray. It is a carnivorous fish that hunts during night and sets up ambush for its victims. It feeds on clams crustaceans and fishes.

Grouper reaches the maximum weight of 60 kilos and the age of 50 years. The maximum length has been reported to be 1.5 metres. This species can be found in all the Mediterranean and also in the Western Atlantic from the southern coasts of Brazil to Argentina (*Figure 160*).

Figure 160: Computer Generated Native Distribution Map of *Epinephelus marginatus*

During 1996 *Epinephelus marginatus* was included in table 3 of the treaty of Bern that concerns species which their population decreased dramatically during the last decades. Measures need to be taken for the protection of this species, like the discovery of reproduction techniques and their farming conditions in aquaculture.

Grouper presents hermaphroditism. The first genetic maturation is reached after the 5^{th} year of age and in length roughly the 38-45 cm (weight 2-3 kilos). At this stage it starts to act as a female. The change of sex begins to be observed at the 9^{th}-17^{th} year of their age and in length roughly 80-90cm (weight 9 kilos). The minimum time needed to double it's population is from 4.5 to 14 years. The reproduction is observed from June until September and it is related with the temperature of waters. Male groupers during the reproductive period protect their region more intensely and they only allow the presence of enough females.

The eggs are laid one hour after sunset and in temperature of surface waters of 25 ^{o}C. The moon was in his first phase when an actual mating was observed. The eggs have diameter 750-810 mm with a small dot of oil in order for them to be able to float. In temperatures of 18-18.5 ^{o}C the eggs are hatched within 50-52 hours.

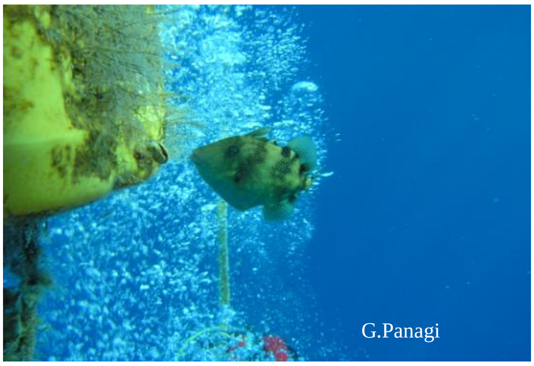
Law in Cyprus allows the fishing of groupers with a minimum length of 45cm (genetic maturation is observed at a length of 38-45 cm).

E. caninus (Blahos)

E. malabaricus (stira)

E.aeneus (sphirida)

Myctoperca rubra (pinga)



Balistes capriscus

Oblada melanura

Lithognathous mourmyrus

Diplodus sargus

Caranx crysos (Souros)

Dentex dentex

Diplodus annularis

Muraena helena

Sciaena umbra

Thynnus alalunga

Spindiliosoma cantharus

Pangrus pangrus

Umbrina cirrosa

Thynnus thynnus

Seriola dumeili

Mullus surmuletus

Coris julis

Figure 161: Various fish species found in the Mediterranean

Other marine vertebrates

In subphylum Vertebrata, there are four more major classes: *Amphibia* (the amphibians), *Reptilia* (the reptiles), *Aves* (the birds), and *Mammalia* (the mammals). The latter three classes have some members that spend most if not all of their lives in a marine environment. However, except for a crab-eating frog that lives in the Southeast Asian mangrove swamps, class Amphibia has no known marine species.

D. Class Reptilia

Class Reptilia includes organisms such as alligators, lizards, snakes, and turtles. These animals are covered with tough, dry scales that help prevent water loss. In a salty environment, scales are helpful to keep the animals from losing moisture. Marine reptiles breathe air with their lungs and, therefore, they must regularly return to the surface of the ocean in order to breathe. Their eggs, which they lay on land, have leathery shells to keep them from drying out. Like fishes, reptiles are ectotherms. Because they have no internal mechanism to keep warm, these creatures get fairly sluggish in cold temperatures, and therefore tend to live in warmer regions. Actually, some biologists consider most reptile species to be behavioural thermoregulators in that they can and do move themselves in and out of sunny and shady areas to regulate body temperatures. They do not have the internal mechanisms for maintaining constant body temperatures like endotherms, but they use external conditions to aid in regulation. This is why reptiles are often found sunning themselves on rocks. They are warming themselves up using the sun and the external weather conditions.

- Sea turtles

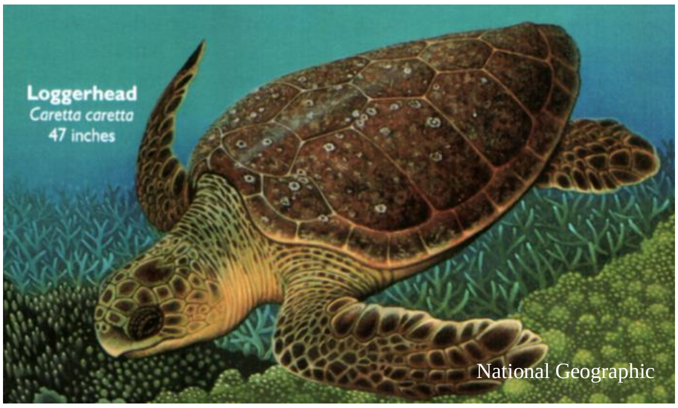


Figure 162: *Careta Careta*

Sea turtles have been in the oceans for at least 150 million years. Foraging for jelly fish, sponges, grasses, or crabs in all but the coldest waters, they nest on scattered tropical and temperate shores.

Sea turtle has a fleshy head and fleshy appendages that stick out of an armoured shell. The shell is called a carapace, and the turtle's backbone is fused to the inside of the shell. Thus, the turtle cannot get rid of its shell; it is permanently attached to the turtle's endoskeleton. Unlike a land turtle, a sea turtle cannot pull its head and appendages all the way into its carapace. In addition, instead of thick, clawed legs, a sea turtle has flat flippers for swimming. Males are easily distinguished by long tails, which help grasp the female during mating. Their nostrils are located on the upper part of their snout, which is the perfect design for an aquatic air breather. This allows a sea turtle to get a breath of air without sticking very much of its body out of the water.

Sea turtles also have a salt gland, which removes excess salts from their bodies. This is necessary because sea turtles do not have a source of fresh water to drink. As a result, they have to get their water from their diet or from drinking seawater. The problem with this is that both the turtle's diet and the seawater are salty. This large amount of salt would pull the water out of the sea turtle's cells, eventually killing it. To solve this problem, the salt gland removes excess salts from the sea turtle. Interestingly enough, the salt gland empties highly concentrated salt water in the turtle's eyes, which makes it look like the turtle is "crying."

There are eight known species of sea turtles, all of which spend a majority of their lives in warm waters. The leatherback turtle (*Dermochelys coriacea*) is the largest of the sea turtles, growing over 2 meters long and weighing over 500 kg. Most species of sea turtles eat a variety of invertebrates, such as jellyfish, sponges, and barnacles. An exception to this is the green sea turtle (*Chelonia mydas*), which feeds on sea grasses, using its beak-like mouth to tear off bits of the grass in order to eat it.

The only time a sea turtle comes to shore is when it lays its eggs. The female crawls onto the sandy shore until she gets above the level of high tide. This, of course, is a tough job, because her flippers are designed for swimming, not crawling. She then begins the laborious process of digging a hole in which to lay her eggs. The beach on which she is digging is probably very familiar to her, because she most likely hatched from a nest on that very same beach many years before. These amazing creatures migrate thousands of miles in order to return to the same nesting areas from which they themselves hatched. A female can lay over 150 leathery, round eggs into a hole. She then buries them and returns to the ocean, coming back to lay eggs a few more times during the same breeding season. Once the young turtles hatch, they must dig themselves up out of the sandy nest and make their way to the ocean. They must face a great deal of peril before they reach the relative safety of the ocean. If their nests do not get scavenged by crabs, foraging wild pigs, other animals, or even humans, they are at danger of being eaten during the long trek across the beach to the surf. Birds and land crabs feast on the hatchlings as they emerge out of the nest. They are not even completely safe when they reach the water, because they are still easy prey for fishes and seabirds.

Sea turtles that live in shallow water go to the seafloor and wedge themselves under or between rocks or coral in order to sleep. The fact that they are wedged there keeps them from rising to the surface while they sleep. While underwater, however, they cannot breathe, so they don't breathe while sleeping. Instead, a turtle wakes up once every hour or so and swims to the surface to get air. It then goes back down and sleeps some more. Turtles that live in deep water float to the surface in order to sleep. They sleep with their nostrils above water so they can continue to breathe while they sleep.

In Cyprus we can fine the loggerhead, *Caretta caretta* (*Figure 162*) that can reach the size of 120 cm, the green sea turtle *Chelonia mydas* (*Figure 163*) and the leatherback turtle *Dermochelys coriacea (Figure 164*).

Figure 163: Green sea turtle, *Chelonia mydas*

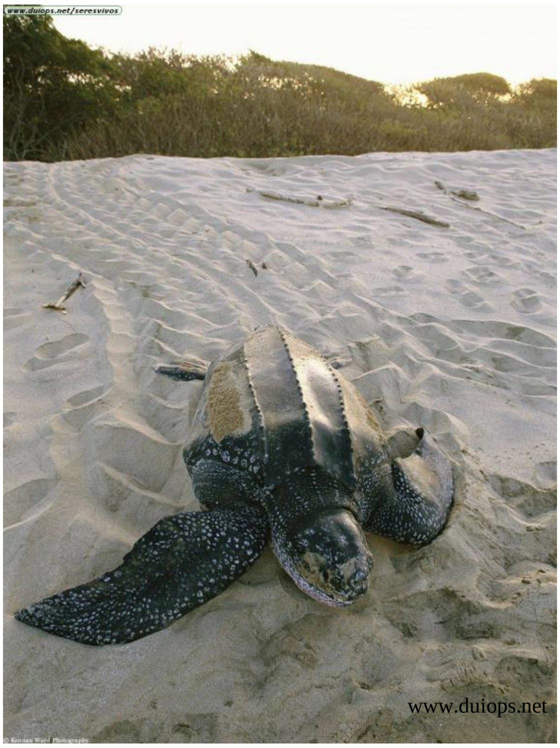


Figure 164: Leatherback sea turtle, *Dermochelys coriacea*

E. Class Reptilia

The sea snakes are not as well known as the sea turtles, but they are represented by more species. They are found in the warmer parts of the Pacific and Indian oceans, and look very much like land snakes with the exception of a laterally flattened tail that aids in their swimming (*Figure 165*). They are extremely poisonous, and interestingly enough, they are more common than the poisonous land snakes. The bite of a sea snake can kill a human, although a sea snake rarely attacks if not provoked. The most common occurrences of sea-snake bites occur when a person unknowingly steps on one.

Figure 165: Garden Sea Snake

Unlike sea turtles, most sea snakes are ovoviviparous, their eggs developing and hatching internally and the young being born live. Because of this, they never need to emerge from the water to lay their eggs.

There is another species of marine reptile that does not live exclusively in the ocean, but instead it spends much of its time on the shore in order to keep its body warm. Marine iguanas (*Figure 166*) live on the Galapagos Islands off the western coast of South America. They move into the ocean to feed on shallow water seaweeds. These are some of the creatures Charles Darwin saw when he first visited the islands, afterward proposing his theory of evolution.

Figure 166: Marine Iguana

At the Galapagos Islands, Darwin saw many creatures that resembled known creatures in other lands but with a few differences. These differences are often called adaptations. For example, a marine iguana has a tail that is laterally flattened versus the rounded tails of the non-marine species of iguanas. The flat tail helps the animal swim quite well by moving its body from side to side. It was believed that long ago a few land iguanas may have been blown off the South American continent during a terrible storm, or perhaps some birds grabbed a few iguana eggs and carried them to these islands. The newly located individuals had a new home in which to live, but they did not have the perfect physical features in order to survive. As a result, they had to "adapt"[33] to their new environment.

Their new environment of the barren, volcanic Galapagos Islands did not provide much in the way of leafy foliage, which is what typical iguanas eat. The presence of un-utilized seaweeds, however, was a source of food that apparently a few of the original land iguana "immigrants" could also use. In order to take advantage of this alternative food source, these creatures had to venture into the water to feed. Therefore, those individuals that had a slightly flattened tail or a darker body colour that warmed up faster after leaving the cool ocean water would have an easier time of entering the water and surviving once they got out. They could therefore obtain more food and have a better chance of surviving and reproducing than individuals that did not have such traits. As a result, their unique traits (flattened tail or darker coloration) would be passed on in greater frequency to later generations.

[33] Adaptation: an expression of a helpful trait coming directly from the genetic information already possessed by at least some individuals in a genetically diverse population.

F. Class Aves (Sea Birds)

Marine birds are present in a wide array of sea environments because they are endothermic and extremely mobile. This allows them to maintain a more constant body heat no matter what the surrounding temperatures are. Their bodies are covered by feathers, which behave as a coat to keep in body heat when needed. If the bird needs to release body heat, feathers can be shed to “thin” the coat. Most birds have waterproof feathers because the birds cover their feathers with a coating of oil they get from a special oil gland found near the base of the tail. You probably have seen ducks preening their feathers by getting some oil from their oil glands with their beaks and then moving their beaks along the length of their feathers in order to distribute it. Also, like the sea turtles, sea birds have salt glands that remove extra salts from their bodies.

A bird is considered a sea bird if it spends a majority of its life at or near the sea and feeds on marine life. Most sea birds have webbed feet to aid in swimming. They feed on fishes, squid, and crustaceans, but have several ways of obtaining their food. They also vary in their abilities to fly, but they all move to land in order to build nests.

The shape of marine birds' beaks plays an important role in their feeding habits (*Figure 167*). As a result, birds have beaks that are often characteristic of their way of life. Hooked beaks aid in tearing off bits of food and grasping prey. Straight beaks are helpful for more streamlined shapes necessary for diving. Some birds even have tubes on top of their beaks that aid in salt removal.

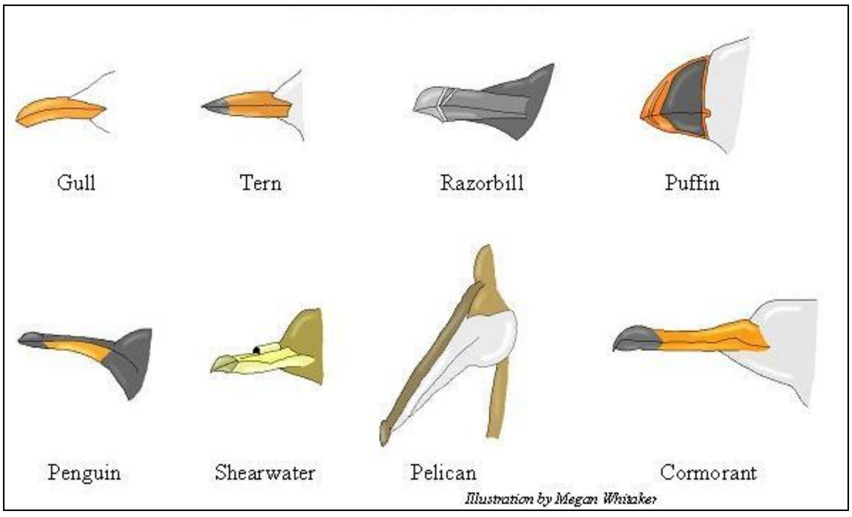


Figure 167: Beaks of some marine birds

- Gulls

Gull, common name for approximately 47 species of long-winged, web-footed seabirds; the most familiar birds of the seashore (*Figure 168*). These excellent fliers have slightly hooked beaks and squared tails. They rarely dive into the water to capture prey, but they can often be seen sitting on the surface of the ocean. Gulls are distributed worldwide, excluding only tropical deserts and jungles, the central Pacific islands, and most of Antarctica. Some gulls are migratory. They are omnivores, feeding on whatever they can catch or scavenge.

Figure 168: Sea Gulls

Gull sizes range from 27 to 80 cm. The bill is hooked. Except for the totally white ivory gull, the birds vary from pale grey to black above, and from white to grey below. The heads of many have black, grey, or dark brown hoods during breeding season. Many of the grey-winged species have black or darker grey wing tips, often with white spots. The sexes are alike in colour. The young have mottled brown or grey plumage, taking as long as four years (in the larger species) to attain the definitive adult coloration through a progressive series of annual molts.

Gulls are equipped for versatility rather than specialization. For example, their wings are good for soaring as well as for strong and agile powered flight, but they cannot use air currents as efficiently as albatrosses or fly as fast as falcons. The foraging of gulls includes fishing, scavenging, egg predation, insect catching, following plows for earthworms and ships for garbage, dropping shellfish from a height to break them open, and foot paddling to stir up organisms in shallow water.

Gulls breed colonially, mostly on the flat ground of beaches, marshes, or riverbeds, where they build simple, shallow, grass-lined nests. Several species nest on ledges of cliffs, notably the kittiwakes. The clutch consists of two or three greenish-brown, speckled eggs, which take 20 to 30 days to incubate. At hatching the chicks have down feathers, and the eyes are open. Chicks can stand but are dependent on their parents for food and warmth. The parents share in incubation of the eggs and in the brooding and feeding (by regurgitation) of the chicks, which fledge between four and six weeks after hatching. Gulls have been known to live as long as 40 years in captivity and as long as 36 years in the wild.

Territory defence, pair formation, parent-chick interactions, and other gull activities involve communication behaviour consisting of postures, movements, and calls, some of which are quite complex both in form and in function. For example, courting gulls perform threat displays, but they do so in sequences that apparently modify the meaning of the display. Recognition of one individual by another by such means has been demonstrated experimentally. Pair bonds may be long lasting.

Gulls may thrive at the expense of other species. For example, larger gulls are known to drive out smaller gulls and terns from nesting territories, partly through egg and chick predation. The scavenging of gulls can also affect the ecology of urban environments. Airfields (and the garbage dumps that are commonly located near them) attract large numbers of gulls, which present a collision hazard to aircraft; this problem has yet to be solved. In some places, gulls' eggs are collected for food.

- Pelicans

Pelican, common name for the species of a genus of large birds having a long, large, flattened bill, the upper mandible terminated by a strong hook that curves over the tip of the lower one (*Figure 169*). Beneath the lower mandible, a great pouch of naked skin is appended. The tongue is short and almost rudimentary. The face and throat are naked, the legs short, and the tail rounded. Pelicans may weigh up to 15 kg, and the wings may span up to 3 m.

Figure 169: Pelicans

Pelicans are widely distributed over most warm regions, frequenting the shores of seas, lakes, and rivers, and feeding chiefly on fish. Pelicans have two distinctive feeding methods. The brown pelican and the larger Peruvian pelican, often considered a subspecies of the brown pelican, plunge-dive from the air into the water for their prey. Most of the other species feed communally, swimming in an open circle in shallow water and driving the fishes into shallower and shallower water, where they snatch the fishes. The pelicans then store the catch in their pouches, from which they can bring it out at leisure either for their own eating or to feed their young. The birds live in large colonies and build crude nests of twigs and branches near a body of water.

- <u>Cormorants</u>

Figure 170: Cormorant

Cormorant, common name for any of several fish-eating, web-footed water birds that nest in colonies on the seacoasts of temperate and tropical regions of the world (*Figure 170*). A few species also live on large island lakes and rivers. They have slender, hooked beaks; long, flexible necks; a patch of bare skin under the mouth; and a stiff tail. Their plumage is usually a glossy black; some have white areas and many have brightly coloured featherless rings around the eyes. They dive and swim deeply underwater in pursuit of fish. They lay two to four eggs in seaweed nests littered with fish remains. They can eat up to 2-4kg of fish per day and some times when is pursuit they throw up in order to get lighter for take off.

- <u>Penguins</u>

Penguin, common name for 17 species of flightless seabirds widely distributed in cooler waters and along coastlines in the Southern Hemisphere (*Figure 171*). Although they are birds, they cannot fly at all. Their wings act as fins for excellent manoeuvrability underwater, and their torpedo-shaped bodies allow for great swimming speeds in order to chase down and capture fish (*Figure 172*). Each individual species has a beak that is specially designed for the food that it eats. The beak of a king penguin, for example, is long and slightly curved, which helps it catch and hold its main food, squid.

Unlike the bones of other birds, penguin bones are solid, not hollow, which helps them remain submerged underwater. On land penguins have a waddling gait due to their short, thick legs set far back on the body. Penguins come ashore to breed, but they are, in fact, true marine animals, spending as much as 80 percent of their lives at sea.

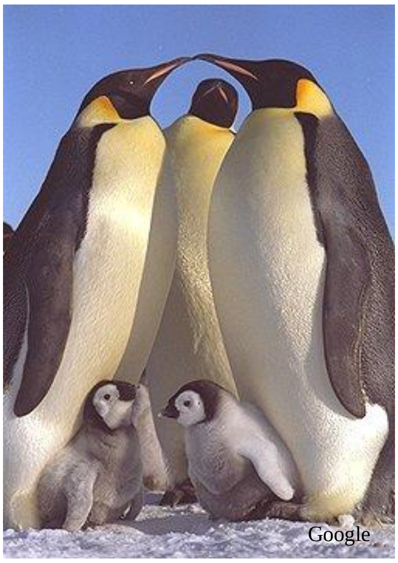


Figure 171: Adult and baby penguins

Penguins vary in size from the little penguin (Eudyptula minor), which weighs 1.1 kg and is about 40 cm tall, to the emperor penguin, which grows to 30 kg in weight and stands about 115 cm tall. The emperor penguin is small compared to the fossil penguin *Anthropornis,* which lived 37 million to 45 million years ago on Seymour Island near Antarctica. Fossil records indicate that *Anthropornis* was around 170 cm in height, almost the size of a human.

All penguins have a black back and head and a white breast, but individual species can be distinguished by certain physical characteristics. For instance, the birds in the genus *Eudyptes* are commonly known as crested penguins for the tuft of bright yellow plumage on their head. *Adélie* penguins have white, spectacle-like rings around their eyes. Other penguins can be distinguished by bare, pink skin on the head and neck, or varied black and white breast bands. Penguin bills can be black or red, ranging in shape from short and stout to long and curved. Penguin feet are webbed with three toes. Male and female penguins are similar in appearance, although males usually weigh more than females and there are small differences in bill size between the sexes.

Penguins are well adapted to cold weather. Their short, stiff feathers form a dense waterproof coat that prevents excess heat loss. Some species have a thick layer of blubber under their skin, but this fat layer mainly acts as a food reserve and contributes little to insulation.

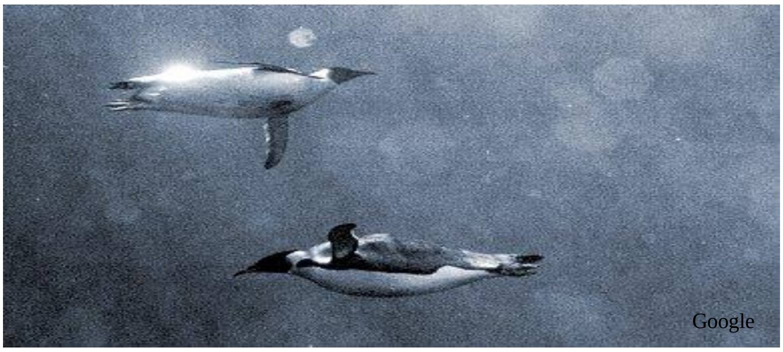


Figure 172: Penguins are excellent swimmers

G. Class Mammalia

The organisms in this group are endotherms, and like the marine birds, they are widely distributed throughout the world. Most marine mammals are members of three orders: *Cetacea* (including dolphins, porpoises, and whales), *Pinnipedia* (including seals and sea lions) and *Sirenia* (including manatees and dugongs) (*Figures 173, 174 and 175*).

Figure 173: Humpback Whale – Order Cetacea

Figure 174: Sea Lion
Order Pinnipedia

Figure 175: Manatee
Order Sirenia

- Order Cetacean

Cetaceans form one of the most dramatically-derived groups of mammals. Indeed, during their transition from the terrestrial to the aquatic environment, they experienced spectacular transformation of many biological systems.

All cetaceans, except for a few species of fresh water dolphins, are marine. Cetaceans comprise approximately 87 species in 14 families and two sub-orders: *Mysticeti* (baleen-bearing whales) and *Odontoceti* (teeth-bearing whales) (Rice, 1998). Dolphins and porpoises are technically considered whales and are included in the toothed-whale group. In fact, dolphins and porpoises include almost half of all cetacean species and more than half of the species of toothed whales. Adult size ranges from less than 1.5 meters for some representatives of the *Cephalorhynchus* genus, to more than 30 meters for the largest blue whales. Cetaceans are ecologically very diverse as their habitats vary from coastal to pelagic, from tropical to polar, and from marine to fresh water, while their preys vary from planctonic crustaceans to fish, squids, and marine mammals.

The major morphological transformations related to the transition to the aquatic environment include:

- Loss of external hind limbs, although vestigial pelvic girdle bones are still present in all extant species;
- Paddle-like forelimbs with hyperphalangy and a non-rotational elbow joint;
- Torpedo-shaped body, with addition of vertebrae, reduction of the neck, and development of a horizontal caudal tail;
- Development of a thick blubber layer that prevents heat-loss;
- Telescoping of the skull, and posterior movement of the narial openings. The position of the external nares on the top of the skull allows cetacean to breathe while keeping the rest of the head underwater. The telescoping of the skull mostly involves the posterior extension of the bones of the elongated rostrum: maxillae, premaxillae, vomer and mesethmoid;
- Isolation of the earbones related to the development of underwater hearing and echolocation abilities.

In mysticetes the nasal passages are separate tubes all the way to the external nares, whereas in odontocetes, the two nasal passages branch into a complex series of nasal sacs that eventually coalesce into a single blowhole. The sperm whale is however intermediate as it exhibits a sigmoidally-shaped blowhole formed by two nasal tubes that remain distinct from the bony nares to the top of the head: the anterior and posterior curves of the sigmoid blowhole represent the apertures of the right and left nares, respectively (rare examples of adult sperm whales with two distinct blowholes have even been reported) (*Figure 177*). In the pygmy sperm whales (Kogiidae), the situation is only slightly different since the nasal passages remain discrete tubes until just proximal to the single blowhole (*Figure 176*).

Figure 176: Left: Toothed whales have a single blowhole. Right: Baleen whales have two blowholes.

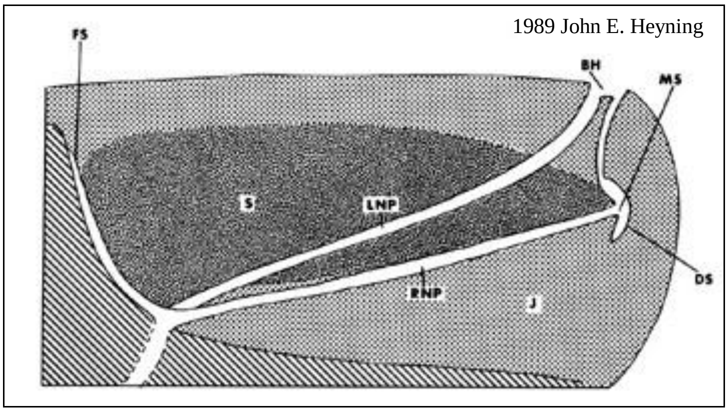


Figure 177: In the giant sperm whale, the nasal passages remain discrete tubes until just proximal to the single s-shaped blowhole.

Sound – Echolocation

Echolocation is the ability to assess the environment (mostly, detecting obstacles, conspecifics, predators, and prey) by emitting sounds and listening to the echoes. Echolocation abilities have been conclusively demonstrated in delphinoids and so-called "river dolphins" and seem to be present in beaked and sperm whales as well. Although they can easily detect an object about the size of a ping-pong ball more than 50 meters away, dolphins also use echolocation to inspect objects at very short ranges (*e.g.*, to assess shape, size, and structure). Dolphins produce short "clicks" whose frequencies (10 to 150 kHz) and intervals (as short as 1.2 milliseconds) are adjusted depending on the size and distance of the target (high frequencies dissipate more rapidly than low frequencies but allow the detection of smaller targets and a finer analysis of shape and structure). These sounds are produced by circulation of air in a complex system of facial sacs, reflected by the cranium, and focused into a beam by the melon, a fatty structure located in the forehead and serving as an acoustic lens. Mysticetes possess a small (Heyning 1989), possibly vestigial (Milinkovitch, 1995) melon.

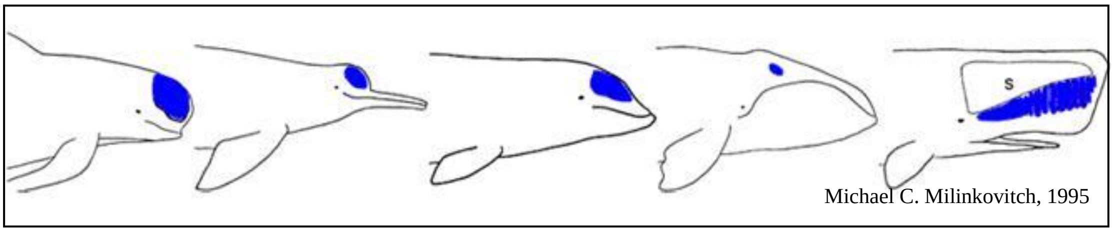


Figure 178: Melon situated in the forehead of the cetaceans. The melon is shown in blue for the genera *Globicephala*, *Inia*, *Ziphius*, *Balaena*, and *Physeter* (from left to right)

The melon is a fatty structure located in the forehead of all cetaceans (*Figure 178*). In most toothed whales, it serves as an acoustic lens for echolocation sound production. The high-frequency echoes are received through the hollow mandible then transferred across fatty channels to the middle ear. Low-frequency sounds on the other hand are perceived through the auditory channels. The middle and inner ears of odontocetes are surrounded by an emulsion of mucus, oil, and air. The whole structure is enclosed into a dense, bony bulla. This high level of acoustic isolation greatly improves directional detection. The isolation mechanism is less complete in mysticetes, but the large distance between the two ears (simply because of the size of these animals) probably helps directional detection. Mysticetes exhibit a peculiar tympanic membrane (the finger glove) and seem to receive sounds through the auditory channels. It is unclear whether mysticetes are able to rely on the echoes of their low-frequency sounds.

Dorsal and anterior to the skull, sperm whales also have a large oily organ (called the “spermaceti organ” because early whalers thought the whitish oily substance was the whale semen) that possibly works as a biological ballast (Raven & Gregory 1933; Clarke 1970) or constitutes a secondary sexual character involved in acoustic display (Cranford 1999). Because of the high specialization of the giant sperm whale facial anatomy, it is unclear what structure in this species is homologous to the melon of other cetaceans.

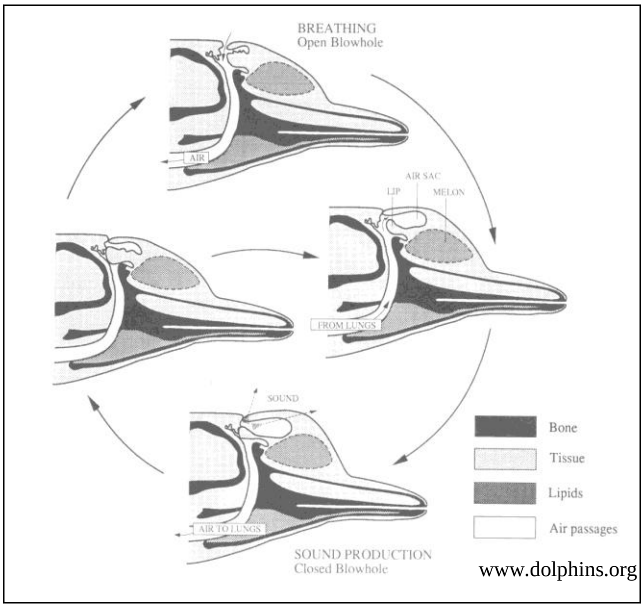


Figure 179: Relation between breathing and vocalizing in dolphins

In breathing, the blowhole is opened and air enters the lungs (*Figure 179*). In vocalizing, air returns from the lungs, inflating one or more air sacs located underneath the blowhole. At the entrance to each air sac is a nasal plug. The nasal plug closes off the air sac and muscles around the sac compress it and force air past the plug, which creates sound. These sounds are reflected by the bony structures of the skull and upper jaw and focused by the melon. The dolphin can refill air sacs to create more sounds without breathing through its blowhole each time. Thus, the dolphin may hold its breath for several minutes and continually make sounds while underwater.

Origin of Cetacea

The oldest known cetaceans are Eocene in age, appearing around 55 million years ago. These primitive toothed cetaceans, lacking odontocetes and mysticetes cranial specializations, form the paraphyletic sub-order Archaeoceti. Representatives of this group have been found in Egypt, Nigeria, India, Pakistan, and USA and show a wide range of morphologies that prompted their classification into several families such as the Pakicetidae (early Eocene), Protocetidae (middle Eocene) and Basilosauridae (middle to Late Eocene). The most primitive taxa exhibited locomotory hind limbs (see Thewissen et al. 1994; Gingerich et al. 2001; Thewissen et al. 2001). The archaeoceti fossils illustrate the progressive reduction of hind limbs, adaptations of the ear for underwater hearing, and the expansion of the pterygoid sinus fossae in the basicranium leading to a better isolation of the ear bones.

SPECIES LIST

Kingdom-- Animalia
Phylum-- Chordata
Subphylum-- Vertebrata
Class-- Mammalia:

- bear live young (two exceptions: Duckbilled Platypus and Spiny Anteater);
- nurse young with milk through mammary glands;
- have fur or hair in at least some stage of development;
- are warm-blooded, breathe air with lungs and have a four-chambered heart.

Order-- Cetacea

Derived from the Latin word *cetus* (Greek word *ketos*), which means whale. The order includes whales, dolphins.

Suborder-- Mysticeti (Baleen Whales)

The baleen whale has a symmetrical skull and a pair of nostrils, called blowholes that open on the top of the head in two longitudinal slits. The whale breathes air through its blowholes when it surfaces. Baleen whales are filter feeders - they eat small organisms that get caught in their baleen plates. A series of baleen plates hang side by side from the roof of the mouth. Each plate is fringed by coarse hairs, and together the fringes form sieves that catch the small fish, crustaceans and plankton that form the usual diet of baleen whales.

Mysticeti - the scientific name for baleen whales - is derived from the Greek words *mystax*, meaning moustache, and *ketos*, meaning whale.

Family - Balaenidae (Right Whales)

Northern Right Whale (*Eubalaena glacialis*)

Family-- Balaenopteridae (Rorquals)

Blue Whale (*Balaenoptera musculus*)
Fin Whale (*Balaenoptera physalus*)
Sei Whale (*Balaenoptera borealis*)
Humpback Whale (*Megaptera novaeangliae*)
Minke Whale (*Balaenoptera acutorostrata*)

Family-- Eschrichtiidae (Gray Whales)

Grey Whale (*Eschrichtius robustus*)

Suborder-- Odontoceti (Toothed Whales)

The toothed whale has a slightly asymmetrical skull and a single nostril - the blowhole - located near the top of the head. The whale breathes air through the blowhole when it surfaces. The toothed whales are named for their teeth: their scientific name, *Odontoceti*, is derived from the Greek *odontos*, meaning tooth, and *ketos*, meaning whale. But some species in this suborder - the beaked whales - have few if any teeth. Even those with many teeth use them only for snatching and holding on to prey, and not for chewing; these whales swallow their food whole. Toothed cetaceans feed mostly on squid, fish and larger aquatic animals, catching their prey one at a time.

Family-- Physeteridae (Sperm Whales)
Sperm Whale (*Physeter catodon*)
Dwarf Sperm Whale (*Kogia simus*)

Family-- Ziphiidae (Beaked Whales)
North Pacific Bottle-nosed Whale (*Berardius bairdii*)
Goose-beaked Whale (*Ziphius cavirostris*)
Bering Sea Beaked Whale (*Mesoplodon stejnegeri*)
Arch-beaked Whale (*Mesoplodon carlhubbsi*)

Family-- Delphinidae (Dolphins)
Killer Whale (*Orcinus orca*)
False Killer Whale (*Pseudorca crassidens*)
Short-finned Pilot Whale (*Globicephala macrorhynchus*)
Saddle-backed Dolphin (*Delphinus delphis*)
Pacific White-sided Dolphin (*Lagenorhynchus obliquidens*)
Northern Right-whale Dolphin (*Lissodelphis borealis*)
Risso's Dolphin (*Grampus griseus*)
Striped Dolphin (*Stenella coeruleoalba*)

Family-- Phocoenidae (Porpoises)
Dall's Porpoise (*Phocoenoides dalli*)
Harbour Porpoise (*Phocoena phocoena)*

Family Balaenopteridae (Rorquals)

- Blue Whale (*Balaenoptera musculus*)

Figure 180: Blue Whale

The Blue Whale is the largest creature ever to have lived on earth. The largest Blue Whale on record was a female from the Antarctic that measured 30 metres long and over 135 tonnes. Most North Pacific Blues reach a length of 25-2\6 metres. This large rorqual can be distinguished by its blue-grey colour (*Figure 180*). Only the undersides of its flippers are white. A small dorsal fin, approximately 30 cm tall, is located on the third of the back nearest the tail. The Blue Whale's tongue, palate and baleen plates are inky black. The blowholes are protected by large fleshy "splash guards" that expand and contract as the animal breathes. On the whale's underside, the throat grooves (found on all the rorquals) extend from near the tip of the jaw to past the navel.

Mating season extends over about five months in the late fall and winter. Because seasons in the southern hemisphere run opposite to those in the northern hemisphere (i.e., when it's summer here, it's winter down under), Blue Whales in one hemisphere cannot breed with those in the other. Blue Whales reach sexual maturity at about ten years old, and females bear young every two to three years. After a gestation period of just over a year, a seven-metre long calf is born, weighing about 2500 kg. The mother supplies over 720 litres of milk a day, which is over 50 percent fat. The calf gains an average of 91 kg per day, and by eight months it weighs 22,680 kg. Adult Blue whales feed on krill, and devour six to eight tonnes of these euphausiids each day. Blue Whales are found throughout the world's oceans, mainly along continental shelves and ice fronts, but also in shallow inshore regions and in the deep ocean.

Family Delphinidae (Dolphins)

- Killer Whale (*Orcinus orca*)

Figure 181: *Orcinus orca* – The killer whale

The most distinctive characteristic of the Killer Whale is its large triangular dorsal fin that can be up to 1.8 metres tall. The dorsal fin on females and immature animals is less than a metre tall and curved backwards slightly, but it is still taller than the dorsal fin of any other cetacean. The Killer Whale - also known as Orca - is mostly black with a large region of white on the underside extending from the lower jaw to tail, with branches reaching up the flanks behind the dorsal fin (*Figure 181*). It also has an oval white patch just above and behind the eye, and a light grey saddle marking just behind the dorsal fin. The Killer Whale is the largest species of dolphin. It is heavy-bodied and has large, paddle-shaped flippers. Males can be as long as 9 metres, but most are around 8.2 metres; females are about 6.7 metres long. Newborn calves are about 2.5 metres long and weigh about 180 kg.

There are three types of Killer Whales: residents, transients and offshore. As their names suggest, residents tend to stay in the same general area in the summer and fall, while transients travel more widely, moving up and down the coast and passing through areas inhabited by different resident pods. Offshore Killer Whales inhabit the open ocean, where they likely feed on sharks and other large fishes. Residents live in large pods of 6 to 50 and prey mostly on fish. Transients form small pods of up to 5 and feed on marine mammals such as seals, sea lions and even other whales. The Killer Whale occurs in oceans throughout the world, but is most common in cold temperate waters and polar waters (*Figure 182*).

Figure 182: Killer whales are common in cold and polar waters

Family Delphinidae (Dolphins)

- Striped Dolphin (*Stenella* coeruleoalba)

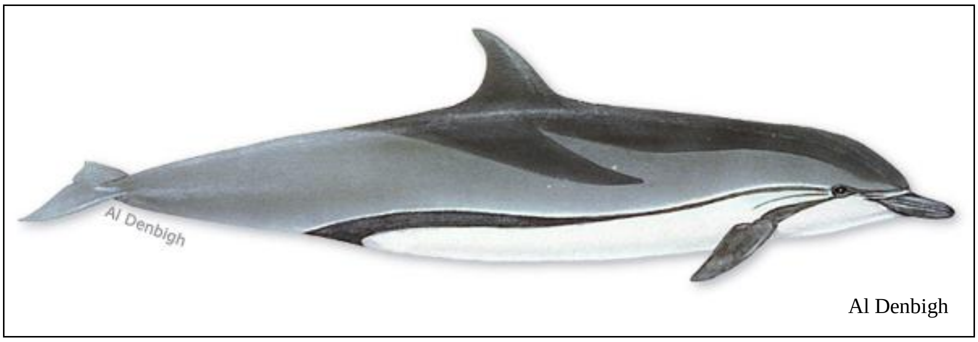


Figure 183: The striped dolphin

The Striped Dolphin is characterized by two distinctive black stripes: a long band that begins near the eye and runs along the side of the body to the anus, and a short sliver that reaches forward from the black area of the dorsal fin to about halfway to the eye (*Figure 183 and 184*). These stripes show clearly against the bluish black and grey sides; the belly is grey or white. The Striped Dolphin grows to a length of about three metres.

The Striped Dolphin eats squid, mackerel, sardines and other fishes. This species travels in large pods, and is often seen jumping clear of the water. Striped Dolphins migrate with the seasons. Found in all the tropical and warm temperate waters of the world.

Figure 184: Striped dolphin with the distinctive black stripes

Family Balaenidae (Right Whales)

- Northern Right Whale (*Eubalaena glacialis*)

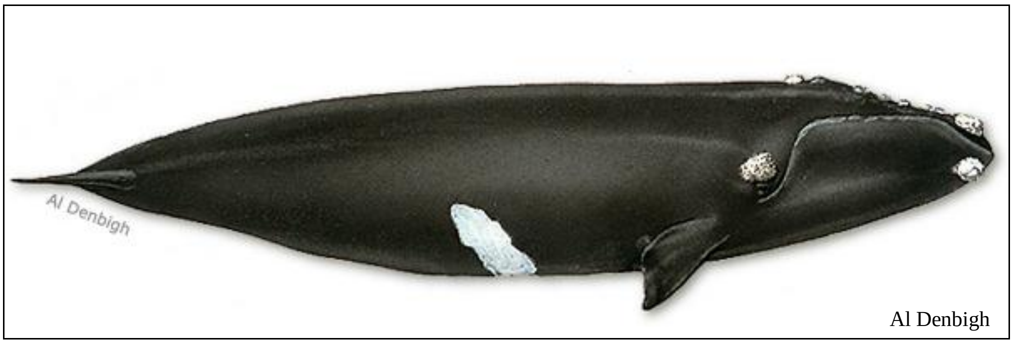


Figure 185: *Eubalaena glacialis*

The Right Whale got its name from whalers who thought it was the "right" whale to hunt. Whalers preferred the Right Whale because it swims slowly and floats when dead. The Northern Right Whale's body is black or charcoal grey, except for a white region on the belly. It has no dorsal fin and its rostrum is low, narrow and arched. It has "bonnets" or bumps on the upper surface of the head just in front of the blowholes. When the Northern Right Whale blows, its plume of exhaled air has a "V" shape, often about 4.5 metres high.

Northern Right Whales rarely dive deep, but they can be very acrobatic, breaching and smacking the surface with tails or flippers. A Northern Right Whale has black baleen plates up to 2.4 metres long, which it uses to catch copepods and euphausiids near the surface. This feeding strategy is known as skimming. Males are sexually mature at a length of 14 to 15.5 metres, and females at 15 to 16 metres; both sexes reach maturity at about ten years old. Cows bear young in winter or spring every two to four years after a 12-month gestation period. A newborn calf is about 4.5 to 6 metres long and has with no bumps on its head. Northern Right Whales migrate seasonally north-south, but migrating whales may linger in the same area for weeks.

It seems doubtful that the Northern Right Whale will ever recover from the intensive commercial harvest of the 19th century. COSEWIC lists this species as **endangered**. Although once found throughout the cooler waters of the northern hemisphere this whale exists today in small remnant populations. In the eastern Pacific Northern Right Whales range from the Gulf of Alaska, south to California. It is a rare species in B.C. waters.

Family Physeteridae (Sperm Whales)

- Sperm Whale (*Physeter catodon*)

Figure 186: Sperm Whale

The Sperm Whale is the largest of the toothed whales. Male Sperm Whales may grow to 18.5 metres long, but only rarely do they exceed 15 metres; females are much smaller, usually 11 metres or less. The Sperm Whale has a huge head, which accounts for a third of its total length. Inside the head is the spermaceti organ, containing a clear liquid oil that hardens when cooled. The blowhole is on the top left side of the head - this offset location is unique to the Sperm Whale Family. The blow comes out at a sharp forward angle. The dorsal fin is humplike and a series of bumps extend along the dorsal ridge to the tail.

Sperm Whales feed primarily on squid, but they also eat octopus and deep water fishes. Since their prey live at great depths, Sperm Whales have to be great divers - they often stay down for over an hour and dive to 2000 metres or more. Sperm Whales are social animals, travelling in pods ranging from ten to several hundred individuals. They shift northward during the summer in the northern hemisphere, and southward during the southern summer.

We do not know the worldwide population of the Sperm Whale. In 1996, COSEWIC designated the Sperm whale **not at risk** in Canada. The Sperm Whale is especially abundant off the outer edges of the world's continental shelves around upwelling areas.

Family Eschrichtiidae (Grey Whales)

<u>Grey Whale (*Eschrichtius robustus*)</u>

Figure 187: Grey Whale

Grey Whales can be easily identified by their mottled grey colour and lack of a dorsal fin. They have a low hump, followed by a series of 10 to 12 knobs along the dorsal ridge of the tail stock, all readily seen as the animal arches to dive. There are two or three grooves on the throat that allow it to expand when feeding. Greys can grow to 15 metres long - the average for males is around 11 metres, and for females, about 11.5 metres. All Grey Whales have large clusters of parasitic barnacles (*Cryptolepas rhachianecti*) on their skin. They are also infested with thousands of parasitic amphipods, called whale lice, belonging to three species of the genus *Cyamus*. Two of these species are unique to the Grey Whale.

Summer is feeding season for Grey Whales. Most spend the summer in the shallow waters of the northern and western Bering Sea, as well as in the adjacent waters of the Arctic Ocean, while some stay farther south, around Vancouver Island. Grey Whales are bottom feeders, sucking up large amounts of sediment and filtering out crustaceans with their baleen. They also feed on sardines and other surface fishes, herring eggs, and other organisms in the plankton.

Grey Whales are well known for their annual migrations. In November and early December, they begin the long migration southward to the shallow breeding waters around Baja California, travelling at a steady speed of about 9 km per hour (5 knots), day and night. They do not feed during the breeding season. From February to early May, they begin migrating northward again. By the time they reach the Arctic, they have lost 20 to 30 per cent of their body weight - as much as 10.5 tonnes. Each migration is about 8,000 km (5,000 miles).

Due to its remarkable recovery since being protected in 1947, the eastern Pacific Grey Whale population appears to be near carrying capacity. COSEWIC has designated the Grey Whale to be **not at risk**. The eastern Pacific population ranges from the Bering and Chukchi seas to Baja Mexico. A western Pacific population exists off Korea and the species once inhabited the Atlantic Ocean where it disappeared about 1500 AD.

Calving occurs in the warm waters of Baja California in winter. In spring the whales begin their migration northward along the coast of North America to summer feeding grounds in the Bering Sea. Along the way many animals stop off to summer off the west coast of Vancouver Island

Family-- Balaenopteridae (Rorquals)

- <u>Humpback Whale (*Megaptera novaengliae*)</u>

Figure 188: Humpback Whale

The Humpback Whale has a black body with an irregular white area on the belly. The undersides of the flippers and flukes are also white. The head in front of the blowhole is covered with wartlike, round protuberances, each containing one hair or hair sac. The Humpback's flippers are exceptionally long, nearly 1/3 the body length, and they are scalloped on the leading edge. The dorsal fin is slightly hooked, and located on the last third of the back. Large barnacles often grow on the chin, the anterior portions of the throat grooves, the flippers and the flukes. The baleen plates are about 75 cm long. A mature male measures about 11.5 metres long, while a mature female is 12 metres. The largest Humpback on record, a whale from Puget Sound, was about 19 metres long and weighed 48 tonnes.

Humpback Whales are famous for their songs. Only the males sing and usually only when breeding. Considered the longest and most complex in the animal kingdom, Humpback songs can last up to 20 minutes and be heard more than 30 km away. A whale may repeat the same song dozens of times over several hours, and whales in the same geographic area sing in very similar "dialects". Humpback songs vary slightly from region to region and year to year.

In the North Pacific, Humpbacks attain sexual maturity in six to twelve years. Calving and mating occur from October to March in warm waters off Mexico and Hawaii. After a 12-month gestation period, mothers bear calves up to five metres long and weighing about two tonnes.

Northward and southward migrations each take about two months; Humpbacks spend five and a half months on the feeding grounds and a little over a month on the breeding grounds. Northward migration begins in March and April from Hawaii, California and Mexican waters, reaching Vancouver Island in May or June. The Humpbacks continue north, travelling at an average rate of 7.5 km per hour, until they reach the feeding grounds of the Bering Strait and the Chukchi Sea. They eat mostly euphausiids, but are also known to eat large meals of fish such as herring, anchovies, sardines and cod.

COSEWIC considers this species **threatened**, because Humpbacks are susceptible to the dangers caused by human activities; they can become entangled in fishing gear, be struck by a ship or suffer from pollutants in the water.

- <u>Bottlenose Dolphin (*Tursiops truncates)*</u>

Figure 189: Bottlenose Dolphin

The Bottlenose dolphin is the most common dolphin found in aquariums (*Figure 189*). It is probably present in all areas of the Mediterranean, but seems to prefer coastal areas where there are some permanent populations. The Bottlenose dolphin is the most opportunist of all Delphinidae: it can adapt to extreme changes caused by humans, such as the effects of busy bays and ports. This species is familiar to fishermen in the Mediterranean because it interferes with fishing activity, in particular with trammel-nets. In fact, the bottlenose's feeding strategy often revolves around local fishing routines: the dolphins pick fish from fishing nets before the fishermen reels them in.

The adults have length from 1.9m up to 3.9m and weight 150kg up to 650kg. The newborn 85cm-1.3m and weight form 15kg up to 30 kg.

Figure 190: Bottlenose dolphin with a defined beak

Clearly defined beak, tapering like a bottle, hence the common name (*Figure 190*). The dorsal fin is tall and falcate, set halfway down the body. The back is dark or pale grey. The sides are generally paler than the back, though not always. There is sometimes a pale flame-shaped stripe that runs from the eye to the dorsal fin, similar to that of the *Stenella coeruleoalba* (Striped dolphin), but not as obvious. The belly varies from white to off-white to pale pink.

It is seen as often in large schools as alone. It tends to swim more slowly and less actively than other small species of Delphinidae (e.g. *Stenella coeruleoalba* and *Delphinus delphis*). Nevertheless, they have been seen performing acrobatics (leaping, tailslapping, tailspinning) when they meet another group of bottlenose dolphins. This behaviour is known as socializing). These performances in the wild show that Bottlenose acrobatics are instinctual, not only the result of human training in aquariums. Dives generally last about 3 or 4 minutes. They mainly feed on fish, squid, octopus and occasionally also on crustaceans.

3. STANDARDS

ALL STANDARDS MUST BE IN COMPLIANCE WITH CMAS MARINE BIOLOGY AS PER THE INSTRUCTION OF THE WORLD UNDERWATER FEDERATION VERSION 2000/00.
MARINE BIOLOGY 20 H PLUS 20 H FIELD WORK INCLUDING OPEN WATER DIVES MINIMUM 15
ADVANCE MARINE BIOLOGY 30 H PLUS 30 H FIELD WORK INCLUDING OPEN WATER DIVES MINIMUM 25

LEARNING MATERIAL AND FIELLD WORK WHICH CONTAINS WRITTEN , ORAL, AND PRACTICAL EXAMS WILL BE UNDER THE ATTENTANCE OF MARINE BIOLOGY INSTRUCTOR

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